Best practice of crane support structures design – an expert survey

By

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Thesis presented in partial fulfilment of the requirements for the degree of Master of Science of Engineering (Civil) at the University of Stellenbosch.

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December 2007

Declaration

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and that I have not previously in its entirety or in part submitted it at any university for a degree.

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Geoffrey B Thompson Date

Synopsis

Research on cranes and crane support structures has been completed at Stellenbosch University's Structural Division. In order to link the research already completed with that which is practically relevant, an industry related expert survey was proposed. Consequently, the research title is "Best Practice of Crane Support Structures Design – An Expert Survey".

The primary objective of the study is to complete research, which can be used at a later stage to compile a "best practice" guideline for support structures design. The expert survey allows practical experience and opinion to be gathered from experts. The primary drawback being the uncertainty involved in such opinionated research material. For this reason an attempt is made in the thesis to apply a scientific approach, in order to attain rationally defendable results.

The survey was conducted using interviews with experienced crane support structure designers and crane manufacturers in South Africa. The experts were then rated according to their answers to seeded questions, the number of colleague recommendations they each received and the years of experience each expert has. The expert opinion was subsequently combined using the expert ratings as weights. To further improve the scientific rationale behind the results, several of the topics mentioned by the experts were verified using related literature - thereby validating the use of the combined expert opinion for this research.

The results obtained from the survey and verification process are regarded as useful to the objectives of the study. Information concerning pre-design specifications, loads and actions, structural analysis, design, design details and fatigue was compiled. The direct results are tabulated in an appendix and commentary, based on the expert opinions, is provided.

A failure investigation was also completed with less success than initially intended. This was due, in part, to confidentiality issues and a lack of failure information easily accessible to the experts. For this reason the results of the failure investigation focuses more on various failure mechanisms.

The success of the survey indicates that expert opinion is a useful tool for research. Furthermore, the minor differences in expert opinion, when compared to information obtained from crane support structure literature, indicates that the expertise in the South African crane support structure design is at an international standard.

OPSomming

Navorsing op krane en kraanondersteuningsstrukture is by die Universiteit van Stellenbos se Struktuur Afdeling uitgevoer. Die resultate soos deur middel van die navorsing verkry, moet met die praktiese inligting wat direk vanuit die nywerheid verkry word, vergelyk word. `n Opname onder kundiges in die nywerheid is as die mees effektiewe manier geidentifiseer om hierdie verbinding te bewerkstellig. Gevolglik is “Best Practice of Crane Support Structures Design – An Expert Survey” gekies.

Die primêre doel van die ondersoek is om navorsingsresultate af te rond en inligting te verkry wat later gebruik kan word om `n “Beste Metodiek” gids vir kraanondersteuningsstrukture te ontwikkel. Die opname maak dit moontlik om praktiese ervaring en opinie by die kundiges te verkry. Die belangrikste nadeel van die tipe opname is die onsekerheid wat verbind kan word aan die opinie van die kundiges. Vir hierdie rede is `n wetenskaplike benadering gevolg, om sodoende resultate te bekom wat rasioneel gestaaf kan word.

Die opname is gemaak deur onderhoude te voer met ervare kraanondersteuningsstruktuur-ontwerpers en kraanvervaardigers in Suid-Afrika. Die kundiges is vervolgens geweeg aan die hand van hulle terugvoer op vrae waarvan die antwoorde voorafbepaal is, die aantal kere wat hulle deur hulle kollegas aanbeveel is en die hoeveelheid jare van ondervinding in kraan ondersteuningsstruktuurontwerp. Sodoende is die rangorde van die kundiges bepaal. Die opinies van die kundiges is dan saamgevat deur die geweegde gemiddeldes te bereken. Die geweegde gemiddeldes is gebaseer op die rangorde van die kundiges. Literatuur word addisioneel gebruik om van die opinies, wat tydens die opname versamel is, te verifieer. Hierdie bevestiging help ook om die resultate rasioneel te kan verdedig.

Die resultate verkry tydens die opname en bevestiging van opinie word as nuttig vir die uitkomstes van die studie geag. Inligting rakende voor-ontwerp spesifikasies, laste en aksies uitgeoefen, strukturele analise, element- en verbindingsontwerp en vermoeidheid bepaling word weergegee. Die resultate wat direk verkry is, word in tabelform weergegee met kommentaar vir verdere verduideliking.

Navorsing oor falings van kraan en kraanondersteuningsstrukture is ook voltooi. Die resultate was nie bevredigend nie, as gevolg van vertroulikheidsbeperkings en `n tekort aan nuttige falingsinligting. Vir hierdie redes is die falingsinligting meer gemik op falingsmeganismes as op die falings self.

Die sukses van die opname bewys dat soortgelyke navorsing gebruik kan word om wetenskaplik-verdedigbare inligting te versamel. Die klein verskille in kundige opinie wanneer dit vergelyk word met inligting wat uit literatuur verkry word, gee `n duidelike aanduiding dat die vlak van kundigheid in kraanondersteuningsstruktuurontwerp in Suid-Afrika op `n internasionaal vergelykbare vlak is.

Acknowledgements

I would like to thank:

- The University of Stellenbosch for the opportunity to complete this research.

- My parents and family, for their support and love. You always helped keep my chin up.

- My loving girlfriend, Jenn. Without you none of this would have been possible. You are always able to provide me with the pep that I need.

- All the experts that took part in the survey - it was a pleasure meeting each of you.

- The Southern African Institute of Steel Construction, for the freedom to complete my studies. David Blitenthall and Spencer Erling, you have always been very facilitating and helpful during my studies.

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CHAPTER 1:

INTRODUCTION

The thesis background, scope and limitations are included in this chapter.

1.1 Background

"Best Practice of Crane Support Structures – An Expert Survey" is the thesis title. It introduces three concepts: best practice, crane support structures and expert surveys. As such it provides a brief description of the research completed in this thesis. A short background to the thesis will therefore be described according to a further development of the title.

1.1.1 Crane Research at Stellenbosch University

At the Institute of Structural Engineering, Department of Civil Engineering, Stellenbosch University, much research has been, and is currently being completed regarding cranes. More crucially the interaction between the crane and the support structure and the design philosophy according to this interaction, have been investigated. An outline of this research is explained by Dymond et al. [2006] which highlights the following topics as the investigation's most important aims. A fair number of Masters and Doctorate level projects are directly related to these overall research topics.

i) Defining the actual imposed loads on the crane support structure.
ii) Determining which crane load models best describe true crane behaviour.
iii) Differences between these load models and the load models of SABS 0160:1989.
iv) The implications of adopting these load models into the proposed new South African loading code SANS 10160.
v) The reliability of present and future South African crane support structures.

The imposed loads influence many of the topics mentioned. Their importance to the research is therefore obvious. The design of the crane support structure is closely connected to these loads, thus the structural design implementing the loads also becomes significant. As a result all of the questions listed above become mutually relevant to "Best Practice of Crane Support Structures Design – An Expert Survey". Furthermore the development and improvement of "best practice" guidelines coincides fully with the development and improvement of South African crane support structures reliability.

1.1.2 Thesis Motivation

In order to improve crane support structures design and develop "best practice" guidelines, it becomes necessary to look at the crane support structure design methods being used in South African industry today. As Lord Byron said in 1821 - "*the best of prophets of the future is the past*". Accordingly experience in the industry from days past, is extremely valuable. "Experience" and "experts" do not begin with the same five letters for nothing. Thus, crane support structure experts were consulted to obtain knowledge of the present and past design conditions.

It would be helpful to compare and evaluate the situation found in practice with the situation as described by research already completed. In this way a practical crane support structures design guide could be compiled, intended to assist the structural designer when faced with the challenging task of designing a crane support structure. The document would be based on academic investigations completed, but be aimed at acceptable practice in industry. The potential development of such a handbook is the chief motivation for this research.

1.2 Research Objectives

Information concerning crane support structure design routines in the South African steel construction industry is required. Based on this principle goal, the aims and intentions of this thesis are:

i) Select and develop an appropriate process to elicit information from expert opinion.
ii) Apply the selected elicitation process in order to acquire industry focused knowledge.
iii) Analyse the data and draft the findings which subsequently will serve as research for a potential crane support structure design guide.
iv) Compare and verify the findings using literature.
v) Compile a list of crane and crane support structure failures that will serve as research for a potential crane support structures design guide.
vi) Identify any uncertainties or shortcomings in the design process followed by South African structural design professionals.

1.3 Research Limitations

Several limitations exist in the development and use of the research. Certain of these limitations are important to note if the document is to be used as a reference for further academic or practical work.

The first limitation is the choice of crane relevant to the research. The applicable crane is the electric overhead travelling crane or EOT crane. In some cases this is expanded to the EOT bridge crane. The limitation is furthermore compatible with the new proposed code, SANS 10160. This code limits its application to indoor and outdoor overhead travelling cranes with both rails at the same height. The rails are additionally assumed to be parallel and the crane should be top running. Although the concepts investigated and discussed are specifically for top running EOT cranes, a portion of the information can be applied to under slung and gantry cranes. A cautious approach must be followed when applying the subjects covered by this thesis to other types of crane structures.

A second limitation is the researcher's limited knowledge of the subject area. Only undergraduate level knowledge combined with post graduate coursework of steel structures design is understood. Therefore much investigation and skills development is required prior to commencement of the expert survey.

No documentation of a similar study conducted in South Africa could be found. Limited references relevant to crane support structures design are available in South Africa. Literature available from the Southern African Institute of Steel Construction Library, the Engineering and JS Gericke libraries of Stellenbosch University and published journals found via the internet were used.

Several codes can be applied in the design of crane support structures. Australian Standards, Eurocode, SABS/SANS, DIN and ISO are some standards that cover the topic. Since the survey is based on present South African practice, SABS 0160:1989 and SANS 10162-1:2005 codes will be utilised in this thesis. The proposed SANS 10160 Section 10 will occasionally be considered. Several of the Eurocodes and Australian codes are also referenced in the document.

The expert survey to be conducted and its findings comprise the most serious restrictions. The use of expert opinion as scientific information is problematic and not immediately plausible. The difficulty is increased by the qualitative (non-numerical) nature of the expert responses. An attempt is made to use a scientifically based approach in this thesis, yet it remains impossible to avoid a certain degree of error and bias. The responses therefore require verification in order to be rationally defendable. Always remember: "Opinion is by its very nature uncertain." [Cooke 1991].

Logistics also limited the extent to which the experts could be reached for interviews. Travel times, financial implications and busy expert schedules meant that a limited number of experts could be interviewed. The interview length and vast variety of subject material also limited the extent and detail of the investigation. It must be added that much assistance was afforded by the experts that were visited.

1.4 Research Scope

As has been stated one of the objectives of this thesis is to obtain functional information concerning crane support structures design by means of an expert survey. In order to propose a process and explain how to achieve the thesis aims efficiently, the following topics will need to be addressed.

i) EOT cranes and the crane support structure are introduced.
ii) Background information on relevant design features of the crane support structure is provided.
iii) A description of how the practical information was selected from available crane support structures design literature must be provided.
iv) The method used to acquire the information from experts in industry is selected and explained – in this case the expert survey and questionnaire development.
v) The elicitation process and related biases are described together with practical implementation advice.
vi) An expert opinion survey is conducted using one on one interviews with structural designers and crane manufacturers.
vii) The expert survey method of data analysis is selected and clearly defined in order to achieve rationally defendable results – in this case the scoring rules and expert rating.
viii) Further preparation and verification of results for "best practice" use is described and implemented.
ix) A list of crane and crane support structure failures in South Africa is compiled according to the information that is made available during the investigation.
x) Conclusions are drawn and recommendations made concerning the research.

1.5 Development of Thesis

The thesis progresses from the introduction into a more detailed explanation of relevant concepts. The literature review investigates these topics in two chapters namely: EOT Crane Support Structures Characterisation and Expert Opinion Surveys. The intention of the literature review is to provide a knowledge base for the reader which focuses on subjects discussed in the thesis. Referral to literature in the results and discussions is also supported by the review.

The literature review is followed by a description of the research procedure utilised. This includes how the expert opinion was gathered and analysed and the results that stemmed from the survey. The results are then discussed and neatly summarised. Lastly conclusions are drawn and recommendations made.

The appendixes at the back of the document include all background information that was not regarded as necessary to the logical development of the thesis topic. This pertains also to a tabulated index of direct weighted results obtained during the interview process.

CHAPTER 2:

Definition of EOT CRANE SUPPORT STRUCTURES DESIGN

First a basic introduction to both electric overhead travelling cranes and their support structures is provided. Following this a further literary investigation is needed. This chapter furthermore examines the EOT crane support structures design procedures. The topics relevant to the project are categorised and diagrammatically displayed. The chapter aims to further improve the reader's background knowledge of the investigated subject and select the material for the "best practice" survey.

2.1 Introduction to Overhead Cranes

As far back as the Middle Ages, crane structures were used to lift objects that were too heavy or cumbersome for hands on lifting. The development of cranes since then has gone hand in hand with the development of modern industry. Man, hydraulic, steam, diesel and electric power are used to drive these massive lifting machines. Today development of cranes continues at a rate that is difficult to match. [Verschoof 2002]

Many different varieties of crane exist. Broughton [1958] grouped all cranes into four main categories which remain applicable today, namely:

i) Overhead travelling – fixed rails lying on one or two elevated girders with a trolley or crane bridge (with hoisting apparatus) that can traverse the length of the rails.
ii) Jib – usually consists of an inclined member that can rotate about a central point and suspends the load from the outer end of the inclined member.
iii) Gantry – a girder, or girders, connected to vertical members which are either fixed or move along tracks at the base of the vertical member. The hoisting equipment can usually traverse the bridge girder, or girders.
iv) Cantilever or tower – a vertical mast with a horizontal cantilever that rotates horizontally around the vertical member. The trolley and hoisting equipment move along the horizontal cantilever.

2.1.1 Electric Overhead Travelling Cranes

The crane specific to this thesis is the overhead travelling crane, or more specifically the electric overhead travelling crane. The definition provided in i) above is generalised but not inaccurate. The EOT crane is now described in more detail. The different components of the crane are illustrated in *figure 2.1*.

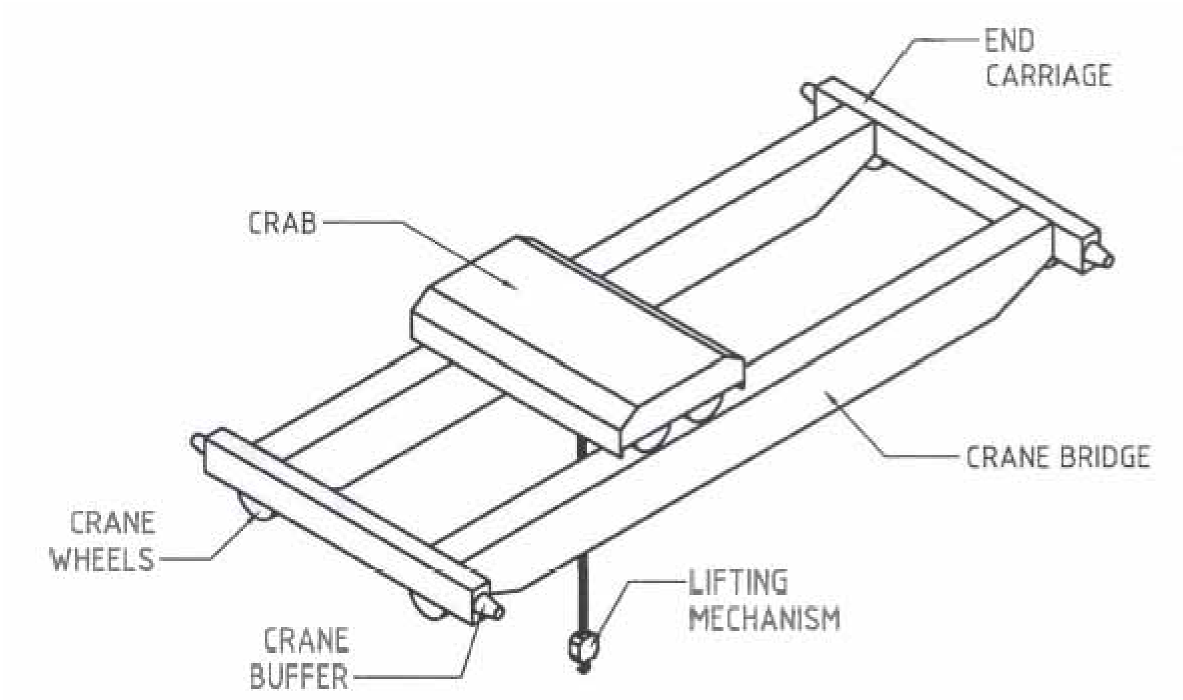


Figure 2.1: The main components of electric overhead travelling cranes. Variations of this standard do occur widely in industry. [Dymond 2005]

The crane wheels are housed within the end carriages. At either end of both end carriages, a crane buffer can be found. In most cases the wheel drives are also situated on, or in, the end carriages. A crab that includes the lifting equipment and crab wheels can traverse the distance between end carriages on the crane bridge. The lifting mechanism, in most cases a hook, also forms part of the lifting equipment. In some cases a control cabin is fixed to the crane bridge or crab, but today most EOT cranes are remote controlled for safety reasons.

The crab and crane individually can be either under slung or top running. The under slung setup has wheels running on the bottom flange of a runway girder and effectively hangs beneath its support structure. The top running example is illustrated above and sits upon the top flange and rail of the support girders. The latter is the focus of this thesis.

The top running EOT cranes are capable of lifting over 600 ton loads. Indoor and outdoor examples exist, though the EOT crane is generally found inside industrial buildings. These cranes have a very wide use, from loading a truck with goods to facilitating a process in a steel mill plant. In a process plant the constant and effective running order of a crane becomes vitally important.

In the event of a process crane failing or needing repair (known as *downtime*), severe financial consequences will be faced by the owner. In the case of an abrupt failure human life and damage to property are also at risk. For this reason, accuracy in design, construction and maintenance (with minimal downtime) becomes essential. [Dymond 2005]

The lifting capacity (safe working load) is not the only EOT crane variable. The speed of longitudinal travel, cross travel and hoist movement are also important factors that can differ per crane. Furthermore the placement and number of cranes within a building also varies and subsequently influences the design of the support structure. A final thought on variability is the number of lifts that a crane will make in its design life. This can be very influential as the cyclic effects of crane loading can lead to fatigue problems. [Broughton 1958; Verschoof 2002; Dymond 2005; Fischer 1993; Goldman 1990; Maas 1972] Certain of these topics are discussed in more detail later on.

All in all these machines and their support structure are very important to modern industry. Their ability to move and make lifts at capacity makes designing the structure that supports them a considerable challenge. [Dunaiski 2006; Southern African Steel Construction Handbook (SASCH) 2005; Collins et al. 1991]

2.1.2 Code Defined Crane Application

Two EOT crane definitions at the hands of the South African Standards and the Eurocode are listed.

New proposed SANS 10160: "*Overhead travelling bridge cranes on runway beams on the same level.*"

Eurocode [prEN 1991-3 2002]: "*A machine for lifting and moving loads that moves on wheels along overhead crane runway beams. It incorporates one or more hoists mounted on crabs or under slung trolleys.*"

From this it is clear that the Eurocode and the South African standards make provision for overhead bridge cranes (under slung and top running), monorails and to a certain extent gantry cranes. Dymond [2005] states that the EOT crane is the most used and designed crane in industry today. Furthermore 95% of these EOT bridge cranes are top running.

For this reason the codified description is narrowed to coincide with the introductory limitation; namely the top running electric overhead travelling crane.

2.2 Introduction to Crane supporting Industrial Structures

EOT crane support structures need to be reliable in order to ensure the safe and continuous working of the cranes that run upon them. Consequences of failure can include loss of life, damage to property as well as large financial losses due to downtime. The design of these support structures should therefore always require a "best practice" approach in order to avoid any downtime or worse consequences. [Dymond 2005]

The crane support structure consists of the rails, crane rail clips (fastening systems and pads), crane runway girders, crane columns, crane column bracing and foundations, crane stops (end stops) and conductor rail supports [Ricker 1982]. Two examples of such structures are provided below.

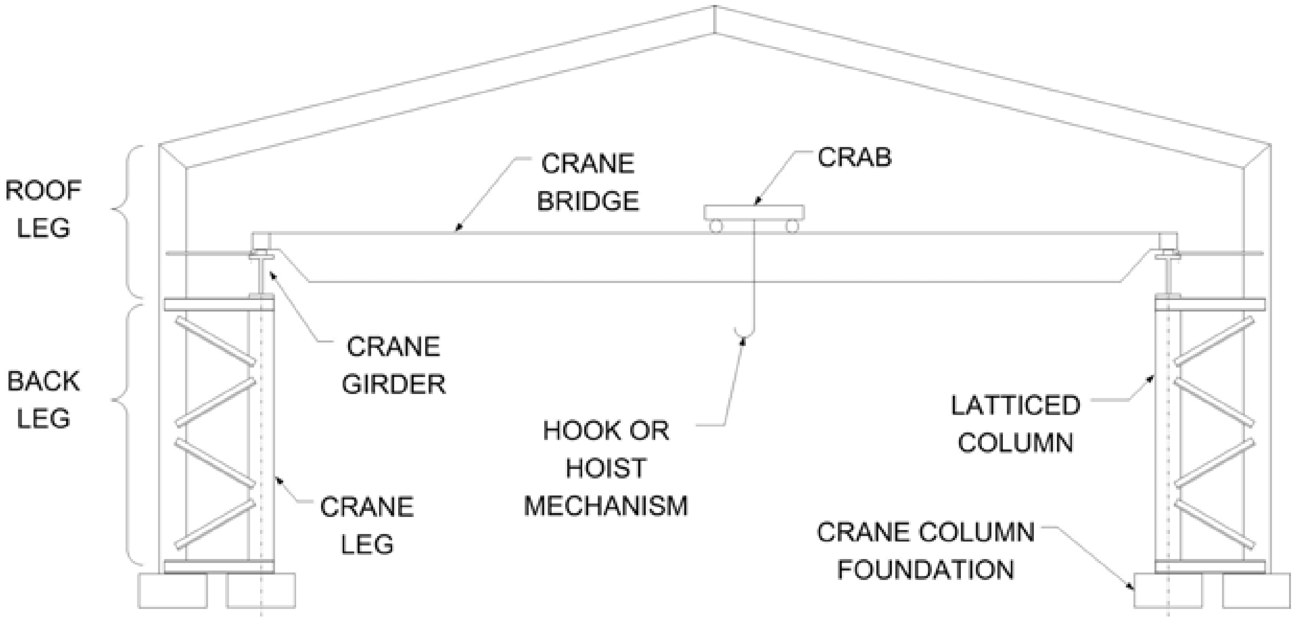


Figure 2.2: Heavy crane buildings often employ the latticed crane column.

