

## INTRODUCTION

**Group Leader's Introduction**

**T**his newsletter is the second newsletter for 2004 and the nineteenth newsletter from the structural assets group.

The past 12 months have seen a consolidation of the structural assets group across Australia. All areas have been productive and our future is looking prosperous.

One of the principles for "good" structural engineering is the prediction of structural performance accurately. The prediction of structural performance is the basis for the ability to design and assess new and existing facilities. In broad terms it involves the determination of actions applied to a structure, prediction of structural behavior that requires a simulated mathematical model, and the evaluation of the structural response. Appropriate fabrication and construction practices will lead to the completion of a safe and reliable structure. The selection of durability related items such as construction materials, protective coatings and detailing practices is essential for the insitu performance of the structure. The performance of a structure is an indirect measurement of its safety and reliability.

There is an increasing trend in the resources industry to minimise design and capital costs. Environmental, social, legal and economic issues demand stringent requirements for new structures and the service life extension or upgrading of existing structures in order to achieve a safe and reliable working environment. Safety and reliability of designs or modifications is now a key parameter for the owners and operators of facilities for mining and resource industries. Hazard identification and assessment techniques are now common practice in order to achieve safe designs by eliminating or reducing as low as reasonably practicable the risks associated with hazards. Further practices can be used to ensure safety and reliability of designs. Periodic inspections and maintenance after the design or modification to a structure are required to ensure its safe and reliable operation.

Reliability of structures is discussed in the following article of this newsletter.

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## RELIABILITY

**Achieving Reliability of Structures for the Mining and Resource Industries**

A minimum level of safety and reliability for structures is implied through the use of standards and codes of practice for their design and condition assessment. Additional measures may be required to ensure that this, or a higher level of structural reliability, is achieved for structures for mining and resource industries due to the consequences if a structure malfunctions or fails. This article discusses the methods of achieving structural reliability presented in [1] AS/NZS 1170 "Structural Design Actions, Part 0: General Principles", and [2] BS

EN1990: "Basis of Structural Design", as well as other methods that can be implemented.

This article is not limited to "building type" structures but covers all of the structures applicable for heavy industry including bins, ducts, calciners, wharves and marine structures. Structural reliability is usually expressed as a percentage and is defined in references [1] and [2] as

"The ability of a structure or structural element to fulfil the specified criteria, including the working life, for which it has been designed."

BS EN1990 [2] states that the methods for which structural reliability is achieved are:

- ◆ Preventative and protective measures;
- ◆ Measures in design detailing, checking of calculations, robustness, accuracy of mechanical models;
- ◆ Efficient construction;
- ◆ Adequate inspection and maintenance;
- ◆ Measures to prevent potential causes of failure and limit the consequences of failure.

Structural engineering is undertaken under the framework and guidance of standards that prescribe minimum requirements for structures. The fundamental assumptions used in the derivation of standards are [2]:

- ◆ Appropriately qualified and experienced personnel choose the structural system and undertake the design of the structure;
- ◆ The structure is adequately maintained;
- ◆ The structure is used in accordance with its design assumptions;
- ◆ Adequate quality assurance and supervision is provided during the design and construction of the structure.

The aim of the structural standards is for the structure to [2,3]:

- ◆ Sustain all actions likely to occur;
- ◆ Remain fit for the use for which it was intended;
- ◆ Have adequate structural resistance, serviceability and durability;
- ◆ Have adequate fire resistance;
- ◆ Avoid causing damage to other structures;
- ◆ Not to be damaged to a disproportionate extent by events such as explosion, impact or the consequences of human error.

Structural design criteria are used throughout the design or condition assessment of any structure to quantify the required performance of the structure. Codes and standards form the basis, and are referenced in this document, which states the structural design situations with the associated structural compliance criteria.

A structural design situation describes a possible combination of actions or influences acting on a structure. A number of design situations are required to be considered for the design or condition assessment of a structure and these should encompass all of the possible combinations of actions, in accordance with the operating requirements, for the facility. The design situations for structures with configurable / movable elements, such as bulk material handling machines, should also describe the corresponding range of positions for these elements.

The design situations can be divided into three categories; main, abnormal and special. The main category of design

situations describes the actions and influences that will generally be applied to the structure i.e. normal operation. Where unusual operating parameters cause an increase in the actions applied to the structure or the maximum environmental loads such as wind or earthquake are applied, these design situations are classified as abnormal. Special design situations describe very rare events that the structure may or may not be specifically designed for. The classification of a structural design situation into a category will depend on the use of the structure, the operating procedures, and the levels of control. For some types of structures the abnormal operating case will be redundant as it will be the main case.

