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Asset Management Manual

Part 1 - General Requirements

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1 Background

Materials handling facilities such as mines and ports require significant capital investment in physical assets as a necessary part of their operation. Some materials handling facilities are well advanced in their design lives and the intention is to continue to use them in excess of this period. As well, there is a need for ongoing upgrades to these facilities to improve occupational health and safety standards and to improve productivity and throughput.

Operators and owners needs to manage their assets effectively and should aim for an optimum risk profile which matches the risk for the business. Too high a risk can lead to unacceptable costs due to unexpected failures and shortened useful life whereas too low a risk can mean high costs due to over-design and excessive maintenance.

The main functions of an effective Risk Management Plan for Structural Integrity are to:

- Create an awareness and understanding of the potential risks. All personnel should understand the risks involved in operating and maintaining the assets. Issues workshops, which look at the potential hazards, are part of creating this awareness.
- Detect and warn of danger. Any abnormal conditions such as spillage, excessive vibration, cracking, and corrosion should be monitored as they may provide signs of more serious problems.
- Protect against failure. Design to best practice; robust and redundant systems.
- Contain the failure. Try to have multiple systems wherever possible, e.g., dual rope system supporting the boom, primary and secondary limit switches.
- Allow recovery from abnormal conditions, eg keep spares of critical items, have contingency plans in case of failures. If failures do occur, they should be contained such that the consequential cost of failure is minimal.

This document presents the Risk Management Standard for Structural Integrity of Materials Handling Facilities. There are four main sections to this standard:

1. Section 1 – Background provides an introduction to the issues associated with structural integrity. Appendix A discusses some of the issues associated with prolonging the life of materials handling machines.

2. Section 2 presents important key areas for structural integrity management and enables the setting of priorities when developing business plans. This provides a consistent framework for evaluating physical assets such as materials handling facilities.

3. Section 3 of this standard introduces the setting-up of a Risk Management Plan for Structural Integrity. The aim of this part is to identify problem areas on existing materials handling facilities without wasting time and expense unnecessarily on safe and adequate parts of structures and equipment. As background to this section, Appendix A presents a review of materials handling machine failures, issues associated with different types of machines and a brief discussion on risk and uncertainty.

4. Section 4 presents the structure for the “*machine book*”. An essential part of a robust structural integrity management plan is the requirement for a “*machine book*”. A “*machine*

book" is a repository for all documentation that is relevant to the structural integrity of materials handling facilities.

2 Key Areas of Focus to Ensure Structural Integrity

Five key areas have been identified as important to ensure the structural integrity of materials handling facilities. The key areas are:

1. Physical condition
2. Regulatory compliance
3. Protection systems
4. Change management
5. Planning and committed investment

It is critical to note that the review of each key area must be based on available reports and documents. Therefore, an essential part of the structural integrity management plan is the requirement for a *machine book*. All documentation that is relevant to the structural integrity of materials handling facilities must be recorded in the *machine book*. It is also critical that a competent, responsible person is nominated to be the custodian of the *machine book*.

The following sections present an explanation and discussion of the five key areas.

2.1 PHYSICAL CONDITION

The materials handling facilities should reflect a high standard of care – no obvious damage, free from corrosion and well-painted. There should not be any notable flaws or defects awaiting rectification.

Inspection is the only real means of determining the physical condition of a structure. Effective inspection programs can play a significant role in minimising structural failures, focusing maintenance and extending the life of the structure. The types of inspection will depend on the item being inspected. There are generally only three major types of inspections although within each type there are varying levels of detail. The three types are visual, non-destructive testing (NDT) and destructive testing. The type of inspection depends largely on what is being inspected and its condition. Often, a visual inspection will precede any other inspection so that costs can be minimised.

The basic sections required for an effective inspection system include:

- Scope of work for inspections
- Inspection schedule
- Identifying action items

An Inspection Standard for materials handling facilities has been developed and provides guidelines for setting up and undertaking a regular inspection programme – Part 2 of this standard.

2.2 REGULATORY COMPLIANCE

Materials handling facilities should be well-engineered and built to industry standards – they should be working within the design envelope. Existing facilities may not comply with the latest design standards however they do not necessarily need to be brought to an “as new” standard. If there are significant concerns or changes have occurred than it would be necessary to re-assess the machine to the latest design standards.

Australian Standard AS ISO 13822-2005 – *Assessment of existing structures* provides guidelines for whether existing materials handling facilities built to an older design standard may need to be upgraded to the latest standard. AS ISO 13822-2005 states:

> *Structures designed and constructed based on earlier codes … may be considered safe to resist actions other than accidental actions provided that*
>
> - *careful inspection does not reveal any evidence of significant damage, distress or deterioration;*
> - *the structural system is reviewed, including investigation of critical details and checking them for stress transfer;*
> - *the structure has demonstrated satisfactory performance for a sufficiently long period of time for extreme actions due to use and environmental effects to have occurred;*
> - *predicted deterioration taking into effect the present condition and planned maintenance ensures sufficient durability; and*
> - *there has been no changes for a sufficiently long period of time that could significantly increase the actions on the structure or affect its durability, and no such actions are anticipated.*

Basically assessment of an existing materials handling machine structure to the latest standard is required if changes have occurred or there are significant concerns.