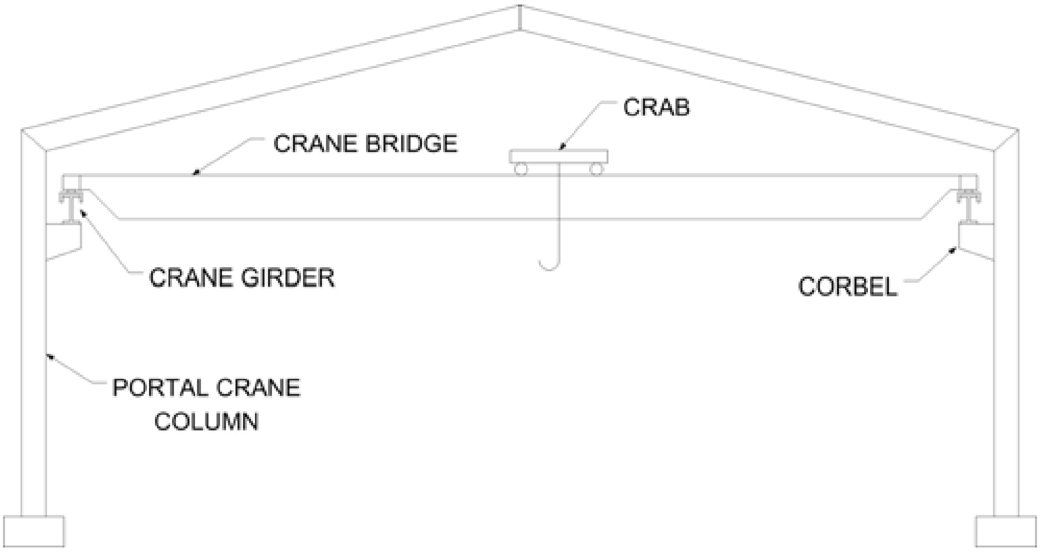


Figure 2.3: The portal frame with the EOT crane on a corbel is more commonly associated with light cranes.

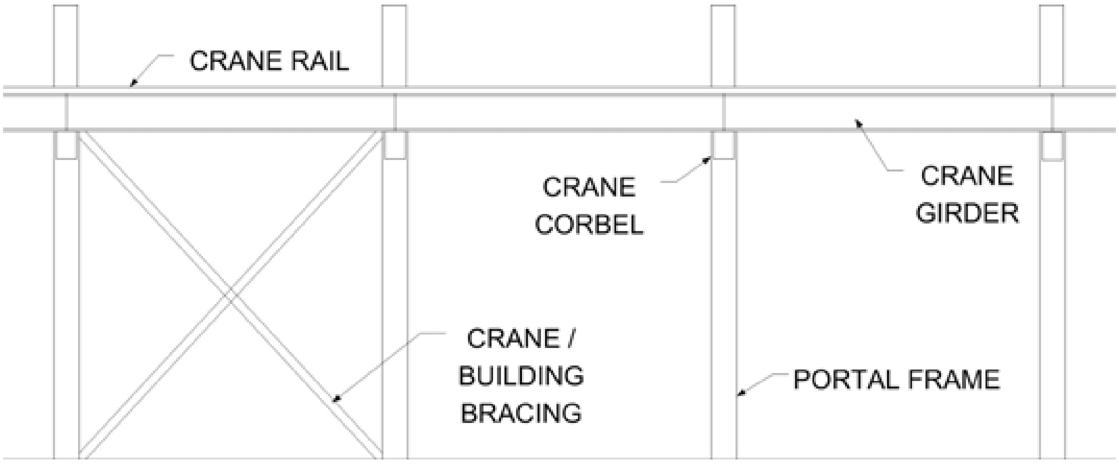


Figure 2.4: A side view of a portal frame structure with the crane girders resting on brackets.

Ensuring the crane is in a safe working condition throughout the cranes design life is the crane manufacturer and client's responsibility. The design of the support structure is the responsibility of the structural engineer. Once the structure has been competently designed, erected to tolerance and commissioned – the responsibility of the structural maintenance shifts to the client.

Correct use of the crane, proper training of the crane drivers and routine maintenance of the structure, must be included in this undertaking. Good quality maintenance of the crane will also aid the structure. Contracts, guarantees and other documentation are important for legal reasons, but at the end of the day it is in the clients own best interests to look after the structure and crane diligently.

2.3 Main Categories of Crane Support Structures Design

According to Dymond [2005] EOT crane support structures design requires a sound understanding of the following process:

i) Identifying the loads imposed upon the support structure.
ii) Modelling the structure and its response.
iii) Choosing (designing) the structural system and details to ensure the reliability of the structure.

This is an uncomplicated break down of the process that needs to be followed when designing crane support structures. Further division of the topic was found in *Guide for the Design of Crane Supporting Steel Structures* [MacCrimmon 2005], *Crane Runway Girders Limit States Design* [Gorenc 2003], *Crane Runway Systems* [Rowswell 1987] and *Guide for the Design and Construction of Mill Buildings* [AISE 2003].

2.3.1 Literature Based Categorisation of Crane Support Structures Design

The design procedure division is summarised according to each aforementioned reference (*figure 2.5* to *figure 2.8*). This includes topics not directly linked to the design. The divisions are then scrutinised and a collective layout for the thesis is chosen. The selected categorisation is illustrated in the *figure 2.9*. This is the key layout to the expert survey and questionnaire. An added incentive for inclusion of these categorisations is that they quickly develop in the reader a feeling for the requirements of crane support structures design and how the different concepts are associated with one another.

Four principal examples are included because each author focuses on unique parts of the design process. Rowswell [1987] for instance gives more attention to rails and the lateral girder connections (transverse “tieback” connections). No distinct correct layout exists.

The crane support structures are broken down into a primary level, secondary level and lastly a tertiary level. Further commentary is provided below each flow diagram.

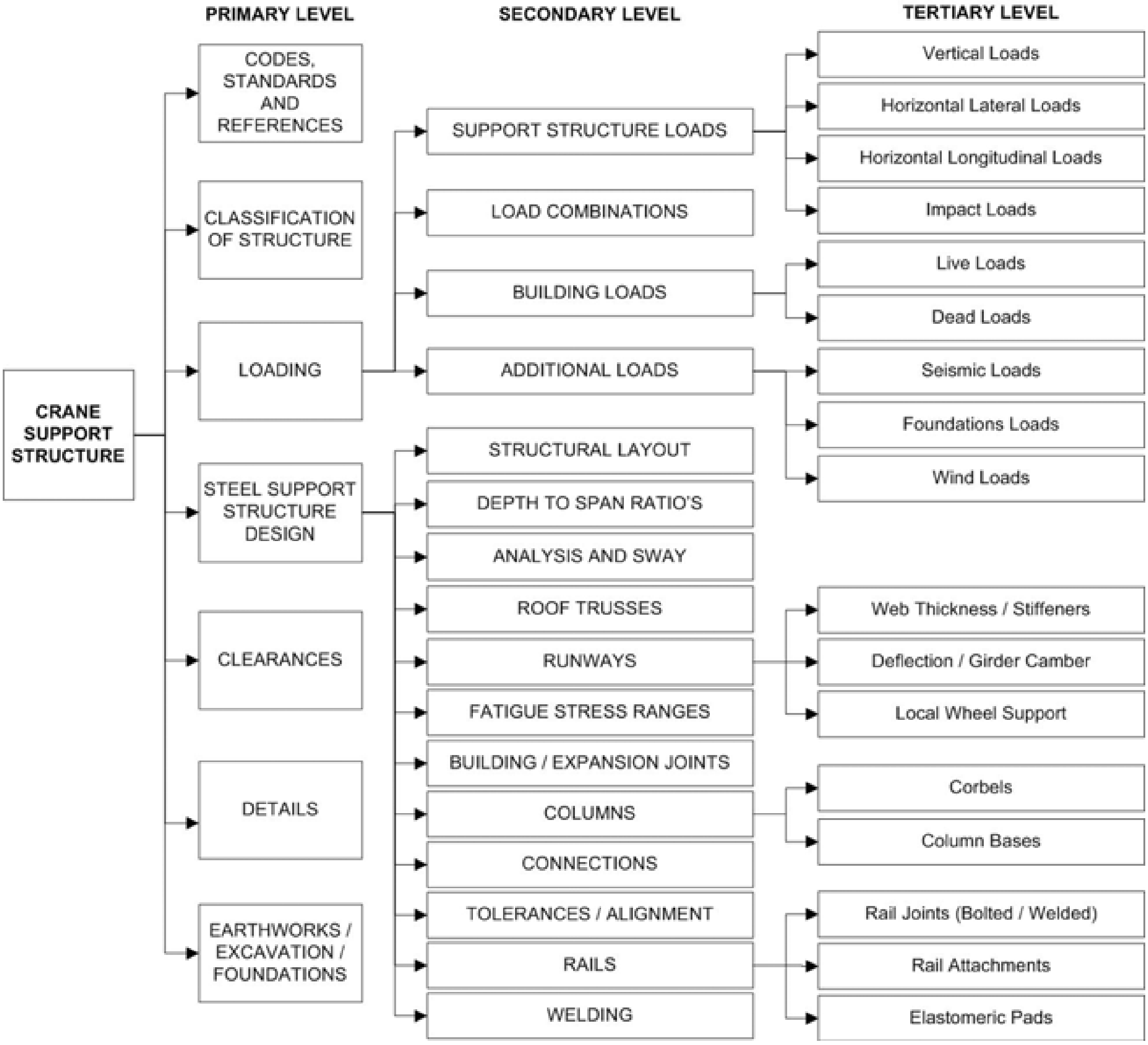


Figure 2.5: Flow diagram of the categorisation of crane support structures according to AISE [2003].

There are only two primary categories that receive attention from AISE Technical Report No. 13 [2003]. These are loading and steel support structure design.

Notably loading is of cardinal importance when designing any structure. Besides ordinary industrial building loads, crane support structures are subject to loads caused by crane actions. The crane affects variable loads and as such can impose impact loads and cause fatigue in the supporting steel members. Lastly the crane horizontal loads also affect the support structure.

Steel support structure design is given a fairly detailed division. Certain of the topics listed in the secondary level could be important enough to be considered on a primary level (e.g. structural layout, analysis, fatigue). Runways, columns and rails receive a justified further break down.

Figure 2.6: Flow diagram of the categorisation of crane support structures according to Gorenc [2003].

Gorenc [2003] includes several very important subjects at the primary level. This division is seen to be very appropriate to a comprehensive design guide. It is also noted that support structures design and loading again receive the most attention at the secondary and tertiary levels. The break down of details and structural classification are quite neatly explained. Although not indicated by the figure, structural classification and the fatigue design procedure are closely linked. As Gorenc intended, this layout is focused more on crane runway girders.

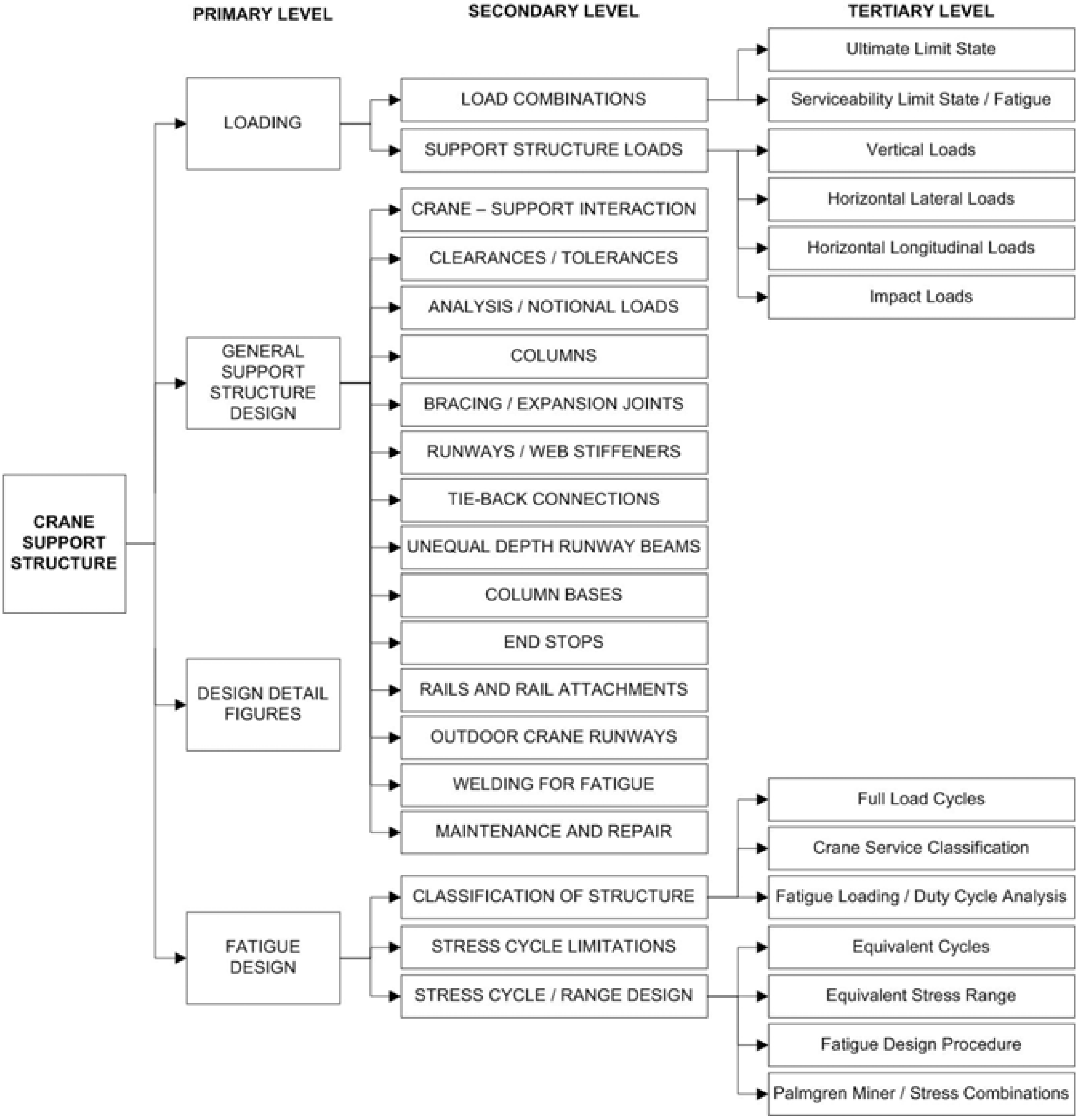


Figure 2.7: Flow diagram of the categorisation of crane support structures according to MacCrimmon [2005].

Although only four categories are found on the primary level, the division is still well selected. Loading, support structure design, detail figures and fatigue design are all highly important topics. MacCrimmon places extra attention on fatigue design in comparison with the previous examples.

The overall layout of this flow diagram is dissimilar to the previous examples. Yet the arrangement is in no way less valuable. Certain topics, previously on a primary level, are simply addressed on a secondary level here (e.g. analysis, classification of structure, details).

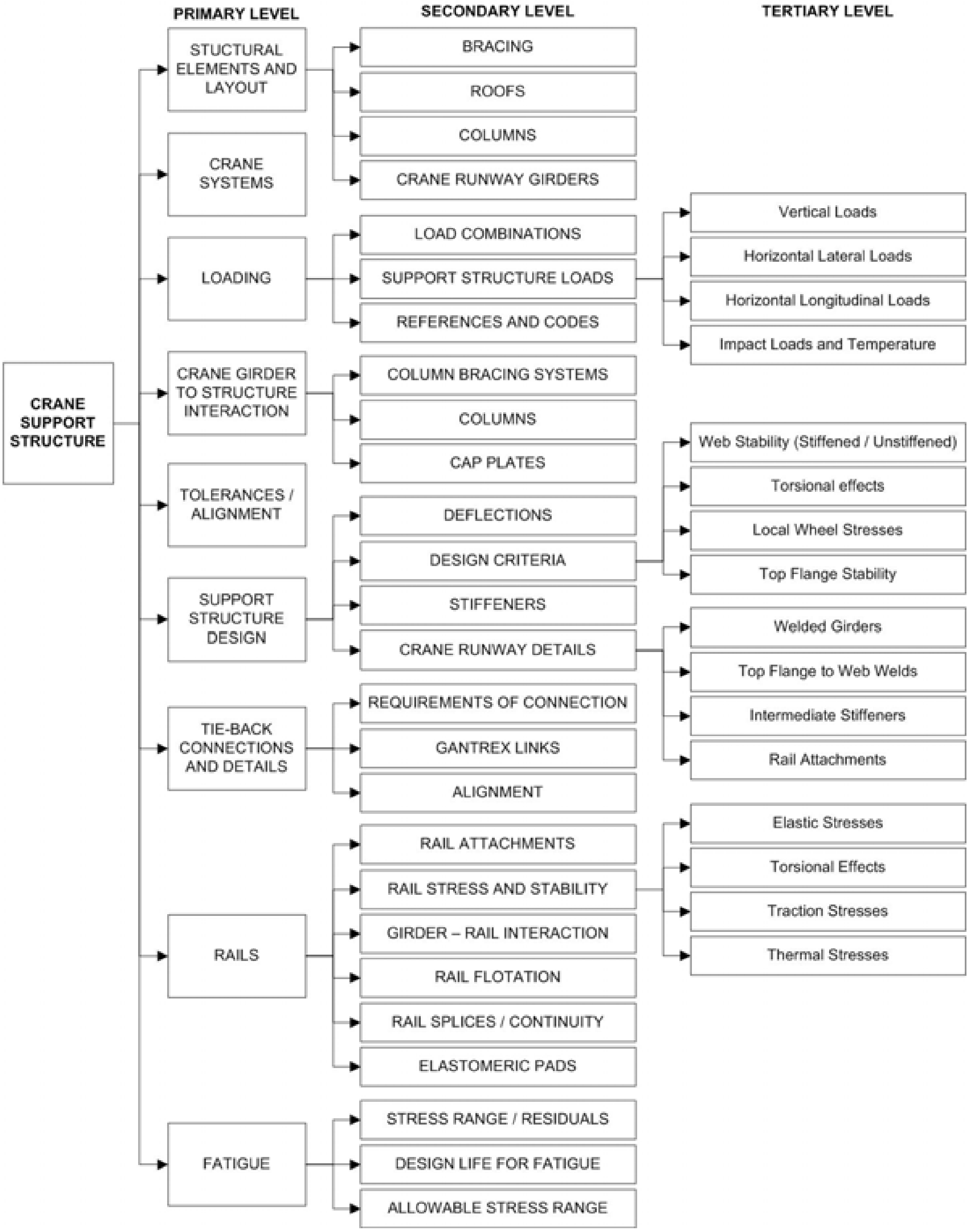


Figure 2.8: Flow diagram of the categorisation of crane support structures according to Rowswell [1987].

Rowswell's division is slightly biased as the research completed focused on certain topics more than others. This is understandable as the literature was not published specifically as a design guide. Two valuable additions at the primary level are crane girder to structure interaction and tieback connections. The choice of ranking these two topics at primary level, indicating the importance they hold to Rowswell and potentially to this thesis.

2.3.2 Thesis Categorisation of Crane Support Structures Design

The examples inspected confirm the variance in opinion of the different authors. However key tendencies are visible in all of the cases. This section will prepare and explain the development of a classification model. The model chosen will be used as a starting point for the subsequent literature explanation and for the expert survey questionnaire.

A glance at the four preceding classification models suggests that loading[1], support structure design[2], fatigue[3] and details[4] are the most important topics. They are present in each flow diagram, albeit at different levels. The four categories will therefore form the basis of the thesis model. After further consideration, three additional categories are ascribed to the primary level; they are pre-design specifications, structural analysis and failure investigation.

Pre-design specifications are important to the design of crane support structure. If a designer has the wrong information, a building will never be accurately designed or constructed. Crane manufacturer and client determined information is imperative and in some cases hard to attain. The overall effect the pre-design information has on an entire project makes the inclusion of the topic at primary level warranted.

Today structural analysis is a very important tool in the design process. It forms a link between the loads and the design procedure. In some cases it is even able to assist with design. If errors occur during analysis the structural reliability will suffer. Structural analysis is not specifically mentioned in all of the author's models, but even so, it is placed in the primary level.

The last addition to the primary level is the failure investigation. This is not directly linked to the design of crane support structures but the information obtained from such an investigation is certainly useful. Often shortcomings in detail selection and design procedures are only detected over time. From a structural engineer's perspective, failure information should be critically important to experience. This subject therefore is directly related to "best practice".

The category model as described above is portrayed in *figure 2.9*. Development to the secondary level is included.