The structures response for the design situations is evaluated against a compliance criteria. The criteria applicable will depend on the function and form of the structure as well as the classification of the design situation. Elements of the structural acceptance criteria may include several of the following items:

- ◆ Strength;
- ◆ Buckling;
- ◆ Fatigue;
- ◆ Deflection and relative deflection;
- ◆ Vibration;
- ◆ Specific criteria for equipment and mechanical items;
- ◆ Robustness requirements;
- ◆ Detailing requirements – corrosion/ erosion allowance, detailing practises for fatigue, earthquake.

The consequences of a structure for the mining or resource industries malfunctioning or failing include safety, legal, social and environmental issues as well as the costs of rectification of the structure and its associated equipment, and consequential losses in production and revenue.

In broad terms there are numerous reasons why a structure or structural element may malfunction or fail. In most cases there will be a number of contributing factors, several of these reasons are listed below:

- 1) Incorrect specification / defects in the formulation of the actions / influences and / or design situations that a structure is to withstand;
- 2) Incomplete / defective formulation of the structural compliance criteria;
- 3) Defects in the original structural design;
- 4) Defects in fabrication and erection;
- 5) The structure is not operated in accordance with its design assumptions / operating procedures.
- 6) Changes to actions / influences on a structure;
- 7) Modifications to the structure;
- 8) Inadequate or modifications to the protective coating systems and other durability related items;
- 9) Inadequate inspection and maintenance programs.

Structural reliability management involves practises to minimise the causes and consequences of a structure not complying with its design compliance criteria.

#### **Reliability Management for Structures – Pre-Construction**

Structural reliability management during the original design and construction involves identifying those structures, or components of a structure, that require a higher level of reliability and implementing additional checks and controls in the design and construction of those items.

BS EN1990 [2] introduces three consequence classes based on the assumed consequences of exposure to hazards and failure. The consequence classes can be applied to a structural element or to an entire structure. A structural element may have a different consequence classification than the complete structure it forms part of. This is due to the local or global consequences of the failure or malfunction of the structural element. The consequence class will be affected by decisions made during the design, such as, type of structural element, predominant action, main purpose, robustness and alternate load paths.

In theory the concept of consequence class can be refined for any structural element or structure, for every structural design

situation, and for each applicable structural compliance criteria. This is clearly impractical. Generally, the consequence classes can be refined for the main categories of design situations taking into account all of the compliance criteria for the main groups of structural elements. The consequences of failure or malfunction, and hence the consequence class, can vary significantly between the main, abnormal and special design situations for industrial structures, particularly structures for process plants. The consequence class can also take into account the frequency of the design situation.

BS EN1990 [2] separates the consequences into three classes relating to high, medium, and low consequences. These relate to loss of life, economic, social and environmental issues. Three reliability classes are introduced, which correspond to the consequence classes.

BS EN1990 [2] states that the reliability levels should take into account the following:

- ◆ Possible consequences of the structural design compliance criteria being exceeded in terms of risk to life, injury, economic losses and environmental damage;
- ◆ Possible causes and modes of elements of the structural design compliance criteria being exceeded;
- ◆ Public aversion to, and perception of, structural failure;
- ◆ Expense and procedures necessary to reduce the risk of failure.

It is more practical, for structures designed to Australian codes, to classify the consequence and reliability classes similar to the importance level presented in the Building Code of Australia or Appendix F of AS/NZS 1170.0.

The classification of the required reliability allows for the reliability between structures, or within a structure, to be differentiated. Reliability management practises can be implemented to place additional checks and controls on structural elements or structures that have a higher reliability classification.

The implementation of reliability management systems is generally project specific and depends on the structures use, the nature and form of the structure, capital and engineering costs, construction schedule and other factors.

#### **Reliability Management for Structures – Post-Construction**

Reliability management for structures in service can be achieved through the use of structural condition assessments.

The durability and deterioration of a structure in service can be quantified by the use of condition assessments / inspections. Once built, and due to their environment, structures for the mining and resources industries can deteriorate at a faster rate than other industrial structures. The owners of facilities generally implement inspection systems as part of their duties and obligations to provide a safe workplace. Durability aspects of structural reliability include the protective coating systems, as well as the inspection and maintenance systems for the structure. Durability of the structure depends on [2]

- ◆ Environmental conditions due to the weather, location and plant;
- ◆ Construction materials;
- ◆ Protective coating systems;
- ◆ Quality of the original workmanship and level of control;
- ◆ Shape of the structural members and detailing practises;
- ◆ Inspection and maintenance program for the structure;
- ◆ Maintenance and Housekeeping.