Other techniques and assessment procedures for design conformance include:

- Structure design conformance checks
- Fatigue life assessment
- Detailed finite element analysis – non-linear, dynamics and buckling as required
- Fracture mechanics assessment
- Strain gauging
- Weighing

2.3 PROTECTION SYSTEMS

People using the machine must not be placed at risk of injury or death as a result of a structural failure. Protection systems on a materials handling machine include:

- Critical safety devices such as brakes, rail clamps, collision detectors and the load limiting devices. These need to be identified, documented and tested. Defeating safety devices should be strictly controlled and, if permitted, is subject to risk management and rigorous control with the defeat log displayed.
- Stairs, ladders and handrails. These need to comply with the relevant and latest design standards. Support structures for platforms, walkways, stairs and ladders need to comply with the relevant structural integrity design standards. As well, access areas need to be free of trip hazards and other obstacles.
- Machinery guarding. Equipment guarding needs to be in place for moving machinery. These need to comply with the relevant and latest design standards.

- Access near moving equipment.

Periodic audits need to be undertaken for the protection systems. Refer to Part 3 of this standard.

2.4 CHANGE MANAGEMENT

Materials handling facilities are a complicated combination of structure, mechanical components, electrical components and control system. A change to any one of the disciplines can have a significant effect on the other disciplines. As such, effective change management is essential for the safe and efficient management of these facilities.

The Change Management Standard must be used for all modifications to materials handling facilities.

2.5 PLANNING AND COMMITTED INVESTMENT

Planning and committed expenditure should be commensurate with the future needs and degradation rates of the machine so as to ensure reliability and availability in line with the sites five year plan.

A Risk Management Plan for Structural Integrity needs to be developed which shows proposed works and expenditure. Allocated funding should be at a level which is in line with current maintenance works, structural integrity works and proposed future upgrades. As well, it is very important to ensure that adequate shutdown time is provided so that the proposed works can be undertaken promptly and effectively.

Appendix B presents good practice guidelines for each of the five key areas.

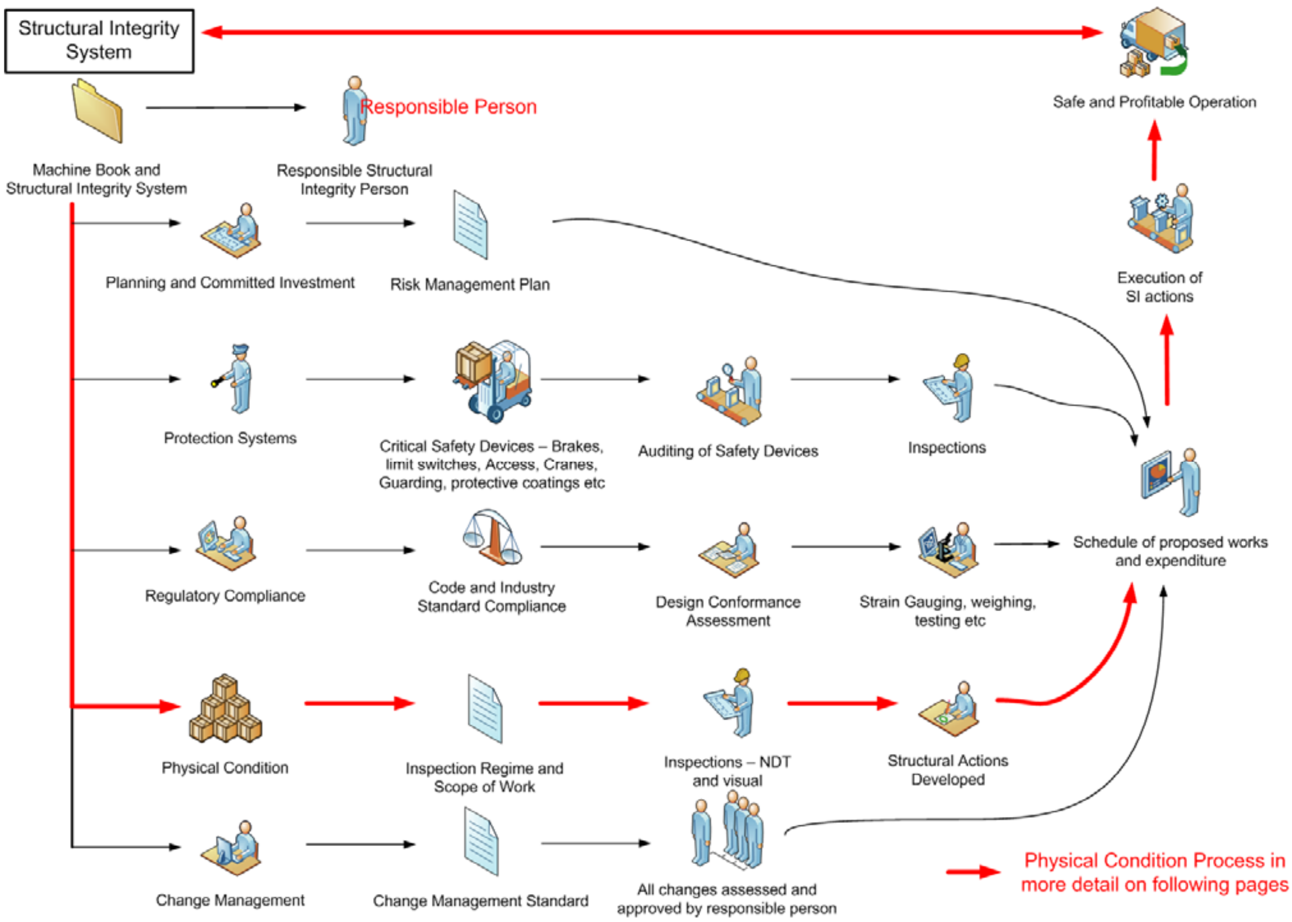
3 The Risk Management Plan for Structural Integrity