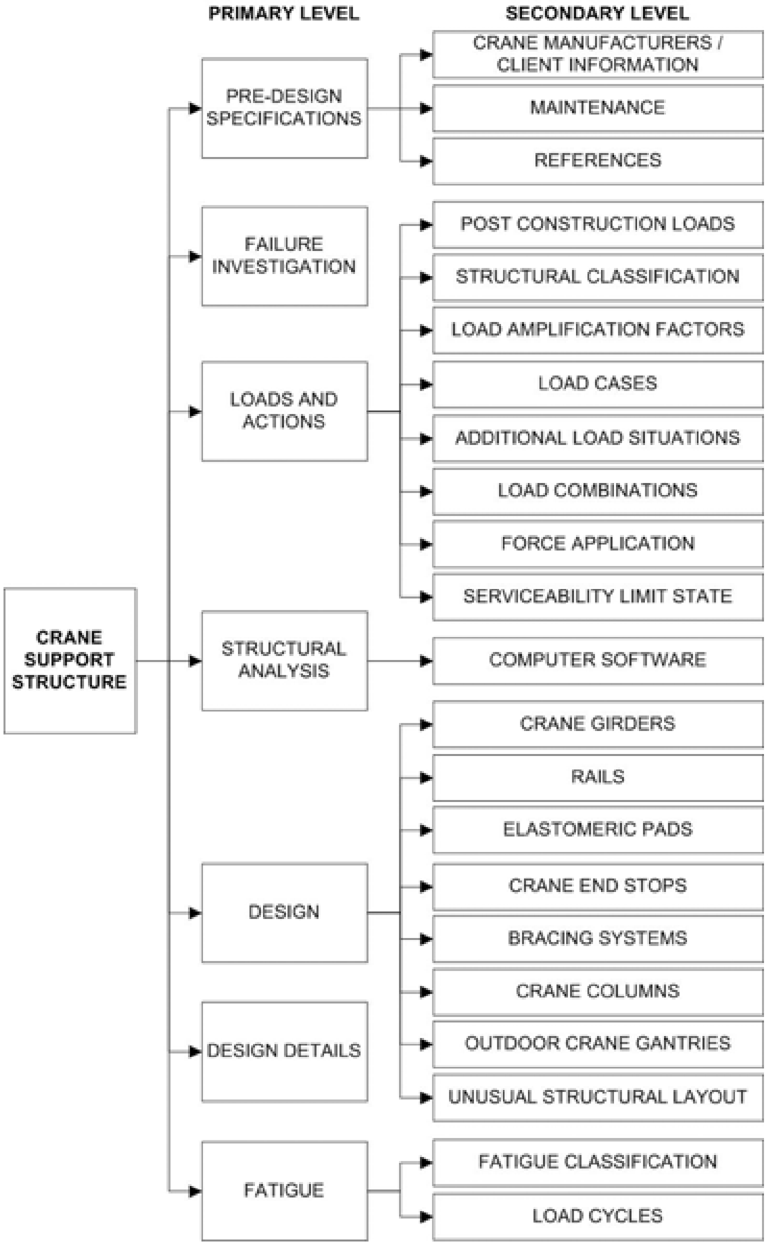


Figure 2.9: Category model developed from previous literature models. The layout is applied throughout the thesis.

The order of the layout (top to bottom) on the primary level is also listed as logically as possible. Pre-design specifications and the failure investigation are all part of gathering information. Loads and actions make use of the pre-design information attained to generate the load cases and combinations. These are then imposed on the structure for analysis. As stated before, structural analysis is the link between the loads and the design process. Design and detailing comprise the generation of the physical structure that will actually be constructed.

Lastly fatigue can form part of the loads, the design and the details used. For lack of a better solution it is situated at the end, but must be carefully incorporated into the total process.

2.4 Literature Development of the Category Model

The category model is developed via literature. Not all the topics are equally explored. The aim is to highlight the topics required for the "Best Practice of Crane Support Structures Design – an Expert Survey". Issues or discrepancies between authors are also sought for later investigation.

2.4.1 Pre-Design Specifications

Information and procedures occurring prior to the actual design are investigated in this section.

2.4.1.1. Crane Manufacturer and Client Information Transfer

Difficulties experienced with information transfer from the crane manufacturer and client to the support structure designer is a reality. A design criteria check list is often a good starting point for the design process, though no official guideline exists.

Such a check list was developed by MacCrimmon [2005]. The list is relatively comprehensive and is found in *table 2.1*. Note that the list, as described by MacCrimmon, is expected to be compiled by the support structure designer. It is then evaluated by the client for approval.

Table 2-1: Example of information required for crane support structures design. [MacCrimmon 2005]

Design Criteria Check List as Required for Crane Support Structure Design
Codes and Standards
Importance
Life of the Structure
Materials (Plates, Shapes, Fasteners, etc.)
Span
Provision for Future Expansion
Simple Span
Lateral Support for Top Flange
Top of Rail Elevation, or Height from Main Floor
Required Clearance to U/S Beam
Side Thrust Equally Distributed Both Sides of Runway
Number of Cranes, Each Runway
Collector Rail Mounting Details
Design for Future Additional Cranes
Jib Cranes, or Provision for Jib Cranes
Design for Future Upgrades
Class of Cranes
Service (Description)
Type of Duty
Crane Hook Capacity
Weight of Crane Bridge
Weight of Crane Trolley
Bridge Wheels per Rail
Bridge Wheel Spacing
Minimum Distance Between Wheels of Cranes in Tandem
Maximum Wheel Load, Each Crane (not including impact)
Minimum Wheel Load, Each Crane (not including impact)
Crane Rail
Rail Joints (bolted or welded)
Resilient Pad Under Rail
Bridge Speed
Type of Bumpers
Bumpers Supplied with Crane
Bumper Force on Runway End Stop (Ultimate Load)
Fatigue Criteria Vertical
Fatigue Criteria Horizontal
Deflection Criteria Vertical
Deflection Criteria Horizontal
Impact Criteria
Foundation Conditions, Limitations
Other Considerations
Weight Certified

In reality the information comes from the crane manufacturer and the client. It is understood that the designer still obtains the information from the manufacturer and the client. The list is then completed and a process of reverse (backwards) editing ensues. Regardless of the direction of information flow, difficulties are experienced.

Dymond [2005] researched the information required for the design of the crane support structures and the calculation of the crane imposed loads. The research was used to compare the design effort between the prEN 1991-3 and the SABS 0160:1989 codes. *Table 2.2* tabulates the results.

Table 2-2: Information for design and load calculations as required by the prEN1991-3 and SABS 0160:1989 codes. [Dymond 2005]

Design Criteria Check List as Required for Crane Support Structure Design					
	prEN	**SABS**		**prEN**	**SABS**
Nominal Weights of Crane and Hoist load			**Wheels and Wheel Drives**		
Weight of Crane Bridge	x	x	Number of Wheels	x	x
Weight of Crab	x	x	Wheel Spacing	x	x
Weight of Hoist load	x	x	Type of Wheel drive	x	
Crane Geometry			Number of Single Wheel Drives	x	
Span of Crane Bridge	x	x	Behaviour of Drives	x	
Minimum Distance Between Hoist and Rail	x	x	Combination of wheel pairs	x	
Rail Type	x	x	**Guide Means**		
Width of Top of Rail	x	x	Guide Rollers Present	x	x
Height of Rail	x	x	Clearance Between Rail and Wheel Flange	x	
Travel and Hoist Speeds			**Buffers**		
Steady Hoisting Speed	x		Buffer Type	x	
Long Travel Speed	x		Buffer Characteristics (Degree of Plasticity)	x	
Cross Travel Speed	x				
Hoist Type and Characteristics					
Hoist Class	x	x			
Type of Load Lifting Mechanism	x				
Hoist load Free to Swing	x	x			

Dymond further states that the information transfer issue is predominantly time orientated. The crucial data may only be released later than necessary according to the structural designer.

The crane is normally only installed at the end of the construction phase and the crane design completed closer to this time. This means that in certain circumstances the specifications are not even available. Contrarily, if competent planning was executed in the first place, related issues would not surface.

Standard crane information is generally available from the manufacturers (±70% of cranes) and can temporarily solve the problem. Problems with custom process cranes are however a true reality (±30% of cranes) that is difficult to avoid. (Percentages are from Dymond [2005])

2.4.1.2. Maintenance

Maintenance is highly important to crane support structures. MacCrimmon [2005] remarks that the fatigue effects caused by cranes, makes maintenance and subsequent repair work to the support structure necessary. MacCrimmon promotes furthermore that inspection and repair work should always be completed by an experienced structural engineer. This will ensure the maintenance work completed does not lead to larger problems later on in the structures design life.

Similarly Fisher and Van de Pos [2002] comment that even when all state of the art design provisions are followed, building owners can expect to perform periodic maintenance on runway systems. Fisher and Van de Pos [2002] furthermore stress that the runway systems will perform better if well maintained and aligned.

AISE [2003] includes some guidelines for inspection of buildings usually pertaining to possible upgrades. This inspection process takes on the format depicted in *figure 2.10*.

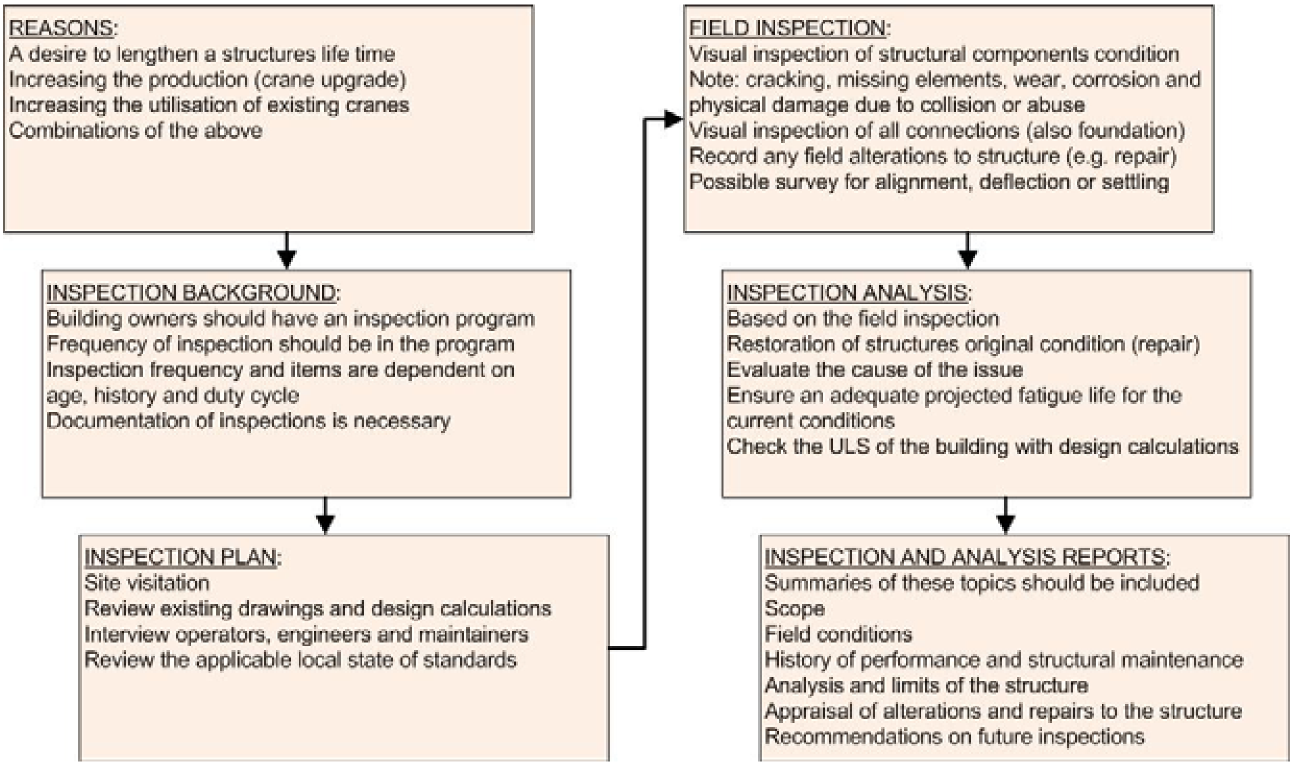


Figure 2.10: AISE [2003] guide for inspection of crane support structures.

The inspection guide presented above is reasonably detailed; however the frequency of inspection is not included. The time between inspections plays an important role in the reliability of the structure and the extent of the inspection needed.

AS 1418.18 includes some useful guidelines for maintenance similar to those provided in *figure 2.10*. The standard also includes periods of inspection which range from six years after construction to six months later in the structures life.

The South African Occupational Health and Safety Act (OHSA) for Construction Regulations, (9) Structures, declares that:

i) A final inspection should be conducted prior to commissioning.
ii) The owner of the building shall ensure that inspections are carried out periodically by a competent person. This must occur every six months for the first two years and once yearly from then on. The structures safety for the period ahead should be declared, if applicable, and a report completed.

The time frame mentioned in OHSA together with the instructions of *figure 2.10* serves as an example of a comprehensive maintenance plan for functional implementation.

2.4.1.3. References

A few design guides have already been introduced. These are useful sources of information for most concepts related to crane support structures design. Codes used for design commonly pertain to the country in which the structure will be constructed, but often a cautious approach with any internationally accepted standard can be used for design. It is important to ensure, in this case, that the codes are compatible with one another, to ensure a consistent level of reliability.

2.4.2 Loads and Actions

If the flow diagrams of *figures 2.5* to *2.8* are recalled, the following load case distinction can be assumed. All possible load cases on the support structure are included. For further detail the design guides and the applicable codes should be consulted.

Table 2-3: Different load cases that a crane support structure is subjected to.

Load Case	Description of Load Case
Dead Load	Permanent structure, material and equipment fastened thereto
Imposed Loads	Loads for accessible / inaccessible roofs; Loads applied to the walkways (often at crane level); Loads related to dust
Crane Vertical Loads	Weight of the crane bridge, crab and lifted load; These loads are subjected to dynamic amplification
Crane Horizontal Lateral (transverse) Loads	Loading imposed by the crane on the support structure, acting in a direction perpendicular to the rails; Includes misalignment, skewing and crab acceleration
Crane Horizontal Longitudinal Loads	Loading imposed by the crane on the support structure, acting in a direction parallel to the rails; Includes crane acceleration
Crane Impact Loads	Accidental loads caused by impact of the crane with the end stop, acting in a direction parallel to the rails
Wind Loads	All wind loads occuring and causing sway or vertical loading (uplift)
Temperature Loads	Loads caused by the expansion and contraction of materials under variable temperatures; Normally only in longer buildings (100m or more)
Seismic Loads	Accidental loads caused by rapid ground accelerations

The load distinction in *table 2.3* is based on the SABS 0160:1989 loading code. In the ensuing definition of the loads, other codes will only be mentioned for comparison purposes. It should be noted that the crane induced forces travel from the crane through the wheels to the support structure. As a result these loads (forces) are often called “wheel loads”.

2.4.2.1. Post Construction Loads

According to South African literature there are no post construction test loads applicable to the structure. The SANS 4310:2002 does however, include test loads for cranes. These are applied indirectly to the support structure and as such can be seen as relevant. This is a similar approach to that found in the Eurocode [ENV 1993-6:1999].

There are two test loads for EOT cranes specified by SANS 4310:2002. The first is static and involves a low lift of approximately 200mm in height at 125% of the rated capacity of the crane. The second is a dynamic lift. The crane lifts 110% of the rated capacity and must function as per normal (according to its regular function). If no damage or loss of function occurs under these lifts, the crane and consequently the structure are assumed safe. A visual and conformity inspection is completed in conjunction with the test loads. Please note that the position of the static loads are not specified and as such should be placed so as to generate the most critical circumstances.

2.4.2.2. *Crane Classification*

The first step in load calculation is the crane classification. The loads imposed on the support structure are calculated according to classification based factors.

The SABS 0160:1989 classification model is simplistic. The appropriate crane class is selected according to the crane use. Note that the designer or client is allowed to assign a higher crane class than specified by the code. The SABS classification model is supplied in *table 2.4* together with a Eurocode comparison.

Table 2-4: Crane classification models as found in SABS 0160:1989 and prEN 1991-3.

SABS 0160:1989		prEN 1991-3	
Class of Crane	**Description of Crane or Crane Use**	**Hoist Class**	**Description of Crane or Crane Use**
Class 1 Light duty	Hand cranes	**HC1**	Hand cranes Powerhouse cranes
Class 2 Medium duty	Cranes for general use in factories and workshops	**HC1, HC2**	Assembly cranes
		HC2	Storage cranes - intermittent usage
Class 3 Heavy duty	Warehouse cranes - continuous operation Scarpyard cranes Rolling mill cranes Grab and magnet cranes - intermittent operation	**HC2, HC3**	Workshop cranes Casting cranes
		HC3, HC4	Storage cranes - continuous operation Scrapyard cranes - continuous operation Soaking pit cranes
Class 4 Extra heavy duty	Grab and magnet cranes - continuous operation Soaking pit cranes	**HC 4**	Stripper cranes Charging cranes

In prEN 1991-3 the classification is made according to a hoist class (HC) rather than a crane class. The crane descriptions are fairly similar to one another. AS1418.1-1994 goes into more detail regarding the classification, yet the rationale used in the classification is the same as for the Eurocode.

The classification models in *table 2.4* are observed to be comparable. The use of the crane class or hoist class in generating the crane loads is where the difference in codes can be found.

The Eurocode makes use of multiple dynamic amplification factors calculated using several different approaches. Only one of these factors is calculated using the hoist class. SABS 0160:1989 however, uses the crane class to calculate the dynamic amplification factors and horizontal loads.

2.4.2.3. Load and Amplification Factors

SABS 0160:1989 determines the maximum dynamic vertical wheel loads using a dynamic amplification factor multiplied by the maximum nominal wheel loads. The nominal wheel loads are generally supplied by the manufacturer. The dynamic vertical wheel loads are used in the ultimate limit state only and as described here must still be factored. Serviceability and fatigue analysis are completed using the nominal (static) wheel loads without dynamic amplification. Note that these amplification factors are not the same as the limit states load combination factors.

2.4.2.4. Load Cases

A summary of the factors used for the SABS 0160:1989 crane load model is supplied in *figure 2.11*. End stop impact is included. Other additional load situations are excluded.

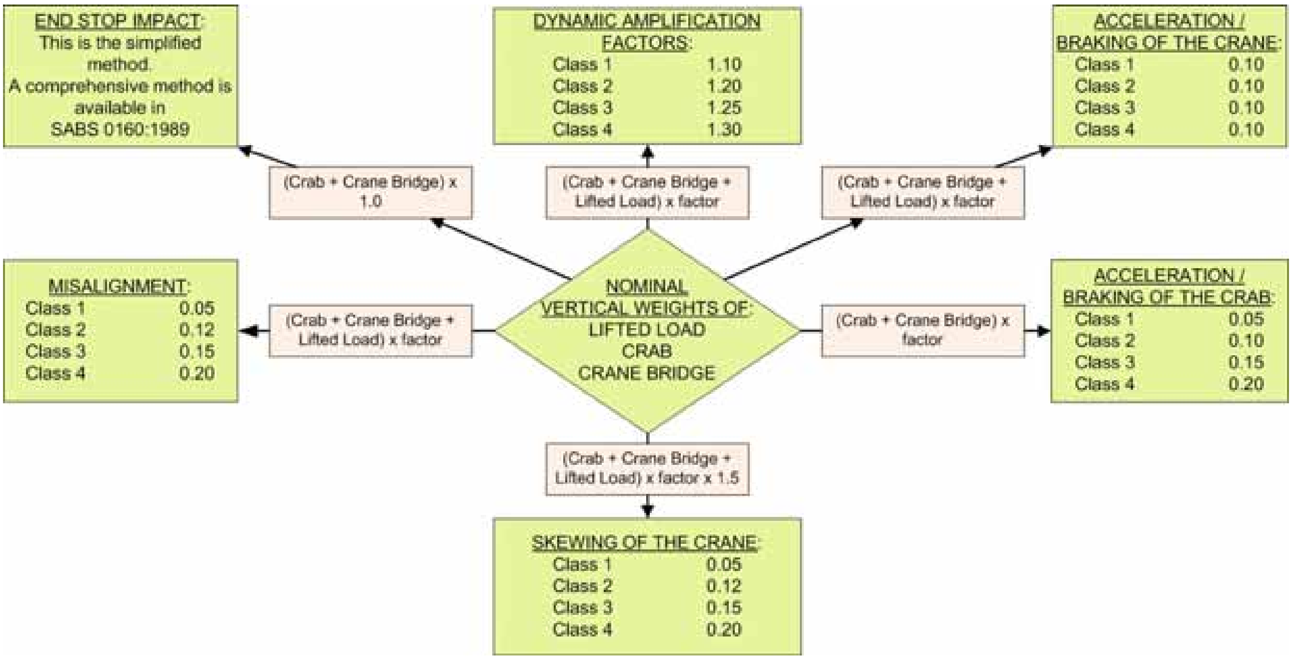


Figure 2.11: Summary of the factors used to calculate the various crane loads imposed on the support structure.

The SANS 0160:1989 load model is rather simplistic when compared to other international codes, crane classification being the only variable. Dymond [2005] compared the loads calculated by prEN 1991-3 and SABS 0160:1989. The results obtained will be briefly reviewed.

Note that the Australian code [AS 1418.1-1994] is somewhat similar to the Eurocode and will not be investigated further. Other codes including crane loads are the German code [DIN 15018-1:1984], the International standard [ISO 8686-1:1989] and the American code [ASCE 7-98].

Table 2-5: Summary of the crane loads considered by Eurocode and the South African Standards. [Dymond 2005]

Crane Load	SABS 0160:1989	prEN 1991-3
Vertical		
Generic dynamic amplification	X	
Hoisting a load off the ground		X
Running on rails		X
Release of payload		X
Test loads		X
Horizontal Transverse (Lateral)		
Acceleration of crane		X
Acceleration of crab	X	
Skewing	X	X
Misalignment	X	
Crab buffer forces		X
Horizontal Longitudinal		
Acceleration of crane	X	X
Crane buffer forces	X	X

Dymond found that in SABS 0160:1989 the dynamic vertical wheel load calculation is simplified compared to the detail the Eurocode goes into. Dymond also comments that the Eurocode is of a higher level of sophistication for horizontal loads given that the span of crane runways and the crane wheel spacing influence the multiplication factors.

Never the less, the loads presently calculated using SABS, compare sufficiently with those calculated in the Eurocode.

2.4.2.5. Notional Loads

Notional loads are prescribed by the South African codes. SABS 10162-1:2005 states that translational load effects produced by notional lateral load effects shall be added to the sway effects for all load combinations. The notional load is 0.005 times the factored gravity loads of the structure applied at crane level. The notional loads should be analysed with second order effects taken into consideration.

Notional loads are understood to account for inaccuracy during construction and fabrication or foundation settlement over time. The notional load induces an initiating sway, which is especially useful in symmetric structures subjected to symmetric loading. The notional loads induce a slight eccentricity to all vertical loads – enhancing the sway caused by other, larger, horizontal load cases.

2.4.2.6. Additional Load Situations

There are several load cases that require investigation, additional to those introduced previously.