Periodic inspection and maintenance is required for all structures to ensure safe and reliable operation. The aim of periodic inspection is to determine the extent and severity of deterioration to the structure. The effect of deterioration on the structure can be assessed and the required remedial action taken in order to maintain the structures' integrity. Database systems, such as Hatch's FAARMS (Facilities And Assets Risk Management System), can assist in this process.

A structure can be checked for compliance with the latest standards and codes by undertaking a structural assessment. The structural assessment may indicate that a structure is no longer complies with the current code, even though the original design was undertaken correctly, due to:

- ◆ Changes to the structural framing system;
- ◆ Changes to the operating procedures / methodology;
- ◆ Changes to the actions applied to the structure due to changes in the codes and standards;
- ◆ Changes to actions applied to the structure due to upgraded equipment or mechanical items supported by the structure, or additional equipment or mechanical items to be supported by the structure;
- ◆ Changes to the structural compliance criteria due to changes in standards and codes, or more stringent requirements for new/ upgraded equipment;
- ◆ Changes to the risk profile of the structure;
- ◆ Deterioration of, or damage to, the structure.

Remedial design and upgrading of existing structures can be expensive. A structural condition assessment enables informed decisions to be made about the structure and its remaining service life. Several of the reliability management systems described in this article can be used to improve the accuracy of the structural condition assessment and the risk profile of the structure by reducing the likelihood of hazards, and their consequences. This will in turn reduce the cost of upgrading an existing structure to make it comply with the latest code requirements.

### Reliability Management Systems

Several of the systems used to differentiate structural reliability, presented in BS EN1990 [2] as well as others, are described as follows;

#### 1. Design Qualifications

The reliability level required of a structure dictates the minimum level of experience and qualifications required by the design and checking structural engineers.

#### 2. Design Reviews

Design reviews are usually made at a broader level than design checking. These concentrate on the basic structural form, assumptions made during the design, structural design criteria, and interface issues. The level of reliability required and the use and form of the structure dictates the need for design reviews to take place and their frequency.

#### 3. Design Supervision

The reliability level required of the structure dictates the minimum level of supervision and extent of checking required. This can vary from basic arithmetic checking to complete independent calculations within the design team/ company or by independent third party proof engineering.

#### 4. Analytical Methods

The design of structures is generally undertaken with the assistance of analytical models. The choice of analysis method will depend on the magnitude and distribution of actions to be applied to the structure, the structural acceptance criteria, the form of the structure, geometric parameters and the required accuracy of the analytical model. Reliability management involves specifying the minimum analytical method for the required reliability of the structure.

#### 5. Load Factor Method

This method involves the addition of a load factor, applied to unfavourable actions, which is dependant on the reliability level. This would involve adjusting the partial load factors for the limit state method of design. Care should be taken when using this method to ensure that the structure does not become uneconomical. There are several types of loads, calculated accurately and with a high degree of confidence, which can be applied to structures for industry. The adjustment of load factors should take into account the accuracy of the estimated loads, the classification of the design situation and the frequency of loading.

#### 6. Material Resistance Method

An additional factor, dependant on the reliability level, is applied to the material strength properties. This is equivalent to increasing the factor of safety for the working stress method, or lowering the material capacity factors for the limit state method. The change in factors may be different for the classification of the design situations.

#### 7. Preventative Action

Preventative action consists of measures taken to avoid certain design situations or hazardous conditions. This may consist of the introduction of barriers, increased separation distances etc. The required reliability of the structure would dictate the necessity for these measures.

#### 8. Operational Procedures

Operational procedures are designed and implemented to reduce the likelihood of certain design situations occurring (particularly the abnormal operating or special design situations) and/ or to reduce the consequences of these events. The procedures would be determined giving consideration to the required reliability of the structure.

#### 9. Action Limiting

The action limiting method provides a series of controls that are implemented to limit the loads applied to the structure, depending on the required reliability level. This may include level, pressure and temperature sensors, an anemometer or load cells with associated control systems.

#### 10. Action Verification Methods

A procedure for verification of the loads applied to the structure is implemented, depending on the type of structure and the reliability level required. Verification could include some or all of weighing, strain gauging, thermography, condition monitoring, wind tunnel testing, testing of bulk materials and surveying.