The Risk Management Plan for Structural Integrity (Plan) should identify problem areas on existing materials handling facilities without wasting time and expense unnecessarily on safe and adequate parts of structures and equipment. Existing materials handling facilities do not necessarily need to be brought to an "*as new*" standard. It is important to note that the Plan focuses on high or critical risks – only items where the consequences are major or higher should be considered. It is assumed that high likelihood – low consequence items are adequately considered in the site maintenance programmes.

The following recommended steps provide a guide for developing a Plan:

Step	Description
1.	*Machine Book* Instructions Assign a responsible, competent person to be the *machine book* custodian. Decide on format of *machine book* (paper, electronic or combination of both) and location of *machine book* (location on network drive). The *machine book* format will be discussed in Section 4. Record instructions on updating and change control for the *machine book*.
2	Design Parameters Collate existing available data including drawings, reports, calculations and repair history. Typically, most sites have a significant amount of documents and information but a lot of this data is difficult to locate, lost or in key personnel's memories. This information should be put into a *machine book*.
3	Issues and Problems It has been found that a facilitated workshop using a narrative approach is a useful way of gathering historical evidence of past problems and issues. Personnel who have had involvement with the materials handling facilities convey "stories" about problems and issues that have occurred in the past. A series and of prompts and tags are used to collect and collate the information.
4	Inspections Inspection is the most effective means of determining the physical condition of a structure.
5	Design Calculations Review design calculations. Summarise available calculations, relevant design standards, critical safety/overload devices and design issues that have been highlighted and critical structural integrity areas on the machine. As mentioned previously, existing materials handling facilities do not necessarily need to be brought to an "*as new*" standard. Therefore it is important to decide if more detailed analysis and assessment is required. Australian Standard AS ISO 13822-2005 – *Basis for design of structures – Assessment of existing structures* provides guidelines for when further assessment is required.

Step	Description
6	<u>Risk Assessment</u> Based on a review of available data, machine history, issues and problems and available design calculations, assess hazards and risks for each of the five key areas.
7	<u>Develop Risk Management Plan</u> Based on the available information and the assessment of risk, a Risk Management Plan should be prepared which details all the proposed engineering investigations, engineering design, inspections and audits and major maintenance items for the next two to five years. Each item should include a detailed scope of work, estimate of cost, estimate of time, pre-requisites, required shut-down time and work order reference. As well as proposed actions items, the plan should include a list of critical items and contingency plans in case of failure of critical items. The Risk Management Plan should be incorporated into the overall mine budget planning.



4 Machine Book

All documentation that is relevant to the structural integrity of the facilities needs to be recorded in the *machine book*. The aim of the *machine book* is to:

- Formalise the control of key information related to the Structural Integrity Management of materials handling facilities
- Provide information for operations, maintenance and engineering personnel when setting priorities and developing business plans

A competent, responsible person must be nominated as the machine custodian.

Typically a *machine book* would be a directory on a computer. An example of a *machine book* directory structure is presented in Figure 1.

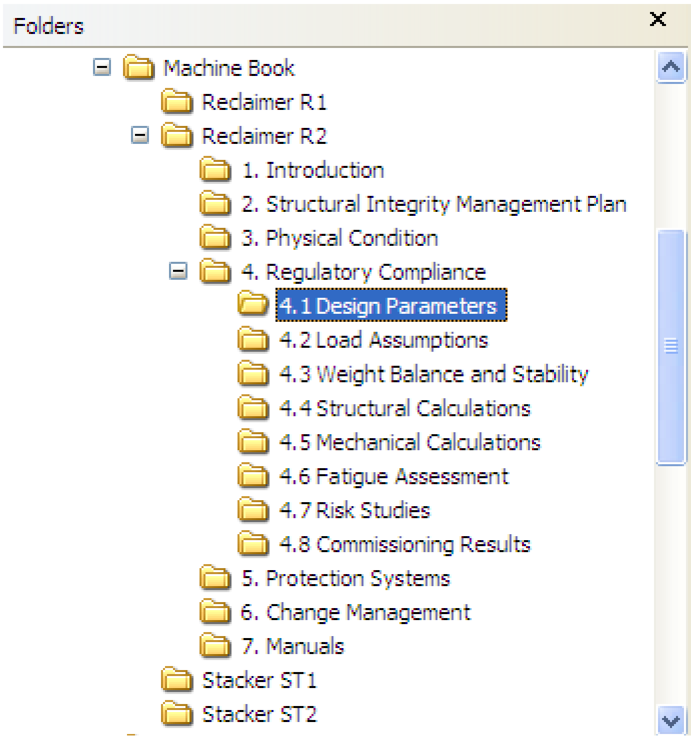


Figure 1 - Example Machine Book directory structure

In order to provide a level of standardisation across sites, the following high level structure must be used. Sub-headings can be set at the discretion of the site.