End stop forces due to crane impact are identified as an accidental load case. These forces can be caused by misuse of the crane, malfunction of the safety switches or storm wind conditions blowing the crane into the end stops. In the South African code there are two methods to determine the forces on the end stops, a simplified and comprehensive method. The simplified method imposes a horizontal force on the end stop at the height of the buffers. This force is equal to the combined weight of the crane bridge and crab. The comprehensive method takes the crane travel speeds, crane buffer resilience (plasticity characteristics) and the end stop resilience into account. This is more complex and presents complications in obtaining the necessary data for the calculation. As the lesser of the two forces calculated is acceptable, using only one method is satisfactory.

Seismic hazard zones do exist in parts of South Africa. Therefore, theoretically a check for the seismic forces should be completed. [Goldman 1990] The seismic design method is not described here and falls outside the scope of this study. Snow loads are generally not applicable in South Africa due to the warm climate. If a structure were to be placed in an area subject to snow loads, the design should take these into account. Temperature forces can have a large effect on steel support structures. Rail continuity and alignment are important and in longer buildings expansion joints may be required due to thermal effects. The structures net deflection is often the critical factor regarding thermal expansions. Expansion joint details are introduced later in this chapter.

2.4.2.7. Load Combinations

The accuracy of the forces calculated above is important. Similarly the combination of these forces is significant. The standard industrial building load combinations (as for any industrial structure) should be checked. [MacCrimmon 2005] These include the dead and live load combinations and those combinations including wind. Additionally dead, live and / or wind loads in combination with crane loads must be investigated as part of the structural analysis. The load combinations for crane runway girder analysis are shown in *figure 2.12* below. [SABS 0160:1989] These loads are applied in combination with the above mentioned industrial building loads to form the structural analysis loading model.

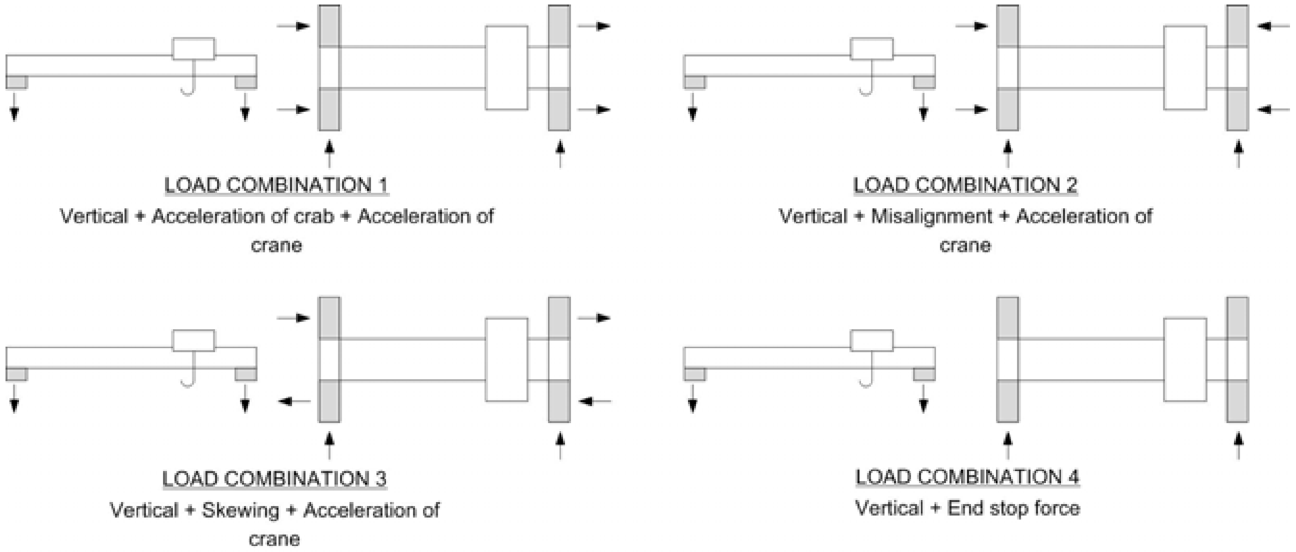


Figure 2.12: Crane load combinations used to analyse the structure and runway girders. [Dymond 2005]

Selected combinations can be found in *table 2.6* below. Notably the combinations used in several major design codes (Eurocode, NBCC, AS) all appear to correspond fairly well with one another, regardless of the total load models calibration. As an example of the relative similarities the fundamental load combinations as described in SABS 0160:1989 and according to MacCrimmon [2005], whose work refers to the NBCC 2005 Canadian code, are considered.

Table 2-6: A comparison of certain load combinations as found in the South African and Canadian codes.

South African Steel Construction Handbook (based on SABS 0160:1989)	**MacCrimmon (based on NBCC 2005)**
1.5D	1.4D
$1.2D + 1.6C_V + 1.2C_H + 0.5L$	$1.25D + 1.5C_{V+H} + 0.4W$
$1.2D + 1.6C_H + 1.2C_V + 0.5L$	$1.25D + 1.5C_{V+H} + 0.5L$
$1.2D + 1.6L + 0.8C_{V+H}$	$1.25D + 1.4W + 0.5C_{V+H}^{\#}$
$1.2D + 1.3W + 0.5L + 0.8C_{V+H}$	$1.25D + 1.5L + 0.5C_{V+H}^{\#}$
1.25D + 1.0C	$1.25D + 1.0C_{impact}$
NOTE: These are not all of the load cases from either code, but simply an indication that the codes make use of similar combinations. # combination factor of 0.5 can be increased to 1.0 for higher class cranes **D** = Dead load; **L** = Live load **C** = Crane load (dominant with vertical and horizontal) $\mathbf{C}_{\mathbf{impact}}$ = Crane buffer impact load; **W** = Wind load	

The scope of load combinations is very wide and requires a fair amount of interpretation. Code definitions involving subjects such as the degree of correlation can lead to a variety of appropriate combinations. It is understood to be the structural designer's responsibility to interpret the load combinations carefully and with thought in order to arrive at a final design that is acceptable.

2.4.2.8. Force Application

Multiple Crane Setups

Multiple crane setups occur frequently in industry. The most common layout involves multiple cranes in the same bay and running on the same pair of rails. Some additional crane setups are illustrated in the figure below. Practically any variety of multiple crane setups is possible. Certain crane arrangements will in turn lead to more than one crane influencing a specific structural member simultaneously.

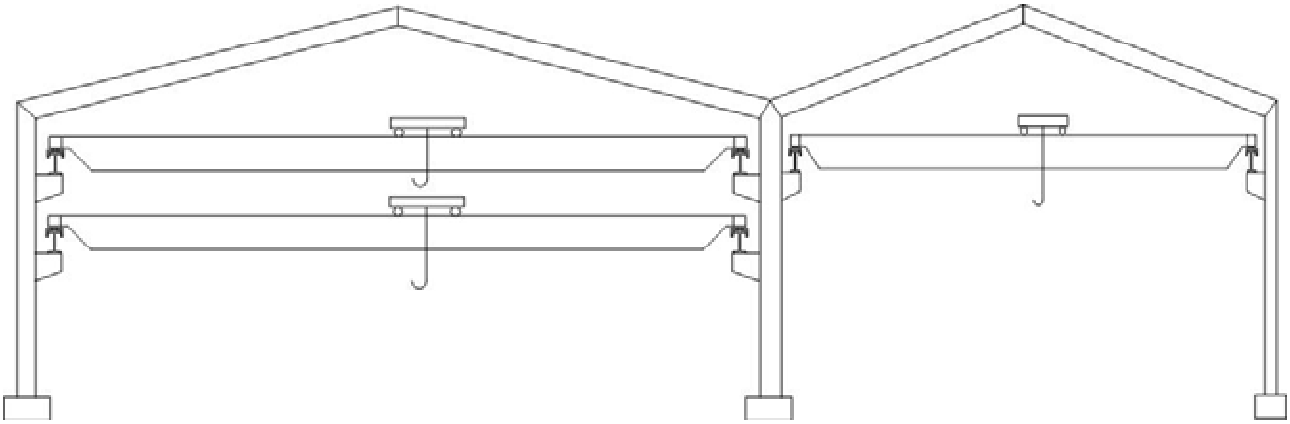


Figure 2.13: Various multiple crane setups are possible. Here cranes above and adjacent to one another are depicted.

The South African code makes provision for multiple cranes by assuming a specific number of cranes to act simultaneously for a given load case, regardless of the layout. These provisos are:

i) Vertical (nominal) – All cranes
ii) Vertical (dynamic) – Any two cranes
iii) Acceleration / braking of the crab – Any two cranes
iv) Misalignment of the wheels / rails – Any two cranes
v) Acceleration / braking of the crane – Any two cranes
vi) Skewing – Any one crane
vii) End stop impact force – Any one crane

MacCrimmon [2005] states that when considering multiple crane setups only load combinations that have a significant possibility of occurring, need to be considered. Again engineering judgement is required to assess the relevance of this statement and the code stipulations.

Force Application Eccentricities

As stated earlier the loads are applied through the wheels and as such these loads are frequently called wheel loads. The wheel to rail contact position and the rail to top flange contact position is not fixed. It must therefore be accepted that a degree of eccentricity is applicable when applying the vertical crane loads. This eccentricity can result in torsional effects and must consequently be catered for during the design. The top flange to web weld is especially sensitive to the stresses produced by this eccentric load application. Considering this, the importance of good rail and girder alignment becomes apparent.

Gorenc [2003] states that the vertical wheel loads should be applied with an eccentricity to the rail centreline. This eccentricity should be equal to the maximum defined in AS 1418.18. MacCrimmon [2005] recommends that the crane rail be assumed to sit eccentrically to the centreline of the crane runway girder. Three methods of calculating the eccentricity are described in *table 2.7*.

Table 2-7: Various methods of calculating the vertical load application eccentricity.

Southern African Steel Construction Handbook	MacCrimmon (based on NBCC 2005)	Gorenc (based on AS 1418.18)
0.25 x (r_H)	0.75 x (t_W)	(r_H / k) + (L / 1000)
r_H = effective rail head width **t_W** = crane runway girder web thickness **k** = 8 for convex headed rails; 4 for square headed rails **L** = length of the crane runway girder		

Although the basis of these methods is different, their resulting eccentricity is implemented in the same way. The magnitude is also rather similar. Due specifically to the possible top flange rotation and related fatigue problems; the eccentricities must be investigated during the crane runway girder design.

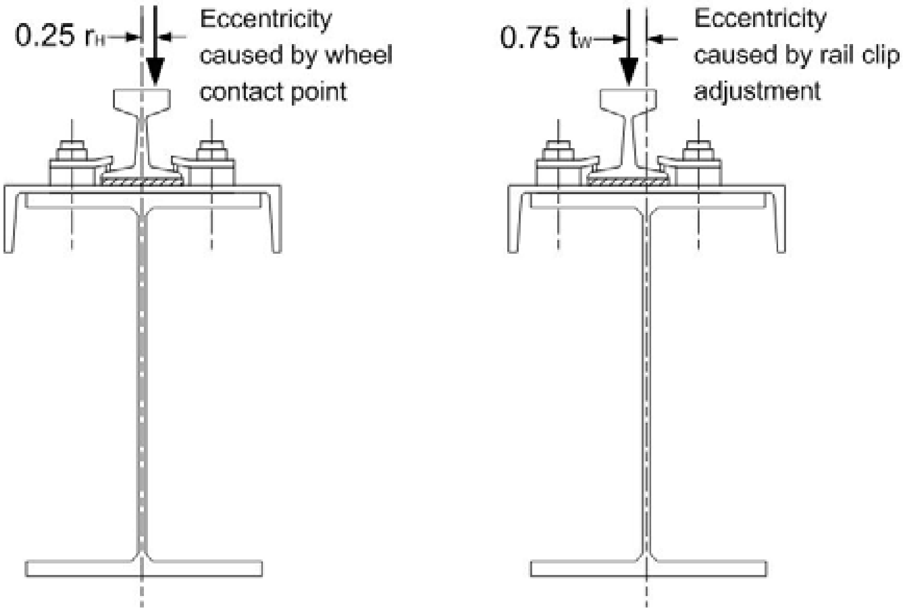


Figure 2.14: The eccentricity caused for two separate reasons. The effect of either is sufficient but required.

2.4.2.9. *Serviceability Limit State*

Deflections are investigated as part of the serviceability loading conditions. Structures with cranes and the crane runways themselves require strict deflection limits. The cranes working proficiency is directly linked to the alignment of the rails. This alignment refers not only to the unloaded state but also to the loaded state. For this reason all deflection limits recommended or stipulated for crane support structures should be satisfied. Gorenc [2003] remarks that the deflection effects are often cumulative in nature and a conservative approach should be followed.

In South Africa recommendations are published in Annex D of the SANS 10162-1:2005 structural steel code. Eurocode specifies its limits as a minimum and more stringent limits may be applied. A few other limits are also provided as published in relevant literature. Furthermore the deflection criteria are directly linked to the structural robustness and stiffness, therefore affecting the relative stiffness of the crane to the support structure. More details are provided on this subject later in the thesis.

Table 2-8: Deflection limits as utilised by different authors. These are based on designs made using the specified code.

Deflection Criteria Description	**Deflection Criteria Limits SANS**	**Deflection Criteria Limits prEN 1993-6**	**Deflection Criteria Limits Gorenc (AS 1418.1)**	**Deflection Criteria Limits AISE Tech. Report No. 13**
Lateral deflections (sway) caused by notional, wind and crane loads	$\frac{height}{200}$ to $\frac{height}{400}$	$\frac{height}{400}$	Not Specified by Gorenc	$\frac{height}{400}$ or $50mm$
Relative column to column lateral deflection	Not specified by SANS	$\frac{height}{600}$	$\frac{height}{600}$	Not specified by AISE
Simply supported crane runway girders horizontal deflection	$\frac{span}{600}$	$\frac{span}{600}$	$\frac{span}{600}$ or $20mm$	Not specified by AISE
Simply supported crane runway girders vertical deflection	$\frac{span}{800}$ $(SWL > 225kN)$	$\frac{span}{600}$ or $25mm$	$\frac{span}{500}$ or $60mm$	$\frac{span}{1000}$ $(high\ duty)$
Simply supported crane runway girders vertical deflection	$\frac{span}{600}$ $(SWL < 225kN)$	$\frac{span}{600}$ or $25mm$	$\frac{span}{500}$ or $60mm$	$\frac{span}{600}$ $(low\ duty)$
Relative rail to rail deflection	Not specified by SANS	$10mm$ $(horizontal)$	$\frac{span}{1000}$ or $10mm$ $(vertical)$	Not specified by AISE

A comparison of the limitations shows the other references to have similar or more stringent deflection limits than the SANS. It is unclear why the vertical deflection limits in SANS vary according to crane lift capacity. If the distinction is made for fatigue reasons, it would be more sensible to apply a crane class distinction. This is what the AISE Technical Report No. 13 specifies.

2.4.3 Structural Analysis

In the past few years computers have been advancing at a very quick rate. The analysis and design software has also progressed rapidly. Crane support structures design and analysis programs have expectedly advanced accordingly.

Many different software packages are available. Most make use of the finite element method. Each package may use finite elements in a slightly different fashion, making untrained application of computer software dangerous. It is imperative that the designer have a sound knowledge of the program and its methodology.

The analysis definitions that follow are primarily based on Prokon, which has frame and beam analysis packages as well as a specific crane runway girder design and analysis package. The definitions shared below may be valid for other programs too. It is the reader's responsibility to determine this validity.

Structural analysis can be divided into global and local analysis. The global effects often pertain to structural criteria; whereas the local effects pertain to specific structural elements. If a crane runway girder was to be analysed separately from the rest of the structure, the global and local definitions must be adjusted. Global now refers to the whole girder. Local simply refers to a localised stress or strain effect in the girder.

Generally the global structural analysis is completed with either a 2D or 3D frame. As mentioned with the notional loads, analysis in the South African context must take second order effects into account, as stipulated in the SANS 10162-1:2005 code.

Crane runway girders are analysed using either a beam analysis package or a finite element model. The decision rides on the detail required from the analysis and the time available. Research has been completed at Stellenbosch University that validates the use of finite elements to analyse crane runway girders. Viljoen [2003] succeeded in generating a finite element model, using Abaqus software, which corresponds well with experimental results on a test runway beam.

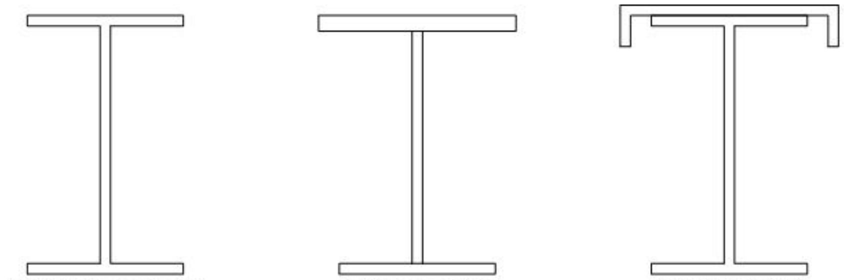
2.4.4 Design and Details

The design of crane support structures is not unlike ordinary industrial building design. Advanced design concepts are used as the loads imposed on the structure are movable and quite large. This does increase the design challenge. This section aims to familiarise crane support structures design concepts. Introductory information is provided rather than focusing on the design calculations.

2.4.4.1. Crane Runway Girders

Crane runway girders come in all shapes and sizes. They can be simply supported, semi-continuous or continuous. Semi-continuous and continuous girders have been found to be problematic and the relative saving in steel is small. [Goldman 1990] Fatigue due to increased and inverted stress distributions at the supports has been identified as the main issue. This subject is mentioned in the article by Collins et al. [1991]. For the purpose of this study however, it is sufficient to understand that simply supported girders are preferred according to literature.

Crane runway girder profiles range from a universal section alone (light duty cranes) to a built up box girder (extremely heavy duty cranes). Girders of up to and over three meter depths are not uncommon. A few basic sections are provided in *figure 2.15*.



Universal Section or Plate Girder

Monosymmetric Plate Girder

Universal section with Channel Cap

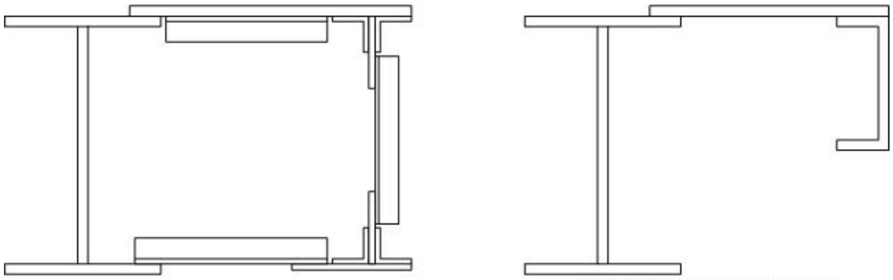


Plate Girder with Surge Plate on a Surge Girder using a Built up Auxiliary Girder

Plate Girder with Auxiliary Girder and Surge Plate

Figure 2.15: Several examples of crane runway girder sections. (Not to scale) [Goldman 1990]

Crane runway girders are subject to vertical forces and horizontal forces applied at or near the top flange. Direct torsional design as a result of the vertical and horizontal eccentric effects is usually avoided. The "twin beam" analogy is used to do this. The approach is explained below.

The vertical force is applied with an eccentricity which causes a torsional moment in the girder. The moment so created, is converted to a couple that acts at the top and bottom flange level. The eccentric horizontal lateral forces undergo a similar conversion. Consequently, the top and bottom flange act independently and are designed as such. [Rowswell 1987, Gorenc 2003] An illustration is provided to explain the concept. The two beams combine for a total effect on the girder.

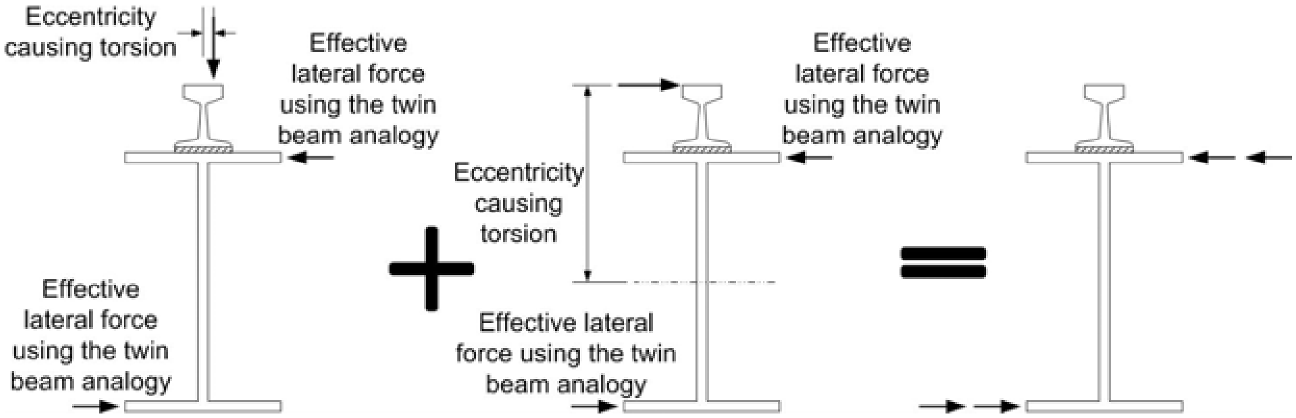


Figure 2.16: The twin beam analogy uses effective couples that are caused by vertical and horizontal eccentricities.

Monosymmetric sections and the horizontal channel on a universal beam section have an enlarged top flange in order to restrain the large horizontal forces exerted on the top flange. Similarly, surge plates and surge girders increase the horizontal section resistance at the top of the crane girders a great deal. Furthermore local bearing under the wheel loads and the lateral stability of the top flange serve as reasons for increasing the effective top flange section.

Crane Runway Girder Design

In South Africa, girder profiles must satisfy the design criteria as specified in SANS 10162-1:2005. These include, but are not limited to, geometric ratios, slenderness ratios, shear, bending, load bearing stiffener design and intermediate stiffener design.

As a continuation of the “twin beam” analogy, horizontal and vertical sections are usually generated, each with its corresponding section properties. The bottom flange can also be investigated individually as a result of the “separate” forces imposed on it. The “twin beam” analogy and section separation aims to transform torsional loads into equivalent lateral loads. Bi-axial bending must still be considered, but the method does simplify the analysis and design.