#### 11. Analytical Verification

A procedure, depending on the type of the structure and the level of reliability required, implemented to verify the analysis model. Method can include surveying, strain gauging, deflection testing and proof loading.

#### 12. Inspection during Construction

The reliability level of the structure dictates the extent of the inspection and quality control imposed during fabrication of the structure. Structures with higher reliability classifications require more extensive inspection during fabrication and erection, which may include independent testing of materials and other components.

#### 13. Inspection during Operation

Structures with a higher level of reliability require a higher frequency of inspection during operation.

At present Australian codes require an importance factor / level to be calculated according to the use of the structure and the potential hazards. This importance factor is used in the calculation of environmental loads applied to the structure. The earthquake code sets minimum analytical model requirements depending on a number of factors, one of which is the importance level.

Several new standards relating to the reliability of structures are currently released in draft form. These are scheduled for publication next year.

The extent to which reliability management is implemented is left to the owner of industrial facilities.

#### References:

- [1] AS/NZS 1170.0 – 2002 Structural Design Actions: Part 0 General Principles, Standards Australia, Sydney NSW, 2002.
- [2] BS EN1990 - 2002 Basis of Structural Design. British Standards Institute LONDON 2002
- [3] Building Code of Australia

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## DESIGN CODES

## Addendum to Previous Article Entitled "Recent Changes to the Australian Loading Codes"

Standards Australia has acknowledged and is aware that there is a typographical error in table F2 of AS/NZS 1170.0 as noted in the previous newsletter. Hatch Associates has been advised by Standards Australia that this error will be corrected in a future amendment to this standard.

The Building Code of Australia (BCA) does allow for the 1989 edition of the loading codes to be used for design purposes. The intent of the previous article was to inform the readers of the changes to the loading codes and the allowable use of the previous standards was stated. The use of the 1989 loading codes may be precluded, as it is general practice to state in structural specifications and project design criteria that the latest version of the design codes be adopted for the design. Table 1 shows a breakdown of the Australian loading codes

**Table 1: Breakdown of Australian Structural Codes**

	Australian Structures Covered by the Building Code of Australia		Australian Structures not Covered by the Building Code of Australia
	Use of pre - 2002 loading codes	Use of 2002 loading codes	
Live Loads	AS 1170.1 - 1989	AS/NZS 1170.1: 2002	AS/NZS 1170.1: 2002
Dead Loads	AS 1170.1 - 1989	AS/NZS 1170.1: 2002	AS/NZS 1170.1: 2002
Load Combinations	AS 1170.1 - 1989	AS/NZS 1170.0: 2002	AS/NZS 1170.0: 2002
Importance Level	N/A	Building Code of Australia	AS/NZS 1170.0: 2002 Appendix F
Design Action Events	N/A	Building Code of Australia	AS/NZS 1170.0: 2002 Appendix F
Wind Loads	AS1170.2 – 1989 <sup>1</sup>	AS/NZS 1170.2: 2002	AS/NZS 1170.2: 2002
Earthquake Loads	AS1170.4 – 1993 <sup>1</sup>	AS 1170.4 – 1993 <sup>2</sup> in conjunction with Appendix D AS/NZS 1170.0: 2002	AS 1170.4 – 1993 <sup>2</sup> in conjunction with Appendix D AS/NZS 1170.0: 2002

### Note

- AS1170.2 and AS1170.4 have importance factors relating to the function of the structure in the calculation of the loads.
- A draft earthquake code is currently open for comment and includes the variation of ground acceleration for different return periods.

The Earthquake code, AS 1170.4, is currently being revised. It is being issued as an Australian standard and not as a joint New Zealand/Australian Standard due to the required level of detailing and other issues between the two countries. The draft copy of the new Australian earthquake code is numbered DR 04303 and is available at the Standards Australia web site.

## PEOPLE AND EVENTS

The group leader of structural assets Dr. Loganathan has been invited by MSC Software to attend their "Virtual Product Development Conference - 2004" to be held in Melbourne. Logan has been invited to deliver the Keynote Address to delegates who will be attending from Australia, New Zealand and South East Asia

The Australian Steel Institute has presented it's annual undergraduate steel design award to the youngest (and at present part time) member of the structural assets group Alistair Deane. This award is presented to a student, from each Queensland participating university, who achieves the highest degree of excellence in steel structures and steel design by the end of their third year in the Bachelor of Engineering Course. The University of Queensland nominated Alistair for his work at the end of last year. Congratulations go to Alistair for the hard work that earned him this prestigious award.

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