1. Introduction
2. Structural Integrity Management Plan
3. Physical Condition
4. Regulatory Compliance
5. Protection Systems
6. Change Management
7. Manuals

The major headings map to the key areas that have been identified as important for Structural Integrity Management (refer to Section 2). Each of these headings is discussed in more detail.

3.1 INTRODUCTION

This section contains general *machine book* instructions including *machine book* custodian, information on updating and change control for the *machine book*, update frequencies and a record of the *machine book* audit history. Appendix C provides a sample *machine book* instructions.

3.2 STRUCTURAL INTEGRITY MANAGEMENT PLAN

A copy of the structural integrity management plan should be placed in the section. As mentioned previously, this should include:

- Time line showing proposed engineering investigations, engineering design, inspections and audits and major maintenance items
- Budgets and planned expenditure
- Contingency planning for critical items
- Instructions / methodology for major maintenance works (eg slew bearing change, rope change)

3.3 PHYSICAL CONDITION

This section contains all Inspection reports – electrical, mechanical, structural, hydraulics

3.4 REGULATORY COMPLIANCE

This section contains all the design calculations and risk reviews: This includes:

- A list of statutory requirements and relevant design standards
- OEM recommendations
- Relevant design and operating parameters - a sample design parameters document is presented in Appendix D.
- Load calculations
- Design calculations for mechanical, electrical and structural
- Measurement results such as strain gauging and weighing
- Reports on risk assessments and hazards studies
- Commissioning results

3.5 PROTECTION SYSTEMS

This section contains a description of the major protection devices and systems. This includes:

- Settings for protection devices such as brakes (eg long travel, slew and winch), rail clamps, collision detectors (eg lanyards, microwave sensors, strikers) and the load limiting devices on slew drives (eg clutch), bucket-wheel drives (eg strain gauging of torque arm) and hydraulic cylinders (eg pressure relief valves).
- Audit and test results for protection devices
- Procedures for operational shutdowns (eg storm winds)

3.6 CHANGE MANAGEMENT

This section contains a record of significant issues, incidents, event history and any changes made to the facilities.

The Change Management Form shall be used to assess the effects of any proposed changes. Copies of the completed forms shall be kept in this section of the machine book.

3.7 MANUALS

This section contains operating, maintenance and training manuals.

4 Key Performance Indicators

Effective measures are important to help maintain optimal performance. The adage “if you can’t measure it, you can’t manage it” is especially true for physical assets. Traditionally the process of managing assets has been governed by financial reports. The data from financial reports is immediate, unambiguous, reliable and continuous. However, it tells only one part of the picture and is not sufficient to allow for informed management decisions to be made.

It is possible to use a scoring criteria based on the five key areas and enable comparisons to be made across different sites and different types of materials handling machines. A five-point scale is recommended for monitoring the execution of the Risk Management System. A recommended scoring system is presented in Table 1.

Table 1 - Recommended Scoring System

Score			Description
As-new	4	100%	Compliant in all respects
Good	3	75%	Minor changes required
Satisfactory	2	50%	Major changes required. Below today’s best practice but still adequate for the operation. Consequences are understood but no formal planning exists.
Borderline	1	25%	Critical changes required. Well below best practice, work performed on a reactive or “ad-hoc” basis, basic implementation
Inadequate	0	0%	Inadequate or non-existent

The following sections present the scoring for each of the five key areas identified as important for the Structural Integrity Management Plan.

Physical Condition

Item	Requirements for full compliance
Scope of work for inspections	Traceable inspection system in place Inspection sheets identify all areas to be inspected and type of inspection Standard rating system used Actions identify risk, estimated cost and priority
Inspection schedule	Appropriate schedule in place Inspection by competent inspectors Inspections completed on schedule

Item	Requirements for full compliance
Machine appearance	No obvious signs of damage Minimal spillage, housekeeping in order Protection corrosion coating in good condition No signs of excessive vibration
Action follow-up	No notable defects or flaws awaiting rectification or further investigation The progress of actions identified in any audit report can be easily tracked and the status readily established

Regulatory Compliance

Item	Requirements for full compliance
Design information	All relevant design information available and collated in the Machine Book. This includes drawings, specification, design calculations, design model and test and commissioning certificates.
Design compliance	Machine complies to the latest design standards Well-engineered and working within design envelope
Machine balance (where applicable)	Machine balance is documented and checked regularly

Protection Systems for People and Equipment

Item	Requirements for full compliance
Access systems	Access audit undertaken and report available Demonstrated compliance to latest version of AS1657
Guarding	Guarding audit undertaken and report available Demonstrated compliance to latest version of AS4024.1
Safety equipment (fire extinguishers, fire systems)	Safety equipment available and well-suited to the task Inspection schedule in place and reports available
Critical machines safety devices (rail clamps, brakes, collision detectors and load limiting devices)	All devices listed with function and functional test described Demonstrated compliance to functional testing of critical safety devices Brake settings are identified, documented and tested within regular intervals Procedure in the event of a storm wind in place and documented