Accordingly use of a universal section or plate girder would result in the design of the top and bottom flanges horizontally and the full section vertically. Surge plate sections are slightly more complicated. *Figure 2.17* below is based on the Southern African Steel Construction Handbook [2006] and illustrates the division of the girder profile for surge plates. Other codes and literature agree on a similar surge plate division concept. In these cases the top flange level horizontal section is assumed to resist all of the horizontal lateral forces.

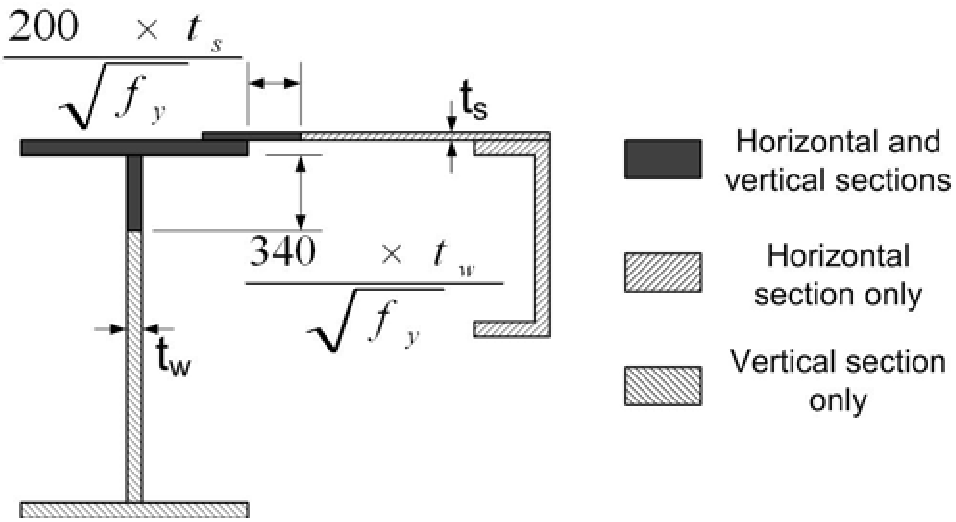


Figure 2.17: The proposed method of separating the horizontal design from the vertical design. [SASCH 2005]

Once a girder has been divided into effective sections and uni-axial bending has been investigated – the combined effect of biaxial bending must be examined. Accordingly *equation 2.1* [MacCrimmon 2005, Gorenc 2003] needs to be satisfied, with M_{ux} = Moment applied about the X-axis, M_{uy} = Moment applied about the Y-axis, M_{rx} = Moment of resistance about the X-axis, M_{ry} = Moment of resistance about the Y-axis.

$$\boxed{\frac{M_{ux}}{M_{rx}} + \frac{M_{uy}}{M_{ry}} \leq 1.0} \qquad (\textit{Equation 2.1})$$

Top Flange and Web Rotation

It has been mentioned previously that out of plane bending of the top flange, greatly influences the top flange to web weld. Bearing from local wheel loads, web buckling and bending of the top flange also increase the stresses experienced. [Gorenc 2003] An illustrative sketch of the out of plane rotation of the top flange and web is supplied in *figure 2.18*. Commentary follows after the sketch.

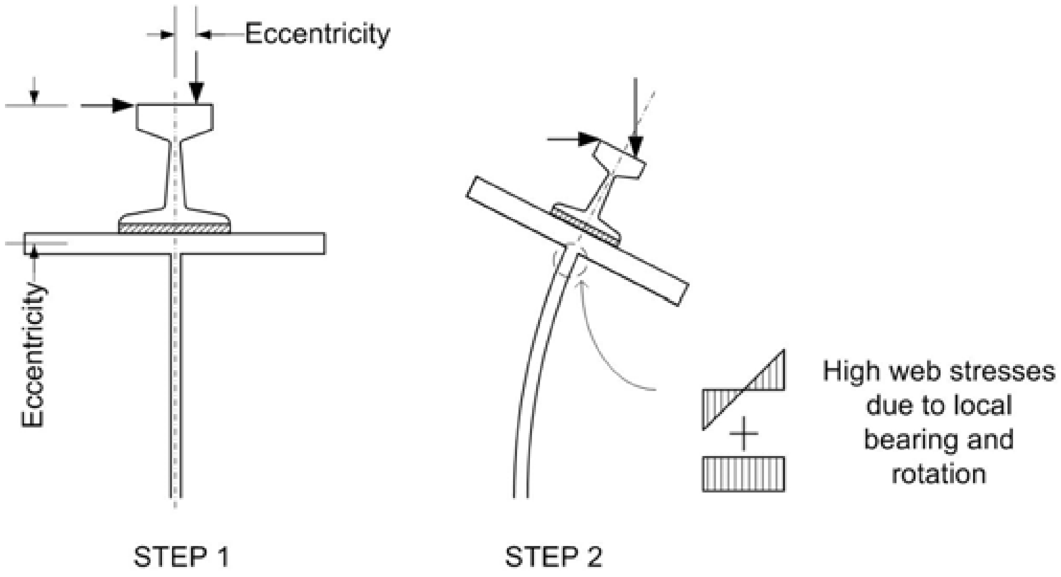


Figure 2.18: High stresses can occur due to the rotation of the top flange under vertical and horizontal eccentric loads.

In step one of *figure 2.18* the horizontal and vertical eccentric loads are applied. Step two shows the top flange and web rotating under the eccentricity. Rowswell [1987] mentions the significance of rotation of the top flange and web. He provides intermediate bearing stiffeners or a much thicker web to reduce the effect. Gorenc [2003] also attempts to facilitate the rotation of the top flange and web.

Practical, simplified analysis methods for the top flange to web connection design do exist. They include out of plane bending of the web and horizontal bending of the top flange. For further details on the actual design calculation consult Gorenc [2003].

Crane Girder Best Practice

Gorenc lists five points relevant to good quality girder design. He recommends that multiple sections be investigated before the final decision is made. Designers should not accept software designed sections without proper investigation of the section prescribed. The five steps can be accepted as a prerequisite for “best practice”.

i) Structural efficiency
ii) Rigidity in the vertical direction, the lateral direction and against torsion
iii) Constructability
iv) Welding and inspection access
v) Sufficient width of top flange to accommodate rail fixings

2.4.4.2. Crane Rail

Crane to support structure interaction is a very important aspect of crane support structures. The rail primarily forms the interaction surface and as such is an integral part of the support structure. Rails are very highly stressed elements due in part to large bearing stresses. Torsional effects also influence crane rails as the horizontal crane forces act at the top of the rail attempting to tilt the rail - the taller the rail the larger this effect. [Gorenc 2003]

Several rail sections are used in practice. The first is not entirely a rail, but rather the crane running directly on the top flange. This is only done in extremely low duty, low capacity cranes and is not advisable. Other rail types include a square bar, railway rail and the squat crane rail. The choice of rail is made primarily according to the wheel forces and crane wheel diameter. [Rowswell 1987]

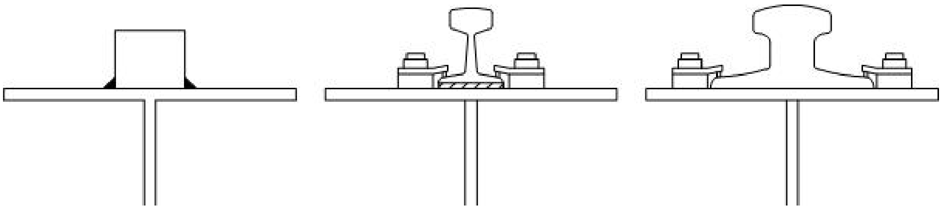


Figure 2.19: Rail types as available and used in the industry. The rail clips are separate to the rail.

Rail Attachments

Figure 2.19 also includes two ways of fixing the rail to the crane runway girder. The first is a welded block and the second is a rail clip. The mechanism used to fix the rail to the crane girder is critical for satisfactory working of the crane. The rail is highly stressed and in turn imposes high forces on the rail clips. Moreover, the clips provide the necessary support to the rail in order to maintain sufficient alignment.

For lower class cranes the welded block is the simplest solution. As it is welded it can be included in the crane girder section. This is understood to be unfavourable because the welds often break and the combined effects of the girder and rail section lost. As such the welded connection between the girder and block should be designed to accommodate the forces and ensure a lasting connection. Some rail clips are also capable of clamping a rail sufficiently to allow for this compound rail-girder action. In this case it is better to assume the compound action does not occur at all, as is done with most other rails.

Rail Alignment and Continuity

In many circumstances the rail clips are the only method of aligning a crane gantry after construction. For this reason most patented rail clips allow for a degree of lateral adjustment. Careful use of this tolerance should be made. Out of plane bending of the top flange can be greatly increased if the rail web and the girder web are eccentric to one another.

The SASCH [2005] and Gorenc [2003] state that for all heavy duty cranes continuous floating rails should be used. Implementation of a continuous floating rail is subsequently described.

The floating rail necessitates continuity by means of effective splicing of rail sections. Splicing is normally done by means of a good quality weld. Most commonly thermit welding is used which is a process first employed by railway companies. Thermit welding basically entails using a chemical reaction between iron oxide and aluminium which creates a super heated steel solution (approximately 2500°C). This is then poured from above the weld surface into a cast around the welded sections where it melts a portion of the rail. Heat loss causes the fusion of the metals into a continuous rail section. The surface is ground level to ensure a smooth running crane. [www.key-to-steel.com] Alternatively fishplates can create a degree of continuity for lower duty, lighter cranes.

Top Flange Wear

For effective use, a continuous rail is fastened down sufficiently to withstand vertical movement (the so called "bow wave" effect and tilting) and horizontal transverse movement. The rail is however given room at the end stops to expand and "float" in a horizontal longitudinal direction. The movement does occur relative to the crane runway girders and can lead to steel wear problems.

The wear occurs on the underside of the rail and more commonly on the top flange of the girder. This wearing is often increased by the slight arching of the base of the rail. The rail load is then not evenly transferred from the rail to the top flange of the girder. Instead two smaller bearing zones develop at the tips of the rail base. A sketch is provided to illustrate this curvature and its effect.

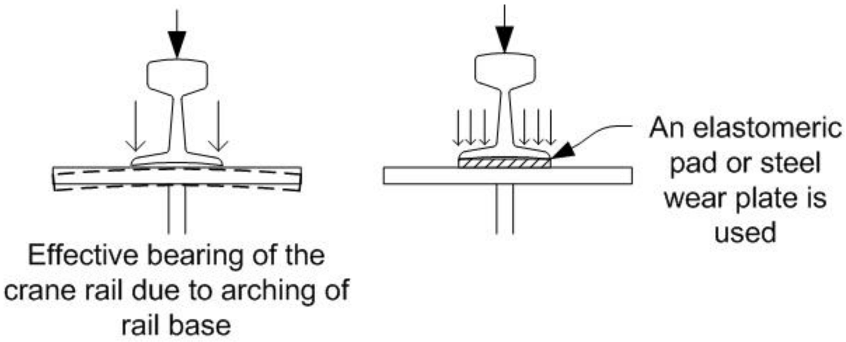


Figure 2.20: The arching of the rail base can lead to excessive wear and out of plane bending of the top flange. An elastomeric pad is one option to reduce this effect.

2.4.4.3. Elastomeric Pads

An elastomeric pad or a steel wearing plate is usually placed beneath the rail. This reduces the wearing action of the arched rail on the top flange and helps to distribute the load more evenly over the section – in turn reducing the stresses due to cross-flange bending.

The elastomeric pads are costly to use, but the suppliers maintain that they help prolong the life of the crane support structure and the crane running upon it. [www.fabreeka.com; www.molyneuxindustries.com] Certain suppliers claim that the pads can relieve girder stress, improve load distribution, eliminate mechanical wear of flange or cover plates, damp vibration and reduce noise. Furthermore the pad restricts lateral movement and provides a low coefficient of friction support for the rail in the longitudinal direction to assist the floating performance of a continuous rail. It must be clarified that exactly how much influence the pad has, is unknown. [Goldman 1990]

2.4.4.4. End Stops

An end stop is placed at the end of each runway. The end stop is attached to the top of the crane runway girder. Details used in the design vary considerably. Two possible end stop details are provided in *figure 2.21*. Attached to the end stop is a buffer, or impact damping device. These are located at the same height as the crane buffers. In the event of the crane running into the end stop, which is an accidental load case, the buffers on the crane and on the end stop can reduce the impact forces transferred to the support structure considerably. The resulting force which is carried over to the structure is taken down into the crane runway girders and conveyed to the longitudinal crane bracing system.

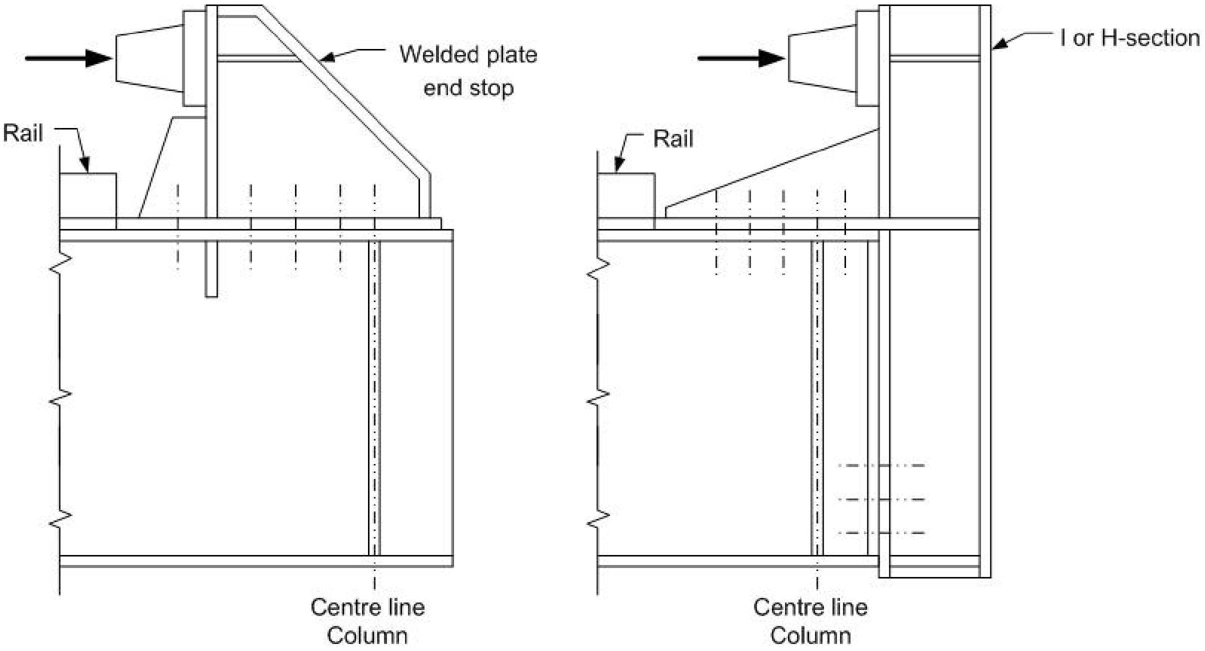


Figure 2.21: Two end stop designs as found in the Southern African Steel Construction Handbook [2006]

SASCH [2005] states that end stops are essential on crane support structures. Cranes have been known to run off the end of the rails. The design of these stops should consequently be robust as accidental loads are hard to accurately predict. There are not many end stops on any one structure – therefore the over design of an end stop would have a negligible financial impact on the structures total cost.

As mentioned above, the damping device also plays a very important role in minimising the end stop impact of a crane on the structure. Hydraulic, spring and elastomeric (or rubber) buffers are available. Hydraulic buffers have the best energy dissipation characteristics and therefore are preferred for higher class cranes. [MacCrimmon 2005]

2.4.4.5. Bracing Systems and Expansion Joints

Bracing systems in industrial buildings with cranes normally constitute two longitudinal bracing systems. These being the crane bracing and building bracing. This is easily achieved with a split or battened column but less appropriate for a bracketed portal frame (see *figure 2.24* for the column types).

Table 2-9: Several sources relating the placement and details of bracing systems and expansion joints.

Code or Reference	Recommendations for Bracing and Expansion Joint Placement
SABS 0160:1989	Buildings of greater than 100 meters in length, should be designed for thermal expansion. Accordingly investigation into the placement of bracing and the possible requirement of expansion joints must be made.
Gorenc [2003]	Expansion joints are required for buildings greater than 150 meters. The maximum distance between the bracing and an expansion joint is 80m. K-bracing is preferred. Two possible solutions for bracing placement are described: [1] Place the bracing in the plane of the runway girders at the end of the building. The building bracing is separate and can be placed elsewhere. [2] Use the building bracing only. Sufficient connection must be provided to transfer the longitudinal forces in the runway girders to the bracing.
AISE Technical Report No. 13 [2003]	Expansion joints need not be placed in buildings smaller than 130 meters, even if subjected to large temperature fluctuations. Bracing should be situated between possible expansion joints or as near to the centre of the structure as possible. In portal structures with a bracket - knee braces should strictly not be used to transfer the forces to the building.
Rowswell [1987]	The maximum distance between expansion joints is 150 meters (also the limit for no expansion joints). The bracing system should be placed between any expansion joints in the structure, even though it would be ideal to place the bracing near the end stops. Expansion joints must allow the structure to expand away from the bracing. The cross-bracing is preferred.
MacCrimmon [2005]	The maximum distance between expansion joints is 150 meters (also the limit for no expansion joints). Light duty cranes only require the building bracing with sufficient connection to transfer the force from the runway girders to the bracing. i.e. The eccentric effects must be catered for. If any longitudinal force exceeds 100 kN, bracing in the runway girder plane is recommended. The bracing systems should be between expansion joints or as near the centre of the building as possible.

Table 2.9 shows the following tendencies. Buildings of around 130m – 150m require expansion joints. The bracing system is placed between expansion joints or as close to the centre of the structure as possible. For low duty structures one set of bracing with sufficient horizontal connection is satisfactory. In high duty cranes two sets of bracing are always required. Either K-bracing or cross-bracing can be used. Structural expansion joints usually constitute a double column. As the need for expansion joints is limited, the cost of an extra column will be negligible. [Rowswell 1987; Fisher 1993]

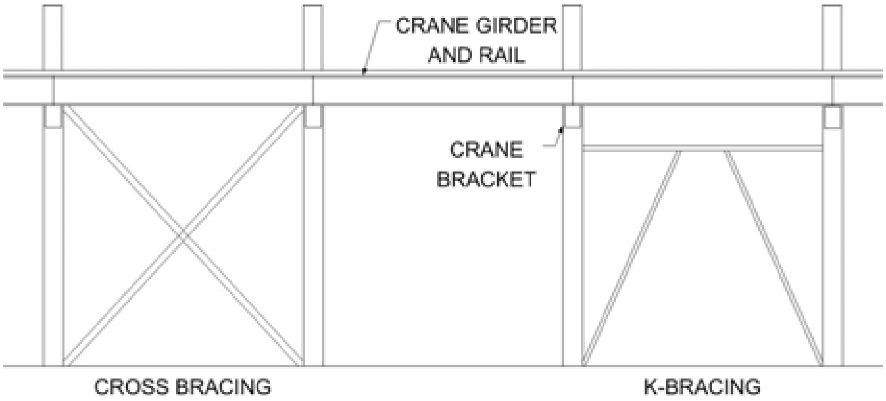


Figure 2.22: Side view of a building illustrating two types of bracing systems.

Careful attention should be given to the rail continuity at expansion joints. If a fully continuous rail is used, expansion of the rail should be provided for at the end stops. For rails that are not fully continuous, the structural expansion joints should not be situated at the same place as a rail splice. Rail splices allowing some expansion are made in different ways. A few examples are sketched below.

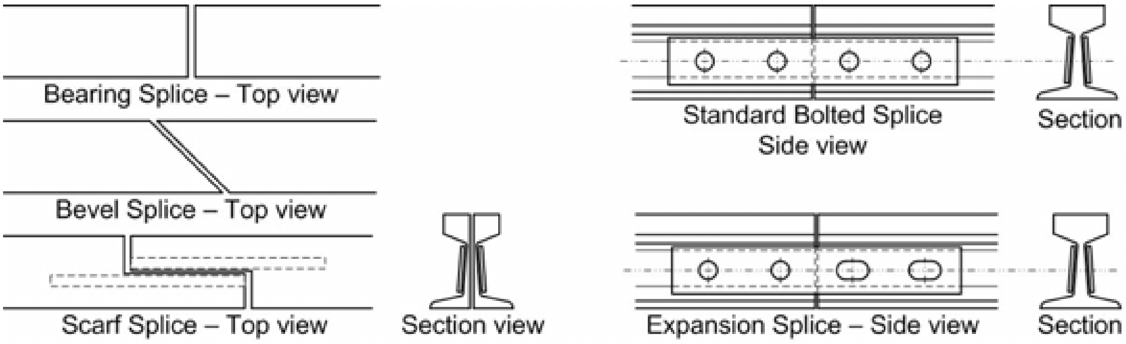


Figure 2.23: Available methods of joining rails to allow for expansion.

2.4.4.6. Crane Columns

Portal frame crane columns are designed as beam-columns according to the SANS 10162-1:2005 steel design code. [SAISC Industrial Course Notes 2007] Latticed columns, alternatively, are designed as a vertical truss designed primarily for axial forces. Analysis is usually completed using software to obtain the critical bending moments, axial forces and shear forces. With larger cranes and larger forces, a single universal column or beam section will quickly become insufficient. MBSM [2002] recommends a portal frame and bracket column limit of 22 tons (50 kips). For this reason different column variations have been developed to account for larger loads.

Examples are supplied in *figure 2.24*. Note that in literature the portal frame with bracket and the latticed column are most common for light cranes and heavy cranes respectively.

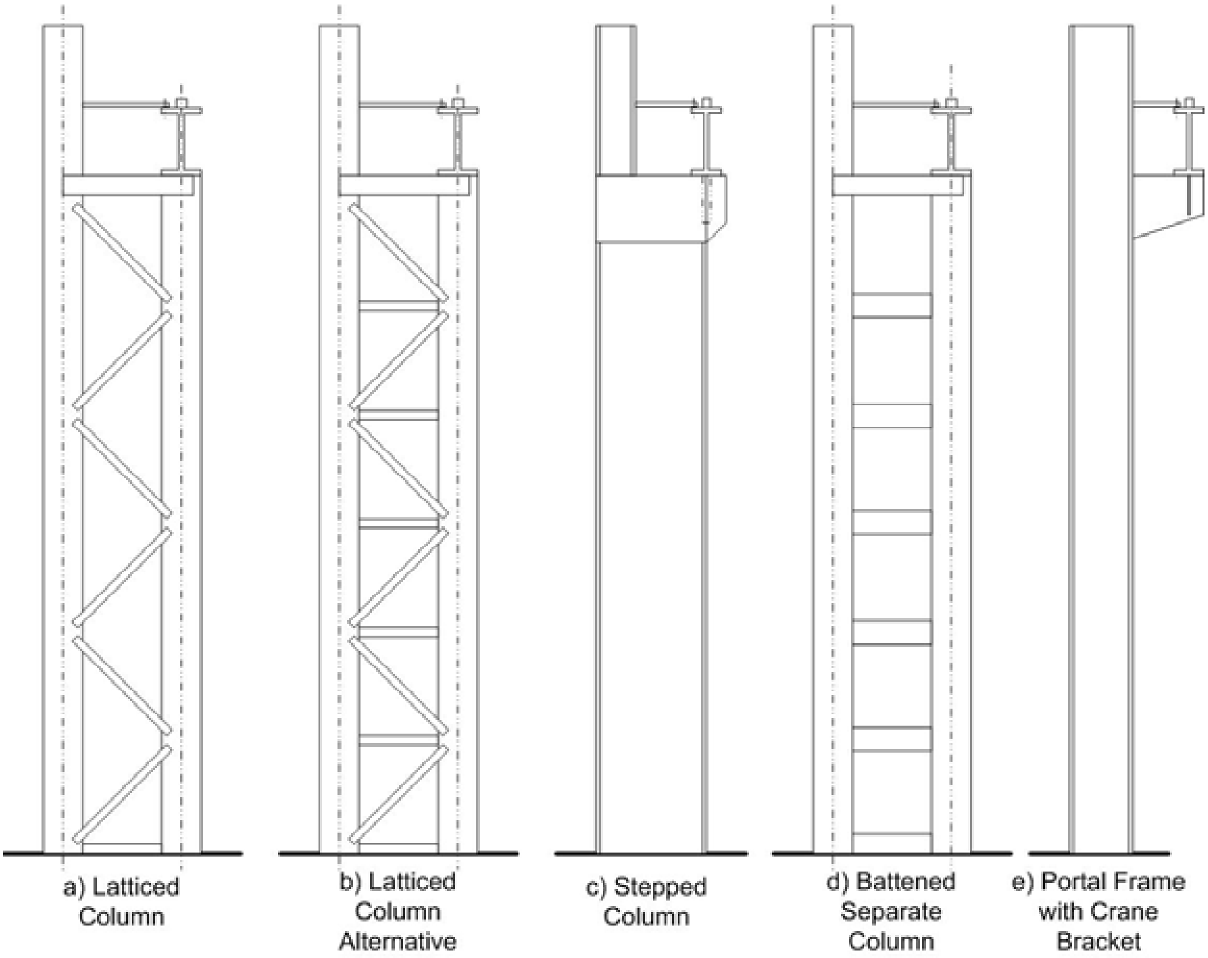


Figure 2.24: Five variations of crane column setups. The latticed column is used on the largest structures.

It is important to ensure that the stiffness of the portal frame column in e) is robust enough at the bracket to column connection to handle the eccentric loading. Also note that for the latticed columns, the rotation of the profile webs are in a plane perpendicular to the page. The joint action of the truss so formed is able to withstand the large transverse forces caused by the crane. The connection at the top of the back column to the roof column is looked at in more detail later in this chapter. It can be noted that crane columns are not normally subjected to fatigue loading as the members are primarily in compression only.

2.4.4.7. Outdoor Crane Gantries

Outdoor crane gantries are applicable to this study as long as they are also of the top running EOT crane type. These structures are subject to wind forces on the crane columns, crane runways and on the crane itself. The use of outdoor cranes is halted if the wind speed exceeds a given limit. This is primarily because of the difficulty with which the lifted load can be controlled and handled.

Another issue that requires special attention for outdoor crane gantry design is the lack of a tie mechanism or roof. This increases the chance of variable movement of the crane rails. Exposure to the elements means that the structural material must be protected against corrosion and designed to reduce pooling of rain water on the gantry. Temperature fluctuations are often larger and special attention must be afforded to thermal expansion; especially in runways that move from indoor to outdoor conditions. [MacCrimmon 2005; Goldman 1990]

Figure 2.25: Example of a crane that is both outdoor and covered. The roof system stops, but the runways continue.

2.4.4.8. Unusual Structural Layout

Crane support structures, as with any building, can have a variable layout. In some circumstances the layout of the building is governed by the process and machinery within the structure. Therefore, even though it is preferred to place columns at equal spans from one another, this may not always be possible. The variations in girder span mean variable girder depths and a variable distribution of wheel loads to the wheels will occur.

Details to provide for the variation in girder depth have been developed. Examples making use of the shallower girder partially resting upon the deeper girder at a column cap are not popular. A useful example involving a small step in the column is illustrated in *figure 2.26* and literature shows that this is generally accepted in practice. Furthermore, haunches or stools beneath the shallow girder are not commonly recommended. [Goldman 1990]

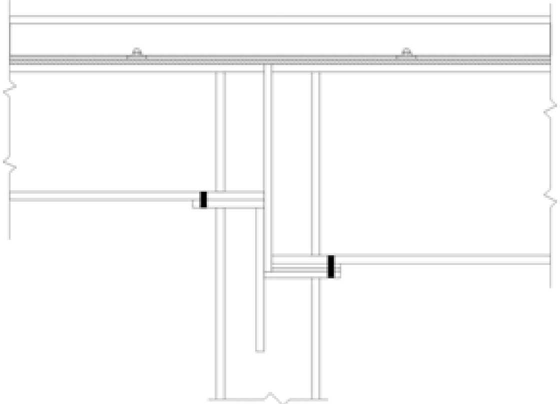


Figure 2.26: Example of a step in the depth of the crane runway girders.

2.4.5 Fatigue

Fatigue is a problem that was first discovered when the iron axles of rail coaches started to break after repeated use. Later on the airplane industry also detected fatigue failures due to the repetitive stresses the aluminium structure of an airplane was subjected to. Steel has since been shown to have fatigue characteristics that resemble an ideal ferrous material. Certain fatigue properties can be ascertained from *figure 2.27*. Aluminium resembles a non-ferrous alloy and steel has properties more similar to a ferrous alloy.

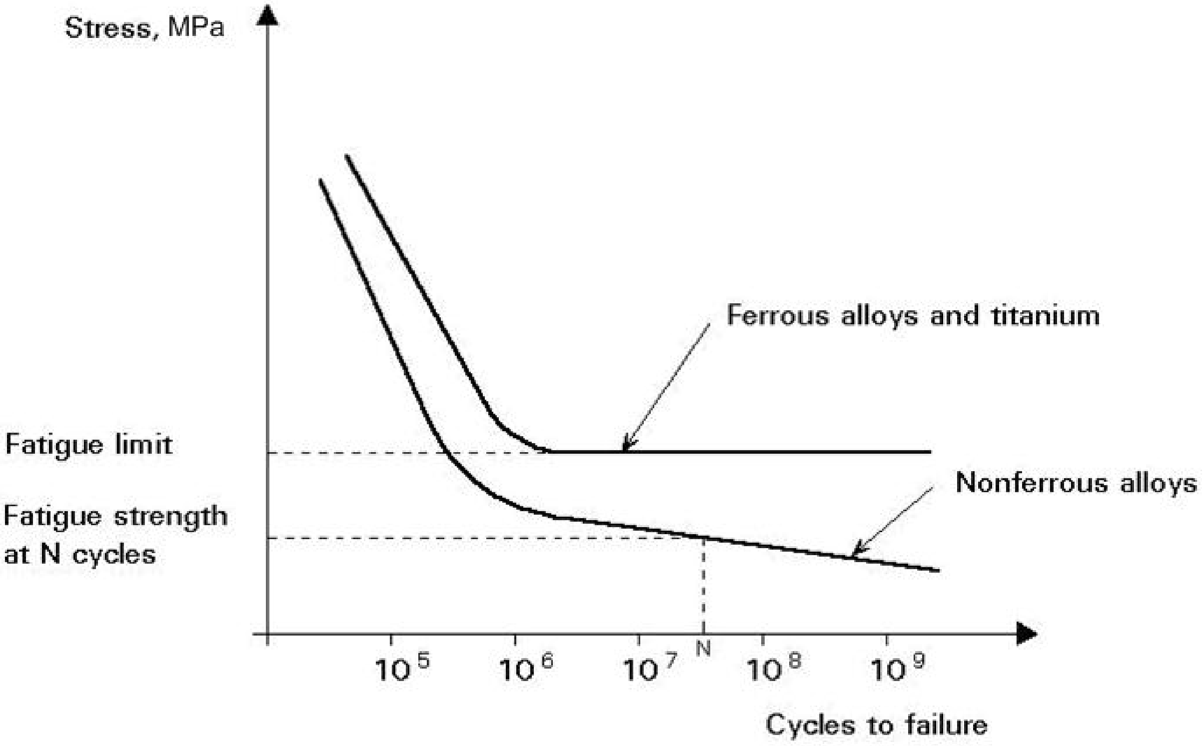


Figure 2.27: Comparison of the number of cycles to failure at a given stress range (amplitude) for steel and aluminium. The curves are better known as S-N curves.

2.4.5.1. S-N Curves

The graph in *figure 2.27* is also a representation of the well known S-N curves. They are a representation of the number of cycles required for a given stress range, in order to cause failure. The results used to compile S-N curves are spread. Using this near linear approach loses the important statistical distribution of the number of cycles to failure. This in turn means that the cycles to failure as calculated using the S-N curves, are not extremely accurate. Never the less, it is the best approach for fatigue design. Other topics are now defined with reference to the information already supplied.

2.4.5.2. Fatigue Definitions

Two definitions for fatigue are provided.

Fatigue is the failure of a material by cracking under the influence of repeated or cyclic stress. [Rowswell 1987]

Fatigue life of a structure is the number of loading cycles required to initiate and propagate a fatigue crack to final fracture. [MacCrimmon 2005]

All materials experience some form of fatigue but certain materials show more fatigue resistance than others. The process leading to fatigue failure is a three step process. First the crack initiates, secondly the crack propagates over time from an invisible tear to a visible crack and finally the crack propagates at an uncontrollable rate leading to abrupt failure. Considering that crane runway girders and the rest of the support structure are subject to cyclic loads, stress variation in the girders is a certainty. Fatigue therefore must be investigated for crane support structure and a brief explanation of the concepts and design methods are provided.

2.4.5.3. Stress Range and Stress Cycles

Stress range and stress cycles are two very important fatigue design concepts. They are clearly linked to the S-N curves, forming the axes of the curves. Stress range describes the absolute maximum to minimum stress difference that an element is subjected to. This stress range could be due to only compressive, tensile and compressive or only tensile stresses. Fortunately it has been shown that fatigue only manifests itself under tensile stresses. Therefore fatigue considerations can be disregarded for elements in compression only.

With large crane runway girders welding can not be completely avoided and welding results in residual stresses. For this reason certain elements, under compressive stress can show fatigue damage. This occurs if the tensile residual stress is larger than the applied compressive stress. Therefore the previously assumed compressive stress range is now, effectively, a tensile stress range. [Rowswell 1987, MacCrimmon 2005; Maas 1972]

A stress cycle is simply the number of occurrences of any given stress range. A few examples of various stress ranges and stress cycles are provided in the graphs below.

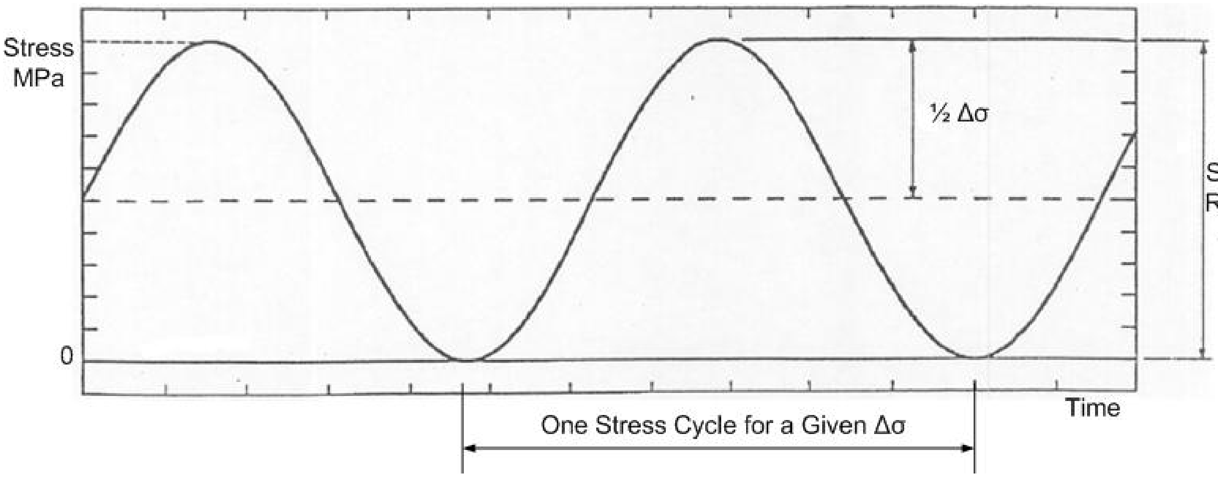


Figure 2.28: Visual explanation of stress range and stress cycle.

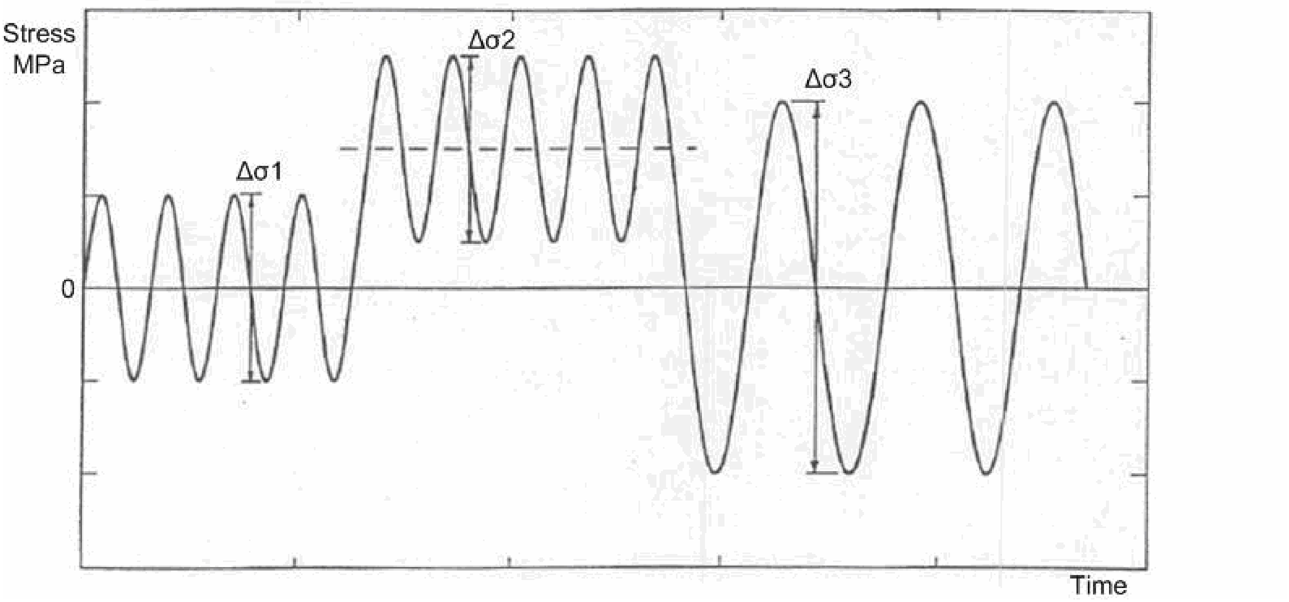


Figure 2.29: Further examples of how various stress ranges can occur. For fatigue analysis the number of stress cycles should be known for each stress range.

2.4.5.4. Fatigue Design

SANS 10162-1:2005 supplies illustrated details for selection by the designer. The sketches then refer to a table for more accurate classification. Each specific detail is subject to a stress range limit according to the classification. An example of such a limit is illustrated in *figure 2.27* on the S-N curves. If a lower stress than the limit is experienced by the respective detail, further analysis is unnecessary. If the stress exceeds the limit, then analysis is required. Each detail on the crane runway girder could be subjected to fatigue and as such should be investigated. AS 1418.18:2001 contains a figure which refers to the important details on a crane runway girder. These are not specifically for fatigue design, but supply a good example of the details that could require a fatigue check.

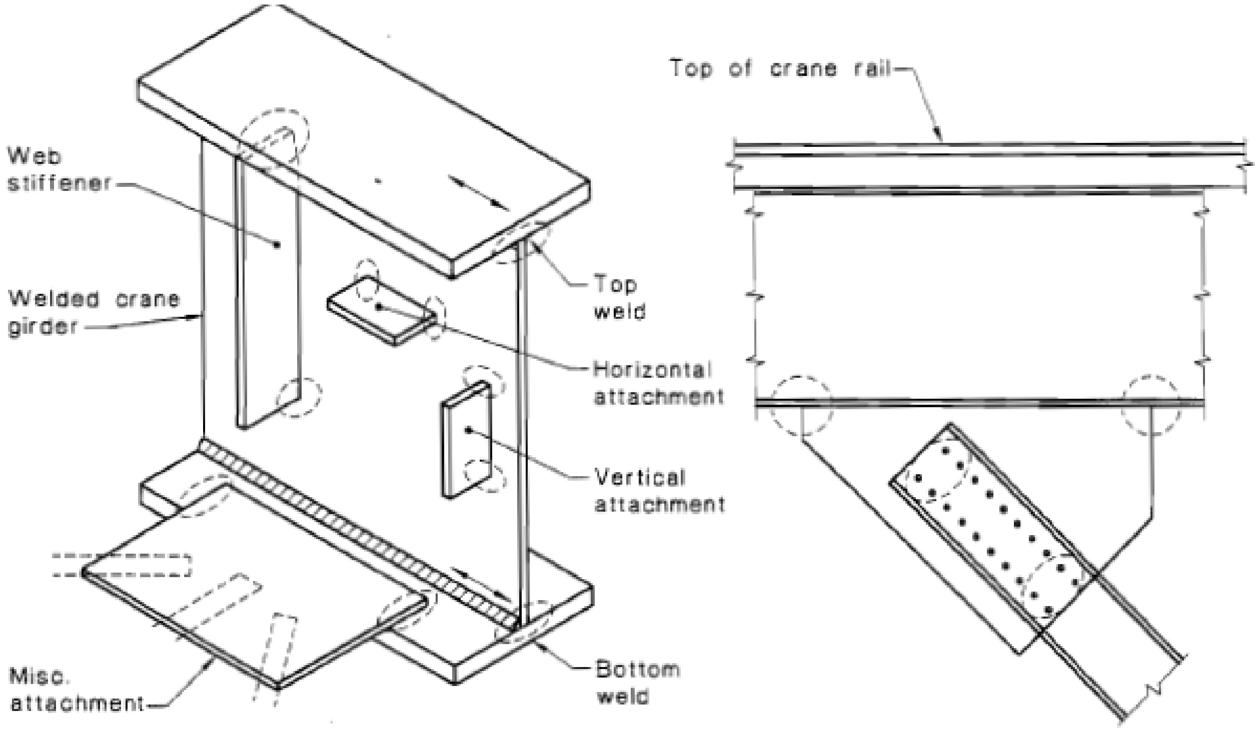


Figure 2.30: The details that may require fatigue design. These commonly do not all require attention. [AS 1418.18]

A diagram explaining the process is provided in *figure 2.31*. When viewing the diagram note:

i) The formulas in step six and seven are based on the S-N curves.

ii) The formula including a third power is for cumulative damage only.

iii) For further details on the formulas and application SANS 10162-1:2005 should be consulted.

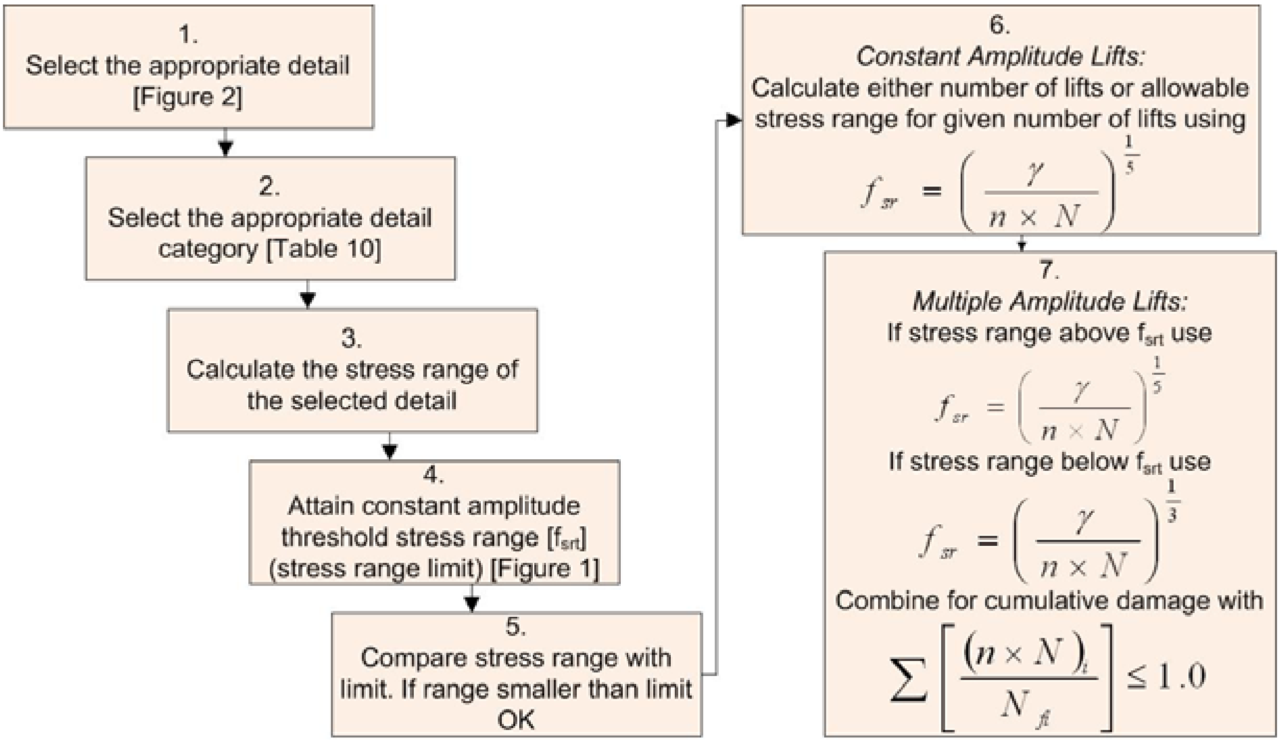


Figure 2.31: Description of process for fatigue design in SANS 10162-1:2005.