Change Management

Item	Requirements for full compliance
Change management	Change management procedure in place and is followed All known changes are documented, as-built drawings are available Authorisations and necessary design documentation are attached

Planning and Committed Investment

Item	Requirements for full compliance
Plan in place	Issues register in place All critical or high risk actions have a full scope of work Costs are included in the plan and approved Outage time has been agreed with operations
Contingency planning	Contingency plans are on a review schedule The contingency plan considers obsolescence and has short term measures in place such as the ability to have major repairs carried out and/or availability at other sites Critical items and items which need to be custom built or have long lead times are clearly identified Operational contingencies are planned and documented
Machine book in place	Machine book is in place Machine book has been audited and demonstrated compliance in all areas
Machine book custodian	A person with relevant competencies has been nominated, has role accountabilities and is actively reviewing the Machine Book

Appendix A

Prolonging the Life of Bulk Materials Handling Machines

Introduction

This Appendix presents a review of materials handling machine failures, issues associated with different types of machines, issues associated with design conformance and a brief discussion on risk and uncertainty.

Structural Failures

Before looking at ways to prolong the life of materials handling machines and equipment, it is worthwhile to examine incidents where these machines have had their lives ended prematurely.

The authors have collected details on fifty-three bulk materials handling machine failures which have occurred in Australia (Morgan et al, 1998). The types of machines include stackers, reclaimers, stacker / reclaimers, ship-loaders and ship-unloaders. The study has looked at two main facets of the failures. These are the rate of failure and the cause of failure, eg deterioration, overloads. Figure 2 shows the number of failures per year over the past twenty-five years.

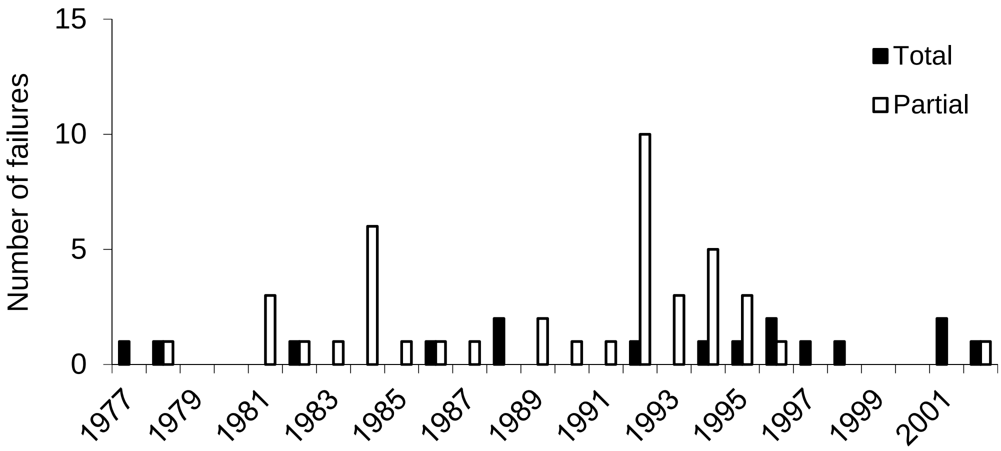


Figure 2. Number of machine failures.

Partial failures are defined as failures which are not part of the regular maintenance and require major repairs. Total failures are defined as the total collapse of the machine. As can be seen from Figure 1, the number of failures has increased with time. There are two possible reasons for this – firstly, the number of machines in service is increasing and secondly, the age of machines in service in increasing.

Figure 3 shows the number of machine failures versus the age of the machine at failure. This chart tends to follow a "bath-tub" type curve - the failures can be divided into two groups: The first group of failures occurs within the first five years after commissioning and the second group of failures occur when the machines are greater than ten years old.

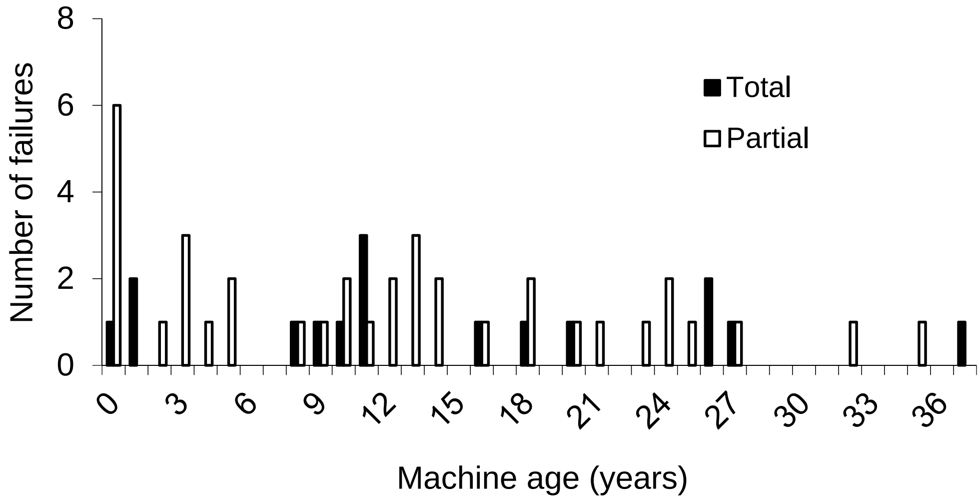


Figure 3. Number of machine failures versus machine age.