According to the South African code, two approaches to fatigue design exist. They are theoretical variations of the formulas provided for in *figure 2.31*. Both variations are correct. Either way a conservative approach is required

The first involves calculating a fatigue stress range limit (f_{srt}) for a given number of loads per detail. The detail in the support structure must be designed in such a way as to not exceed this stress range limit. The loads used for the calculation are generally from a duty cycle analysis. The second approach is simply the reverse of the former. The maximum number of stress cycles is calculated according to a known maximum stress in a structural detail.

2.4.5.5. Multiple Stress Ranges

When a ladle passes a given runway girder in a full state and in an empty state every completion of a specific process multiple stress ranges are being affected. If multiple stress ranges are applicable to a detail, a similar yet separate method of analysis is recommended.

The adjusted method includes all loads, even those below the stress limit, and investigates the so called “linear theory of cumulative damage” caused by multiple stress ranges. Palmgren-Miner developed a formula that can be used to investigate the cumulative effects of multiple loads. This formula is based on the S-N curves. A form of the Palmgren-Miner cumulative damage calculation is completed in the South African code (see step seven in *figure 2.31*).

A method is proposed by Rowswell [1987] which allows multiple stress ranges to be ignored; lodging the cumulative damage analysis unnecessary. He mentions the possibility of reducing the maximum stress range for cases where the maximum stress is unlikely to occur during every cycle. In this way the multiple stress ranges are combined to a estimated single stress range between the stress ranges of its constituents. Thompson [1970] also states this as a possibility. With the approach previously mentioned available, this simplification is not recommended.

2.4.5.6. Duty Cycle Analysis

Some difficulties are commonly experienced in fatigue design. How are fatigue stress cycles calculated? How is a cycle's stress range determined? Accordingly at the beginning of the structures life cycle, when the design is completed, it is difficult to know what the crane duty will be in 20 years time. This is difficult if not impossible to determine accurately. Approximations are required and extrapolation from expected lifts per hour is commonly used.

Lower class cranes are more unpredictable, but generally loaded fewer times than larger process cranes. This is also true for the percentage of maximum lift being handled during each cycle. Low duty cranes lift a more variable portion of the safe working load compared with process cranes and as such are not often subjected to large fatigue problems. Contrarily the process driven cranes often make thousands of lifts at near capacity.

Duty cycle analysis can be very helpful in determining the stress ranges and stress cycles. Duty cycle analysis is the process whereby the concepts just mentioned are ascertained for use in design. A duty cycle analysis can sometimes even go to as much detail as to specify where the crane and crab are going to travel in the building (e.g. against which rail). These stress range, stress cycle and crane movement factors theoretically could be used for fatigue design. Any reductions for crane movement, however, are strictly not recommended.

2.4.6 Failure Investigation

Crane support structures are subjected to harsh loading situations, which few other structures ever experience. This tends to lead to crane function errors, serviceability damage and complete failures. Failures due to exceeding the ultimate limit state are uncommon, but serviceability failures occur more frequently. Cranes are also capable of derailing or running off the rails at the end stops. A few failure mechanisms will be introduced below.

2.4.6.1. End Stop Impact Failures

Crane end stops have been discussed previously and it was recommended that they be designed conservatively. This is firstly because of the low financial implications end stops have on a structure and secondly because of the variable accidental loads imposed on the end stop. Inadequate design of the end stop or poor estimation of the end stop forces can lead to dramatic failure of the crane. The repetitive use of end stops as a brake can damage the structure. More disastrous results can occur due to wind forces on outdoor gantries with ineffective storm brake systems.

2.4.6.2. Fatigue Failures

Fatigue failures are relatively common in crane support structures. The top flange to web weld is a very highly stressed portion of the girder. The rotation of the top flange due to eccentric forces and buckling of the web, the load bearing stresses and the normal global bending stresses all account for stresses in the weld. Cracks develop and in some cases the top flange and web have been disengaged completely from one anther over large lengths of the profile.

2.4.6.3. Steel Wear and Bolt Failures

Wearing of the rail to top flange and wheel flange (roller guide) to rail interface has resulted in reduced crane performance. It is partly for this reason that elastomeric pads are now available for use. The cyclic nature of crane loads also tends to loosen bolts. Tightening of bolts during maintenance is important.

Dymond [2005] also mentions that limiter switches are occasionally intentionally switched off. This safe working load is exceeded and the reliability of the structure and crane is negatively influenced. Exceeding the lifting capacity is one form of misuse that worsens all of the mechanisms mentioned thus far.

2.4.6.4. Tieback Connection Failure

The lateral tieback connection between the girder and (commonly) the roof column is a problematic connection to design. Due to vertical loading the crane runway girders rotate and cause torsional and lateral movement of the connection. Slight vertical movement is also induced due to column shortening. Simultaneously the connection must oppose horizontal forces it was designed to resist. In many cases the details used here also sit eccentrically to the roof columns centre line. As such the tieback connections are commonly found to be damaged or broken if not properly maintained and inspected. An attempted illustration of the range of forces applied to these connections is provided in *figure 2.32*. [MacCrimmon 2005, Rowswell 1987]

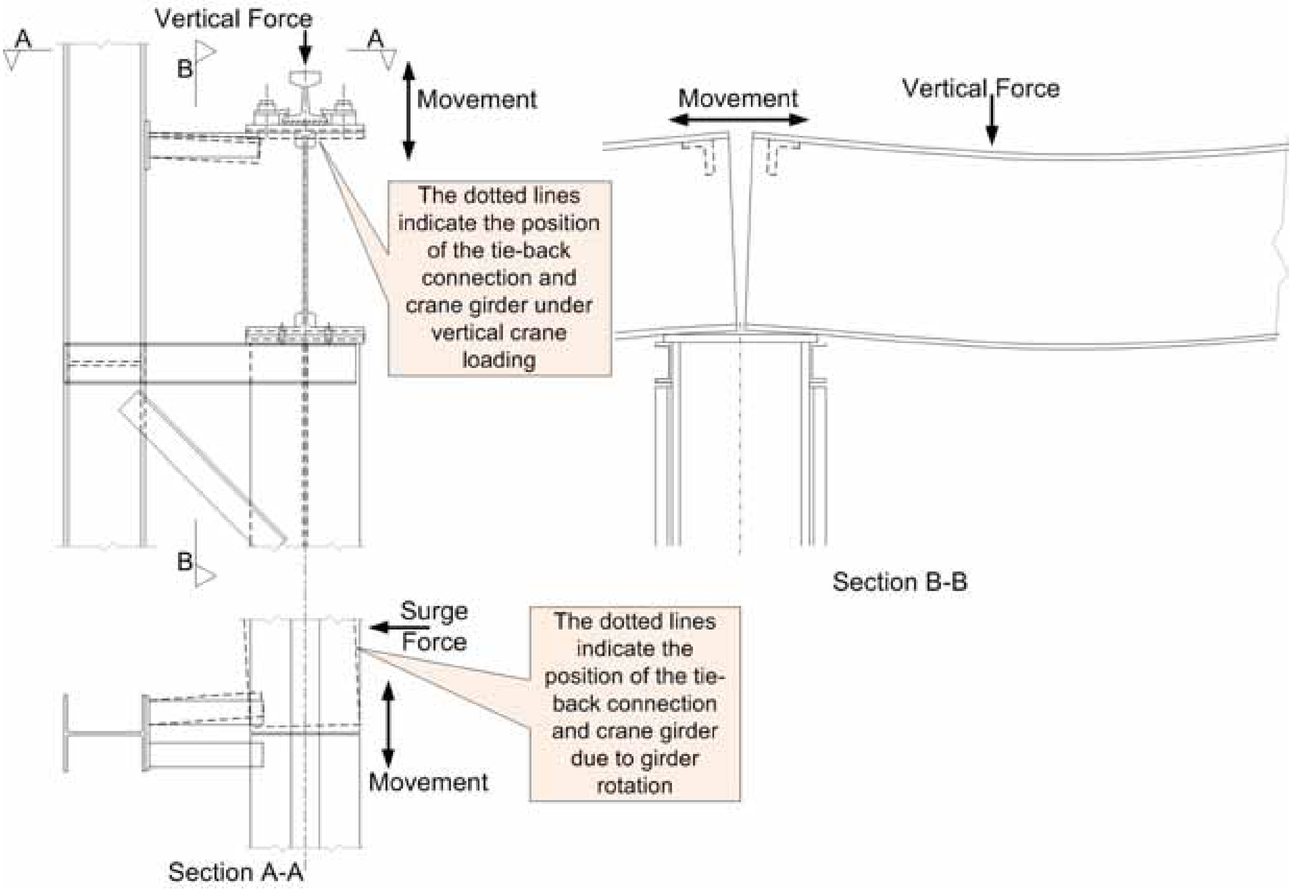


Figure 2.32: Illustration of the variety of movements the tieback connection is subjected to.

As part of this thesis, an investigation into failures is being completed concurrently with the best practice expert survey. Further investigation into the failure mechanisms and details appropriate for crane support structures will be supplied in the results. This will be appropriate as extra information on failures in South African practice will then be available.

CHAPTER 3:

EXPERT OPINION SURVEYS

A background to crane support structures design has been provided. This also serves the purpose of introducing the topics covered by the study. The method or process used to conduct the research for this thesis is discussed in this chapter. Accordingly an introduction to “Expert Surveys” will be furnished in this chapter. Defining the different survey and interview skills and questions employed in an effective expert survey forms the first part of the chapter. Following this the lack of a rational scientific basis when conducting such an expert opinion survey is discussed. The appropriate methods that can be utilised to provide a rational scientific basis are then also described. In the subsequent chapter, the actual procedure and questionnaire will be discussed as used in this study.

The detailed information on several topics discussed in this chapter has been omitted. As a result, certain concepts are only mentioned and not discussed. Further explanation of these concepts, if required, can be found in *appendix F*.

3.1 Definition of an Expert

In the context of this expert survey, an expert can be defined as someone with many years of experience in crane support structures design. This experience should not only be practical in nature but requires a certain degree of insight into the structural design methods and techniques.

In order to classify the type of expertise an individual is able to impart, De Villiers [2003] describes experts as having three different forms of experience. The “best” expert is one that has experience on all three levels.

i) Practical Experience – gained through observation and involvement in a given process or field of work.
ii) Reflective Experience – expertise gained through careful consideration of mechanisms and techniques appropriate to a given field or process.
iii) Philosophy of Design Experience –expertise based on a higher level of consideration and evaluation of mechanisms, principles and techniques appropriate to a given field or process.

3.2 Defining concepts of Expert Opinion

The so called "Expert Opinion Survey" is similar to a regular survey, only conducted using people with ample knowledge of a given subject – an expert. The survey can be completed via mail, telephone or interview. The method chosen here is the structured questionnaire interview. The expert's opinion and experience regarding the subject is elicited by their answers to the questions. The answers received are subsequently interpreted and combined, before the results become presentable.

Literature consulted on surveys indicated that great importance is placed on the approach followed by the surveyor, the physical questionnaire and the combination of the results. Furthermore it is known that many surveys rely on statistical combination of answers. The responses to this research survey are in a non-numerical format. The nature of the answers makes application of many of the statistical principles troublesome. These topics, and others, are developed in this section to help clarify their later application.

3.2.1 Uncertainty in Expert Opinion

Through the ages, much significance has been placed on the opinion of experts. The opinion of several experts, compared to one alone, being considered more authoritative. Ordinarily the use of expert opinion is done in a rather hap-hazard, unmethodical way. Improved methods of combination of opinion are always being developed. Be that as it may, the opinion involved in expert opinion will, at its core, always remain uncertain. It has however been shown that expert opinion can in fact yield useful information. If correctly dealt with, expert opinion can be a valuable, accurate source of information. Notably a clear distinction must be made between expert opinion and expert knowledge. [Cooke 1991]

What is intended in this study is to approach expert opinion within the context of justification in science. According to Cooke, the fundamental aim of science is rational consensus, which is attained through empirical control and reproducibility. Both of these factors become troublesome, yet necessary, to manifest in an expert opinion survey. The guidelines shared below have been developed to improve the scientific basis of expert opinion. Additionally, Cooke postulates that it is important to adequately represent this uncertainty.

For clarity in the forthcoming descriptions note that a well calibrated survey stems from careful management of biases, scoring and thorough systematic evaluation. This lends itself to attaining rationally defendable results. Stated differently, this lends itself to reducing or quantifying uncertainty in opinion.

3.2.1.1. Calibration

Calibration represents a form of empirical control on subjective probability assessments. In layman's terms calibration is a measure of the correctness of an expert or survey. A well calibrated survey is one that is understood to be accurate. Three key notions can be attended to in order to improve a surveys overall calibration. These topics are later studied individually.

i) Debiasing (various biases are more closely studied later)
ii) Use of proper scoring rules
iii) Systematic evaluation

Note that in surveys of this kind, an error is deemed to occur if an expert gives an answer that he knows is not entirely true.

3.2.1.2. Heuristics, Bias and De-biasing

Biases stem from heuristics. Heuristics are certain "rules of thumb" applied in determining a degree of belief of what we hear. Heuristics are unintentionally a part of everyone's nature. When heuristics lead to errors, they are called biases. Four heuristics, which are availability, anchoring, degree of representation and control, were studied by Cooke [1991] and are explained accordingly. Further detail is available in *appendix F*.

i) Availability is the heuristic linked to the ease with which certain information can be obtained.
ii) Anchoring is based on attaching an estimate (answer) to another easily available figure and adjusting from that point.
iii) The degree of representation heuristic leads people to ignore sample sizes when making estimates.
iv) Control manifests itself when subjects act as if they can influence situations over which they actually have no control at all.

3.2.1.3. Domain Biases

The biases introduced thus far are primarily linked to probabilistic biases. Alternatively domain biases are connected to an individual's preferences and must also be accounted for. For instance a specific expert may be sold on a certain design or concept and dislike others. It is very difficult to account for domain biases. Unfortunately this research project is based on opinion of methodology rather than on probability based numerical estimations. As such it is highly influenced by domain biases. Thankfully this is the principle goal of the study and knowledge of this bias is sufficient.

3.2.2 Attaining Rationally Defendable Results by Expert Opinion

"Science aims at rational consensus and the methodology of science must serve to further this aim. Were science to abandon its commitment to rational consensus, then its potential contribution to rational decision making would be compromised. Expert opinion may, in certain circumstances, be a useful source of data, but it is not a source of rational consensus. Given the extreme differences of opinion encountered in virtually every aspect of engineering science, it is clear that an unmethodical use of expert opinion will not contribute to rational consensus building." [Cooke 1991]

Expert opinion at face value is not scientifically acceptable. Certain measures have been developed to assist building a scientific basis when using expert opinion. These include reproducibility, accountability, empirical control, neutrality and fairness. These concepts are explained briefly below and in more detail in *appendix F*.

i) Reproducibility means to make it possible for peers to review and reproduce all of the steps involved in the research.

ii) Accountability means that the acquired information must be traceable.

iii) Empirical control means to evaluate expert opinion on the basis of possible observations. Moreover the evaluation made should be reflected in the utility value or weight of the expert's opinion in the end results. This essentially is the forerunner of scoring, seed questions and seed values to be discussed later on.

iv) Neutrality includes avoiding biases and encouraging experts to give their honest opinion.

v) Fairness involves the equal treatment of all experts prior to processing the results of the observations.

Cooke [1991] concludes that there is no single method that satisfies all of the above expert uncertainty criteria. An attempt must nonetheless be made to address these concepts sufficiently during any expert opinion survey conducted.

3.3 Elicitation and Scoring

Elicitation involves the generation and application of the questionnaire and the process of extracting the expert's opinion on the questions. Scoring focuses primarily on the evaluation and combination of the responses to attain rationally defendable results. The choice of scoring method will affect the nature of the answers. Similarly the nature of the answers will affect the choice of scoring method. Thus elicitation and scoring are dependent on one another. It can be clarified that if suboptimal elicitation methods or suboptimal scoring methods are used, it would not be reasonable to accept the results as rationally defendable. Several elicitation and scoring guidelines are supplied in this section.

3.3.1 Elicitation guidelines

The strategies described in the previous sections should be used in developing a questionnaire and in the elicitation process. A list of guidelines for elicitation and subsequent scoring is published in Cooke [1991] and listed below.

i) Questions must be clear.
ii) Prepare an attractive format for the questionnaire.
iii) Perform a dry run.
iv) An analyst must be present during elicitation.
v) Prepare and supply the experts with a brief explanation of the elicitation and analysis processes.
vi) Avoid coaching or leading the experts. (Fairness).
vii) The elicitation procedure should be short yet thorough.

3.3.2 Scoring Methods and weights

Cooke [1991] roughly speaks of scoring as a numerical evaluation of probability assessments on the basis of observations. Scoring is rewarding those properties of expert responses that we value positively. Much of the literature involved in scoring methodology is also numerically centred. Careful adjustment can be made to available methodology in order to suite the purpose needed for this thesis.

Weights are commonly used to form part of the scoring procedure. If an expert is seen as more reliable or his answers are proven to be better, he receives a larger weight. The experts with heavier weights have more impact on the outcome of the investigation. Four ways of determining weights are proposed:

i) Assign all experts equal weights.
ii) Rank the experts in preference, lower rank corresponding to lower preference, and assign weights proportional to ranks.
iii) Let the expert's weight themselves.
iv) Use proper scoring rules.

The use of proper scoring rules is understood to be a useful scientific method. The other methods either do away with scoring altogether or decrease the accuracy of the method as a whole. Ranking to preference means that the surveyor's opinion will affect the outcome of the expert opinion survey. This is not recommended. Cooke [1991] states that the "classical model" for instance forms weighted combinations of expert opinions. In this case the weights are themselves implemented as strictly proper scoring rules.

3.3.3 Seed Variables

Seeded variables can be used to assess an expert according to events or questions for which the answers are already known. Weights, as above, are then assigned according to the expert responses to the seeded questions. This can be approximated to a proper scoring rule. It must be noted that meaningful and applicable seeded questions are very important to the success of the resulting weighted combination. This in turn influences the efficiency of the entire survey. Cooke [1991] does state that the higher the number of seed variables the greater the confidence in the experts' opinion and the corresponding results will be.

3.3.4 Utility Theory

Utility theory is closely linked to the concept of weights already discussed. This theory assigns weights to variables according to the importance of the respective variables. Generally a total combined weight of one is used for ease of calculation. This process also allows for simple comparison of weights. For example in project management cost, time and performance are three trade-offs. If we want to rate multiple projects according to these three concepts in order to choose the best one, utility theory can be utilised. Suppose cost is twice as important as time and performance. Then weights of 0.5, 0.25 and 0.25 respectively can be assigned for weighted combination. These weights are also known as utility values.

3.4 Questions and conducting surveys

Survey methods are widely used as a means of getting information from a group. To a large extent this information is accepted for research purposes. Surveys in general, and specifically expert opinion surveys, are used on a large scale in the commercial and academic world. As such it is important to ascribe sufficient importance to the entire method of conducting a survey. [Hoinville and Jowell, 1978]

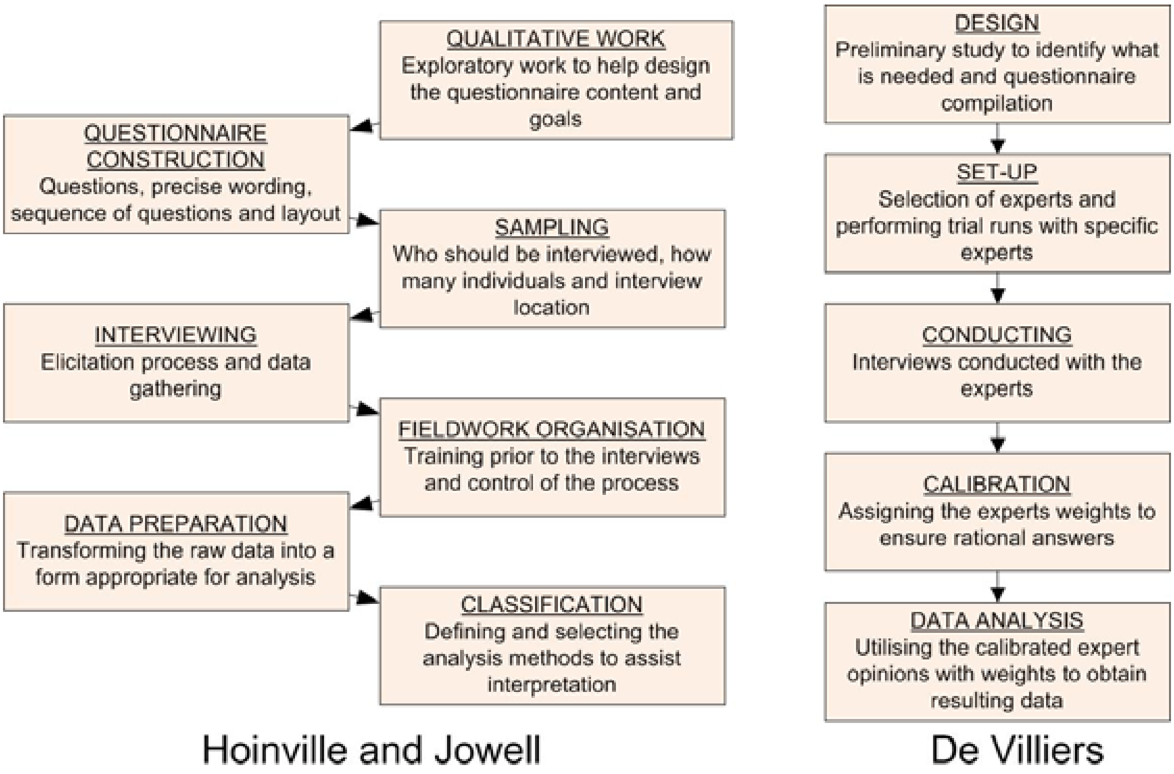


Figure 3.1: Two approaches to the survey process.