Nearly 70 percent of failures which occurred within the first five years of operation were due to operational factors (eg, overloads, changed operations) whereas 90 percent of the failures due to deterioration occur when the machine age is ten years or older.

The likelihood of failure for machines is much higher than the likelihood of failure for structures in general. Our study shows that, based on historical data, the likelihood of a machine failure is about 10 to 100 times greater than the likelihood of a structural failures. What this means is that bulk materials handling machines cannot be designed and operated in the same manner as other structures such as conveyor galleries, workshops, transfer towers, etc.

Issues with Particular Equipment Types

A common feature of the coal industry is the need to efficiently transport large quantities of material. For maximum efficiencies, there is a requirement for dedicated loading or unloading equipment at the loading or unloading ports and suitable stockpiling facilities at the port. Some of the issues associated with various types of coal handling equipment are discussed.

Shiploaders

Shiploaders are the last link in the loading chain from mine to ship. High reliability is essential to maintain throughput to the port. Asset assessment issues for shiploaders include deterioration, physical damage due to collisions and overloading and obsolescence of mechanical and electrical equipment on older machines. Where extensive trimming out of material into the ships holds is required metal fatigue can also be an important consideration.

Figure 4 – 4000tph Shiploader Loading Capesize Ship

Ship Unloaders

Unloading systems are required to remove incoming raw material from bulk carriers. These may be clam-shell grab type or a continuous ship unloader (CSU). Such equipment is subject to heavy repetitive loading and exposed to a marine environment. Issues affecting the condition of ship unloaders include deterioration (due to corrosion, metal fatigue) and physical damage due to collisions and overloading. Obsolescence of mechanical and electrical equipment is also an issue on older machines.

Stacking and Reclaiming Machines

Stacking and reclaiming machines such as bucketwheel stacker reclaimers are highly loaded structures and are generally very sensitive to changes in balance. Issues affecting the condition of the machines include deterioration, physical damage due to overloads and collisions and metal fatigue, particularly for reclaiming machines. Machine balance is a major issue and changes in weight and weight distribution need to be monitored carefully.

Figure 5 - 4000tph Stacker Reclaimer

Conveyor Systems

Conveyor systems are used extensively to move bulk coal between handling machines and storage facilities. Integrity of structural and mechanical components is necessary for reliable performance often in a difficult environment prone to corrosion. Conveyor drive systems also require close attention to ensure that adequate maintenance, vibration and noise reduction, reliable stopping and starting can be achieved.

Expected Life and Design Conformance

Service Life

Many industrial structures in Australia were intended to have a design life of around 25 years. The effective limitation has often been due to steel fatigue, concrete durability, paint systems and detailing practices (which allowed accumulation of corrosive material), rather than by strength or other limit states. Frequently, well into the originally intended design life of the structure it becomes obvious that the life should be longer so that further commercial opportunities from the equipment can be realised.

The service life depends on the design and construction methods, usage and environment and maintenance and operation practices. Service life is the period in years from the time of completion of the facility to the time when the complete facility or its components are expected to reach a state where it cannot provide acceptable service because of physical deterioration, poor performance, functional obsolescence or unacceptably high operating costs. Evaluation of the service life is quite complex, because different components of a facility can have varying ranges of possible service life. Service life of critical structural components should be taken as a representative estimate to plan new construction, major repair and reconstruction.

Some examples of the minimum service lives expected for different types of infrastructure assets are:

Bridges	50 years
Road pavements	20 years
Industrial buildings	25 years
Public buildings	50 years
Dams	100 years

Different environments, ground and operating conditions can lead to significant difference in service life between two similar assets.

Design Standards

Most design standards are relatively new and have had many significant modifications from their old form – refer to Table 2. A lot of older machines and equipment may not strictly comply with the latest design standards. The cost of retro-fitting existing structures such that they comply fully with the latest Standard can be very high. As well, most design Standards provide guidelines for the design of new structures. A lot more information concerning the behaviour of an existing structure may be available, for example, material properties, geometrical dimensions, loads and loading parameters, degree of deterioration, etc. Standards for the design assessment of existing structures are not available in Australia. Recently, Australian Standard AS ISO 13822 – 2005 has been released. This standard provides a guide for the assessment of existing structures.

Table 2 - Australian Standards

Title of Standard	Designation	Year of Latest Release
Minimum Design Loads on Structures	AS1170	2002
Steel Structures	AS4100	1998
Concrete Structures	AS3600	2001
Masonry Structures	AS3700	1998
Timber Structures	AS1720	1997
Composite Structures	AS2327	1996
Piling Design	AS2159	1995
Cranes General Requirements	AS1418	2002
Safe Use of Cranes - General Requirements	AS2550	2002

AS4324.1 Mobile equipment for continuous handling of bulk materials - General requirements for the design of steel structures was introduced in 1995 in response to a number of failures of bulk materials handling machines within Australia. This Standard specifies general requirements, design loads and specific requirements for structures of mobile equipment for continuous handling of bulk materials, including appliances and machines that are intended to carry out similar functions (e.g. excavators, stackers, reclaimers, ship loaders, ship unloaders).

AS4324.1 calls up other Australian Standards such as *AS1170.2* for Wind Loads, *AS3990* for permissible stress steel design and *AS4100* for limit states steel design. *AS4324.1* requires that fatigue design be carried out to *AS4100.*

The International Standards Organisation has published design standards bulk materials handling machines such as stackers, reclaimers, ship loaders and ship unloaders (*ISO5049.1*) *ISO5049.1* has been widely used internationally; however its use has been discontinued in Australia since the introduction of *AS4324.1* in 1995. Steel design requirements for strength and fatigue and wind loading are covered in ISO5049.1. However these vary from Australian Standard requirements in a number of respects.

Risk and Uncertainty

The risk diagram in Figure 6 shows the relationship between the different risk regimes encountered in a typical industrial or mining enterprise in terms of likelihood of occurrence versus severity of consequence. The “reliability region” is mainly concerned with day to day efficiency in operation translating to return to shareholders – this is covered by the maintenance management system. The “risk region” is concerned with long term value of assets, business interpretation, safety and other aspects of an enterprise which in addition to being important to shareholders may also be subject to judicial scrutiny.

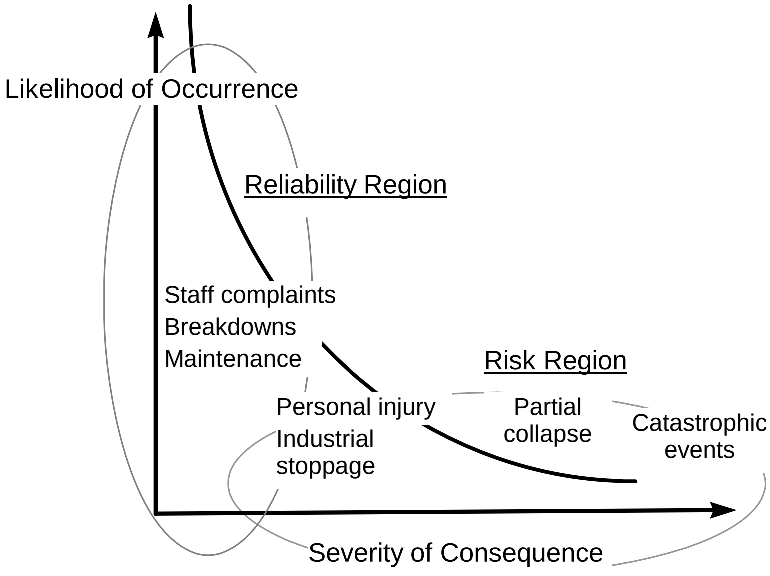


Figure 6 - Risk diagram.

Some events in the "risk region" are very low probability and may not even have been contemplated in the set of probabilities. How can we be confident that low probability events are considered properly, if at all – the patterns of the past do not necessarily reveal the path into the future (Bernstein, 1996).

Frank Knight, an American economist, made the distinction between risk and uncertainty. He wrote in 1921:

> *Uncertainty must be taken in a sense radically distinct from the familiar notion of risk, from which it has never been probably separated. …It will appear that a measurable uncertainty or "risk" … is so far different from an unmeasurable one that it is not in effect an uncertainty at all (Bernstein, 1996).*

Instances which lead to catastrophic consequences may have such a low probability, that there is insufficient number to form a basis for any inference about any real probability.

Methodology for Life Extension

The aim of the process adopted by the authors is to identify problem areas on existing structures and equipment without wasting time and expense unnecessarily on safe and adequate parts of structures and equipment.

Materials handling machines, which are significant investment items, have consistently been a large source of potential hazards with higher failure rates than standard structures. Traditionally the structural engineers involved with such equipment have checked the designs for compliance with relevant Codes of Practice and Statutory Regulations. However such codes and regulations are by their nature prescriptive, providing minimum standards for design and levels of maintenance to retain overall integrity.

Assessment of Existing Facilities

Most design standards provide guidelines for the design of new structures and standards for the design assessment of existing structures are not available in all countries. If the equipment being scrutinized was designed to a design standard that has since been updated and altered then compliance with the older design standard is not necessarily sufficient from a liability perspective. However, the cost of retro-fitting existing structures can be very high compared to the cost of new construction. Guidelines are required which allow more flexibility for assessment of existing structures and require more professional judgement.

Ellingwood (1996) states that assessments of existing structures may need to be conducted for various reasons including the following:

- Change of use including increased load requirements
- Concern about design or construction errors
- Concern about quality of building materials or workmanship
- Assessment of effects of deterioration
- Assessment of damage following an extreme loading event (such as a wind storm or an earthquake)
- Concern about serviceability

Risk Management

Structural failures and associated injuries and/or loss of availability are usually due to a combination of causes of which design is only be one of many factors. Method of operation, deterioration and wear as well as human error is often also contributory (Kletz (1)). Rather than relying on the prescriptive approach embodied in many codes and regulations, a more fundamental risk based methodology has been developed to assist engineers, owners and operators to identify high risk areas and set in place controls to reduce risks and the potential for failures.

Australian Standard AS/NZS 4360 - Risk Management defines risk management as:

> *the systematic application of management policies, procedures and practices to the tasks of identifying, analysing, assessing, treating and monitoring risk*

Some of the main factors which contribute to asset risk include physical environment, design, mode of operation, programmed maintenance and human error in all of its forms. The scope of work for the risk review includes:

- Identification and assessment of the risks associated with the maintenance and operation
- Evaluation of the effectiveness of existing operational practices and protection systems in maintaining the risk to an acceptable level
- Determination of control measures to be put in place to reduce the risks that are identified to an acceptable level

Effectiveness of Actions

As discussed in the previous section on Risk and Uncertainty, how can we be confident that low probability / high consequence events are considered properly. Control measures (or defences) put in place are not perfect; they may contain gaps, may fail to operate, or maybe bypassed for a host of different reasons (some predictable, some unpredictable). Reason (1997) has suggested that it is necessary to apply multiple layers of defences – “defences in depth” (Figure 7).

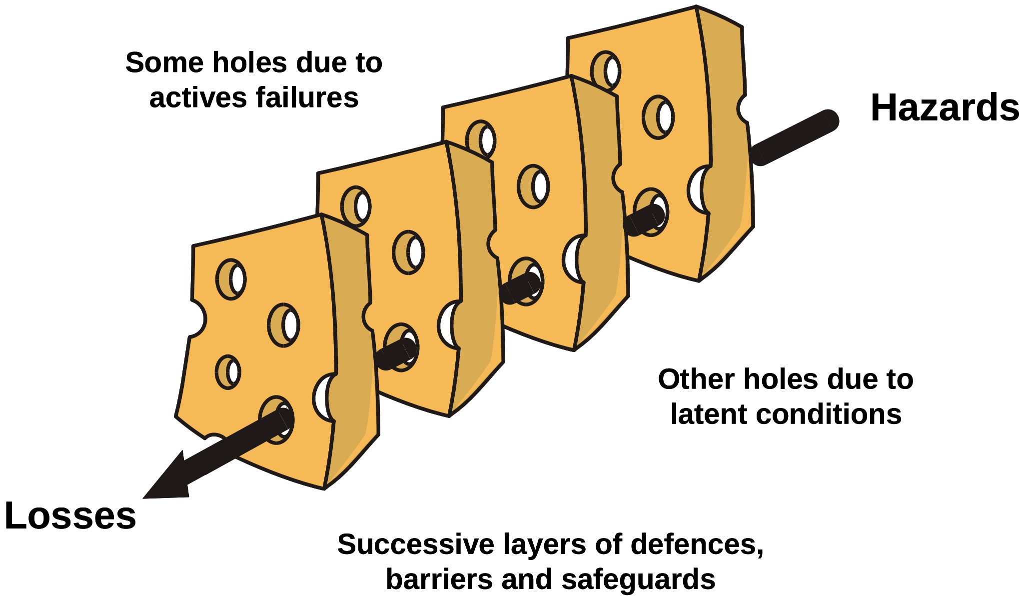


Figure 7 - Reason's "Swiss Cheese" model.

The number of layers in the system is a measure of how or robust the risk management system is. The fewer defences the more brittle this system, the more defences and more diverse the defences, the more robust. A convenient way to assess the robustness of the system defences or controls is to plot them on a matrix such as that shown in Figure 8. The matrix shows methods of providing effective controls against the main functions of the controls (Reason, 1997). The more populated the matrix, the more robust the system.

	Engineering	Policies & Standards	Procedures	Training	Separation PPE
Awareness					
Detect & Warn					
Protect					
Recover					
Contain					
Escape					

Figure 8 - System Defences.

The methods of providing effective defences include:

- Engineered systems: engineering design, detection and warning systems.
- Policies, standards and controls: administrative and managerial measures designed to promote standardised safe working practices.
- Procedures, instructions and supervision: measures aimed at local task-related know-how.
- Training, briefs and drills: provision, and consolidation of technical skills, safety awareness and knowledge.
- Personal protective equipment: anything designed to provide physical separation between people and hazards.

The main functions of an effective risk management plan are to:

- Create an awareness and understanding of the potential risks. All personnel should understand the risks involved in operating and maintaining the assets. Workshops, which look at the potential hazards, are part of creating this awareness.
- Detect and warn of danger. The performance of some assets relies heavily on the use of safety devices and machine settings. These settings should be documented and checked regularly. Any abnormal conditions such as spillage, excessive vibration, cracking, and corrosion should be monitored as they may provide signs of more serious problems.
- Protect against failure. Design to best practice; robust and redundant systems.
- Contain the failure. Try to have multiple systems wherever possible, eg, dual rope system supporting the boom, primary and secondary limit switches.
- Allow recovery from abnormal conditions, eg keep spares of critical items, have contingency plans in case of failures. If failures do occur, they should be contained such that the consequential cost of failure is minimal.
- Enable potential victims to escape should a failure occur. Procedures, training and equipment are required minimise the danger to operating and maintenance personnel.

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