Hoinville et al. describe conducting a survey as a seven phase process. Comparatively De Villiers [2003] looks at the similarities between a laboratory experiment and the survey process. From this comparison, De Villiers found the five step process described in *figure 3.1*. The examples of Hoinville et al. and De Villiers equate well with one another.

Furthermore the questions used in a survey can be either qualitative or data collection questions. Qualitative questions are much less structured and more conversational. They are useful in obtaining opinion. Data collection questions on the other hand are more structured and allow a researcher to obtain information directly required, by asking more specific questions.

3.5 Questionnaires

It is important that questionnaires be neat and well planned. This facilitates the questionnaire and interviews flow. A questionnaire must be accurate in order to accommodate neutrality and reproduction principle. Respondents need to be asked the same questions in the same way each time. Furthermore the responses must be recorded in an orderly fashion to ensure continuity and as little error as possible. Hoinville et al. [1978] recommends that the interviewer make use of some form of recording device. This will allow the surveyor's concentration to be on the interview process itself. Ensuring that the responses are appropriate and include the information required for the study. Relying on memory alone is always going to lead to distortion of the results. It is furthermore appreciated that the results of a questionnaire can be improved if the questions are asked correctly.

3.6 Post Survey Analysis

Analysis of the survey responses has a large effect on the effectiveness of the research. In *figure 3.2* Hoinville et al. [1978] describes the whole analysis process as used for a large survey.

Open ended answers always vary. Listing and coding are two measures that can be taken in order to manage these variations. Coding involves grouping random answers into categories by finding similarities in the answers. Response listing is the primary step in achieving well coded answers. Good coding practice requires creating a listing sheet with possible responses and the number of times the relevant responses occur. Reviewing the listing sheet, the researcher is able to compile a coding frame encompassing all possible answers. The process is a form of control employed to simplify the combination of answers in analysis. Well coded responses are called "clean".

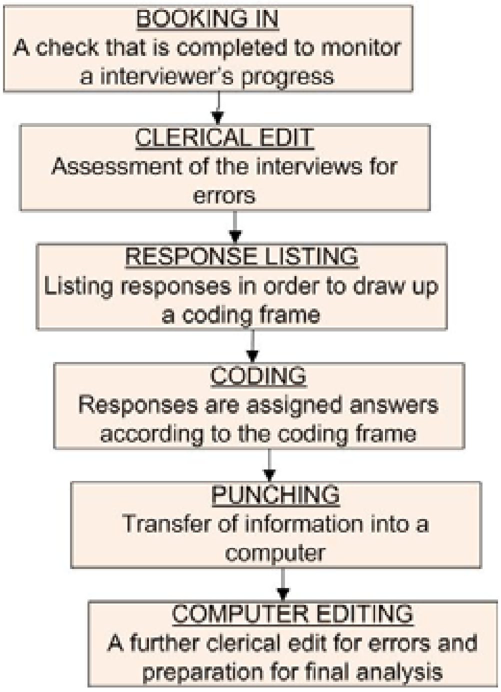


Figure 3.2: The process of preparing survey responses for analysis in a large survey.

3.7 Comments on practical implementation

Is there an effort to make a questionnaire bias free? Are assumptions well spelt out in the questions? Has the relevant literature been reviewed and systematically evaluated? How are experts selected? Are they truly experts?

These questions are very useful to ask when conducting any expert survey, as they instigate a degree of scientific grounding when answered. The procedure described in the next chapter intends to answer these questions.

CHAPTER 4:
METHOD AND PROCEDURE

This chapter describes the entire process followed in conducting the research for this thesis. An attempt is made to explain the procedure chronologically and rationalise the method chosen. Commentary on the procedure and survey results is provided in subsequent chapters. This chapter begins with the motivation for using the expert opinion survey.

4.1 Motivation for Using the Expert Survey

The University of Stellenbosch' structural division has conducted much research on crane support structures. As the research project nears completion, a survey to investigate present practice in industry is needed. This will aid the implementation of the research already completed. A "best practice" methodology could then be investigated and compiled. The final aim is to introduce a crane support structures design guide based on "best practice" principles.

Several methods are available to obtain applicable "best practice" design information. A flow chart listing various approach options is shown in *figure 4.1*.

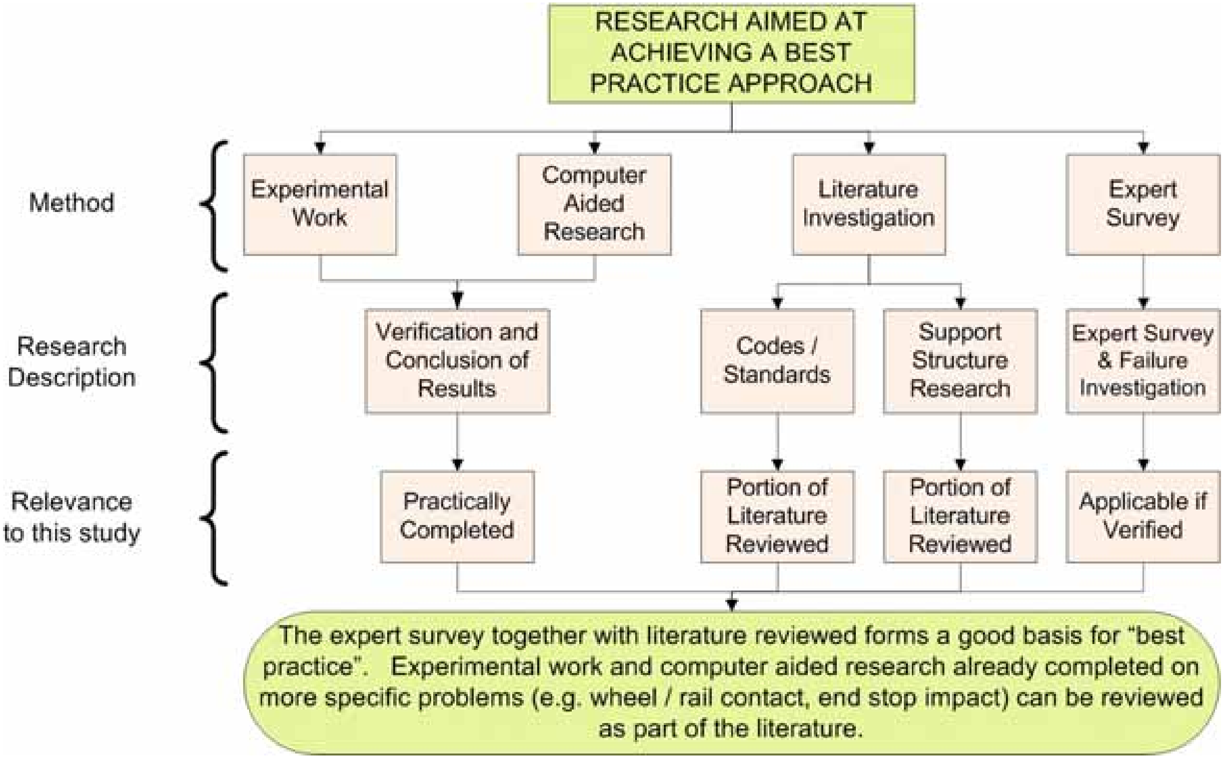


Figure 4.1: Flow diagram explaining the choice of an expert survey as the research method.

Before continuing, the basic breakdown of the procedure, as described in this chapter, is provided. Each phase can be considered individually, but in the context of the research, none are independent.

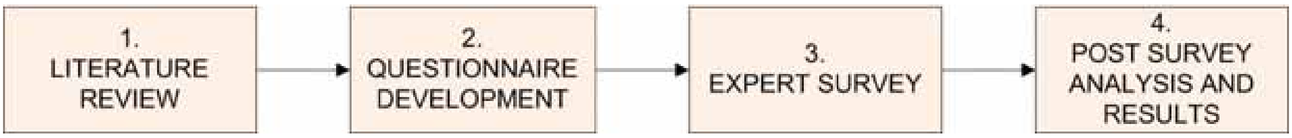


Figure 4.2: Basic components of the procedure followed whilst completing the research.

4.2 Literature Review and Information Accumulation

The first phase of the thesis research involved accumulating literary information concerning crane support structures. An intensive investigation of the collected literature was then performed. The purpose of the literature review was primarily to obtain sufficient knowledge of the subject material in order to conduct the thesis research. As a result of the type of study to be carried out, the research also formed the basis for development of a questionnaire. In addition to this, the literature is also used to verify the expert responses during the post survey analysis.

The literature reviewed therefore forms an integral part of each subsequent phase of the project. The literature reviewed was summarised in the previous chapters. For example the outline of crane support structures design as developed in the earlier chapters is used again here in the questionnaire development. For ease of reference the layout is provided in *figure 4.3*. Note that the nature of the material used to develop the layout, means that the generated layout would also be a good starting point for a potential “Best Practice Design Guide”.

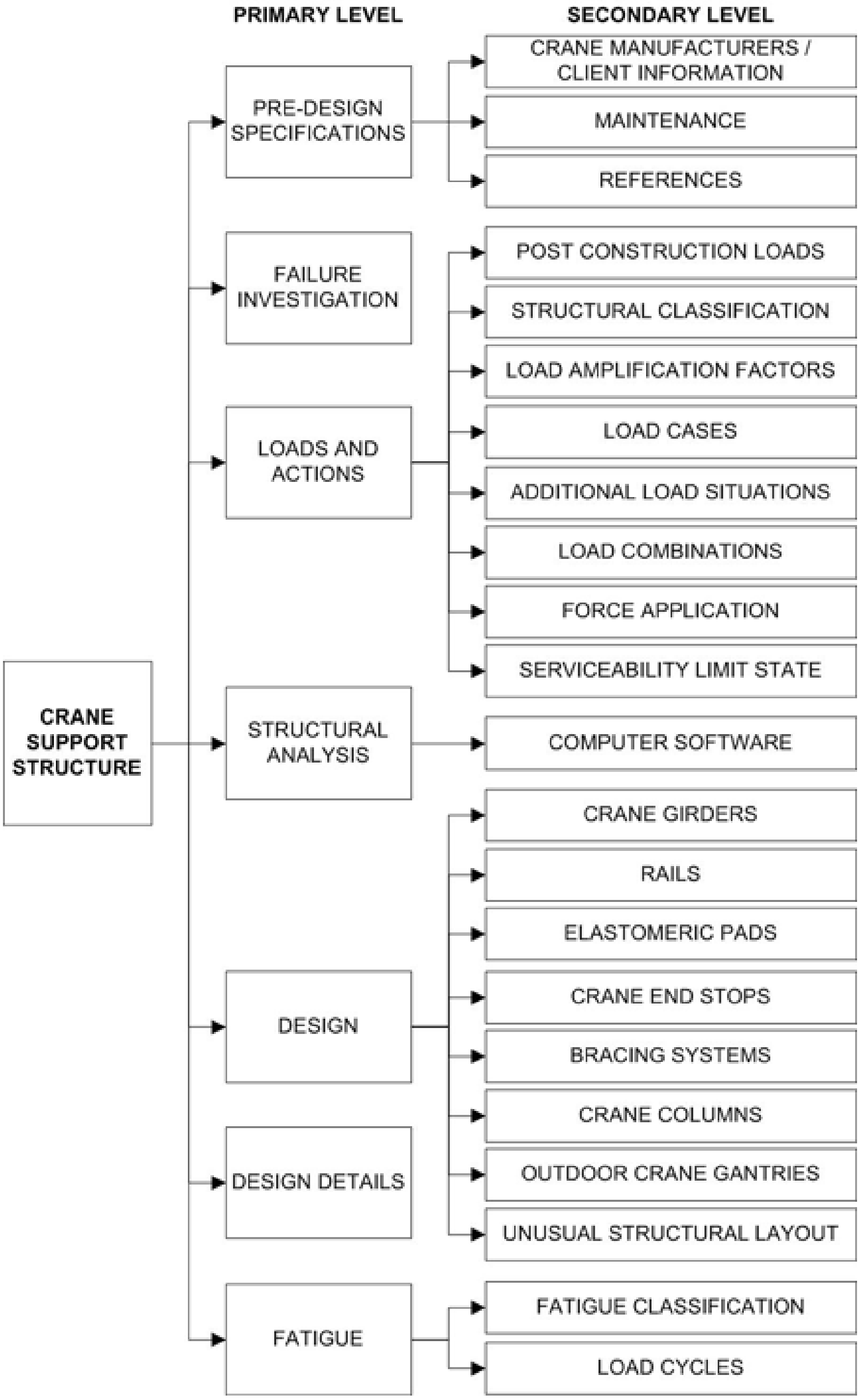


Figure 4.3: The outline developed in the literature review will also be used in the questionnaire development.

4.3 Questionnaire Development

The development of a questionnaire is an iterative process. As such the questionnaire is constructed and adjusted repetitively in order to obtain the best possible product. This will in turn assist elicitation and post survey analysis, enabling rationally defendable results to be attained. The iterations are required in order to:

i) Extract the correct topics for investigation.
ii) Select the style of question to suite the study.
iii) Develop the questions in order to elicit the information required for the study.
iv) Determine the questionnaire length and elicitation time to best suite the study.
v) Correctly structure the visual layout and flow of the questionnaire.

Ultimately all of these concepts are aimed at achieving the goal of the research. Knowing your goal is crucial to the success of the questionnaire and the expert survey. Morgan [1998] emphasises the importance of research aims when developing the style of questions. Be it of a structured format eliciting only the information the researcher requires, or less structured in order to obtain what the expert wants to share. In order to achieve the research goals successfully the five statements above should be considered during each step in the iterative process.

Accordingly the objective of this study is to obtain subject specific information. In other words the expert opinions are intended to be focused on certain chosen research topics. The opinion of the experts is not meant to dominate the direction of the survey. In order for the questionnaire to elicit the required research data, a more structured layout was required. Fundamentally however, the unique expert opinions are needed for the thesis research. Opinion should therefore not be discarded, but simply assessed in a structured manner.

4.3.1 Literature Based first draft Questionnaire Development

The first list of questions was developed from the description of EOT cranes and their support structure. Every topic was covered and relevant questions formulated. This very first compilation of questions was overly comprehensive, weakly structured and time consuming to apply. Several duplicate or even triplicate questions were present. This had to be corrected as the “parameters” measured should be “independent”. The questions needed much work during the iterative process in order to facilitate the statements found at the top of this page. The approach utilised to make these adjustment can be compared to brainstorming.

Part of the brainstorming process involves sorting, selecting and developing the ideas gathered. In a similar fashion, all the questions were sorted and selected in order to form a complete questionnaire.

Once the actual questionnaire content was acceptable and the questions were formulated in the appropriate manner, the layout, flow and length were adjusted to a suitable format.

Main and sub headings were used (as in *figure 4.3*) to rearrange the questions into appropriate categories. The first draft questionnaire at this stage included the appropriate questions and grouped them in a structured manner. This structured layout additionally improved the flow of the questionnaire.

The only thing remaining to be addressed in the primary development of the questionnaire was to ensure the visual layout of the document was appealing, professional and easy to follow. A neat version was completed using Microsoft Word.

4.3.2 Seeded Questions

At this point in the procedure it becomes necessary to address the seeded variables for inclusion in the questionnaire.

Results from an expert survey are always going to be opinionated, making scientific grounding difficult to achieve. In chapter three expert surveys were introduced. Some steps, that can and should be employed in order to achieve rationally defendable results, were listed. These steps should improve the calibration of the expert survey. Most important to the compilation of the questionnaire was the use of a proper scoring system. Seeded questions were selected as the most appropriate approach.

In developing the seeded variables, the questions were constructed similarly to the questions already in the questionnaire. Seeded variable topics that are relevant to the subject material were utilised. The questions are then placed in suitable positions in the questionnaire. The experts are not meant to notice any difference in the question style.

Once the elicitation process is complete, it becomes possible to compare the experts' responses with the actual answers. The experts are consequently given a score according to the seeded question responses. The results from the seeded variables are then combined per expert according to utility theory and a rating assigned to each expert. This rating (expert weight) is then used to combine the expert responses to formulate useful conclusions.

The choice of seeded questions was made difficult by the nature of the responses. Statistic principles could not be used because the majority of questions were not based on value estimates. The scoring therefore takes on a “right or wrong” format.

Careful consideration lead to the following seed questions being chosen. The selection was based on whether an accurate answer, that is either right or wrong, can be determined for the question. In *table 4.1* the answers and the references are also included.

Table 4-1: Summary of the seeded questions used in the questionnaire.

No.	Questionnaire Reference	Seeded Question	Answer	Reference
1	Appendix B: Expert Survey Questionnaire. Loads and Actions - 4. Post Construction Test Loads: Question 4.1	Describe the crane test loads used to inspect the working safety of the crane and crane support structure?	There are two test loads: A dynamic lift where the crane is put through ordinary use.Done with a load of (1.1 * rated capacity) A static lift where the crane is simply lifted, deflections checked, and dropped again. Done with a load of (1.25 * rated capacity).	SANS 4310:2002
2	Appendix B: Expert Survey Questionnaire. Loads and Actions - 7. Load Cases: Question 7.2	For the purpose of a "second order analysis", how is the horizontal notional load calculated and where is it applied to the structure?	The translational load effects produced by horizontal notional loads are to be added to the sway effects for all load combinations. The notional load equals a force of (0.005 * gravity loads) applied at the crane level.	SANS 10162:1 - 2005
3	Appendix B: Expert Survey Questionnaire. Design - 13. Crane Girder: Question 13.8	How do you calculate the following parameters for a mono-symmetric plate girder section (as used for some simply supported crane runway girders)? C_w ? J ? β_x?	Any reference or formula could be supplied that is similar to those supplied in *equation 5.1 - 5.3*.	Advanced Structural Steel Design 841 (Part 2) Class Notes [Dunaiski 2006]
4	Appendix B: Expert Survey Questionnaire. Design - 18. Crane Column: Question 18.3	Explain what effect the crane load applied to the crane girder has on the force distribution along the two columns? Comment on each scenario as the connections fixity (restraint) is adjusted?	The forces do distribute between the two columns. When the connection is totally free all the force travels down the crane column. When fully fixed (X-direction or z-axis or both) the forces spread almost equally relevant to the profile sizes. Partial restraint lies between these two barriers.	Prokon frame model analysis with varying restraint to the connection.
5	Appendix B: Expert Survey Questionnaire. Fatigue - 22. Load Cycles: Question 22.1	For the example given please calculate the number of stress cycles the top flange to web weld [1], the stiffener toe [2] and the corbel to column connection [3] will be subjected to?	Top flange to web weld: 2 cycles Stiffener toe: 2 cycles Bracket connection: 1 cycle	Prokon shell model analysis with a load that moves across the crane runway girder.

$$C_w = \frac{h'^2 \times w_{tf}{}^3 \times t_{tf} \times \alpha}{12} \qquad (\textit{Equation 4.1})$$

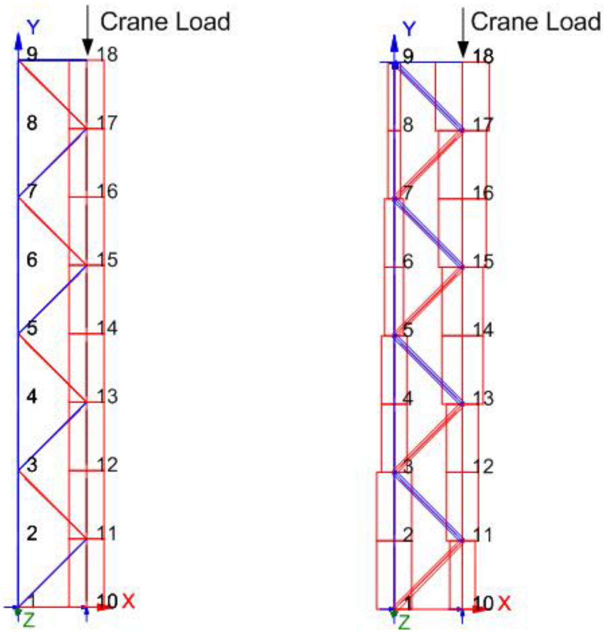
$$J = \frac{1}{3} \times \left[w_{tf} \times t_{tf}{}^3 + w_{bf} \times t_{bf}{}^3 + h' \times t_w{}^3 \right] \qquad (\textit{Equation 4.2})$$

$$\beta_x = 0.9 \times h' \times \left[2 \times \frac{I_{ytf}}{I_y} - 1 \right] \times \left[1 - \left(\frac{I_y}{I_x} \right)^2 \right] \qquad (\textit{Equation 4.3})$$

Seed questions one and two are both relatively straight forward to understand. The answers are taken directly from the code. Question three intends to determine if account is taken of mono-symmetric section properties when designing this type of crane runway girder. In the class notes used for the Advanced Structural Steel Design 841 post graduate course at Stellenbosch University several examples of the coefficient of mono-symmetry (β_x) are available. *Equation 4.3* is a slightly simplified version.

Question four and five are more detailed than the previous three. Seed question four attempts to determine the experts understanding of the elastic shortening of columns. Whilst the crane column shortens under the crane load, the question arises – is the back column loaded. Various interpretations of the resulting effects on the back column existed. Computer software has been useful in obtaining a conclusion that is easier to trust.

To this end a Prokon frame analysis was completed in which the supporting effects of the roof system and the crane bridge were simulated. This was done by adjusting the fixity (restraint) of the two columns at crane level. Two explanatory illustrations are included. The first shows the axial forces generated in the columns when totally free - practically all of the force is found in the crane column. The second shows axial forces when the connection is assumed to be totally fixed against horizontal movement and rotation. In this case the load is distributed between the two columns. At the base the forces are nearly equal. Further details can be found in *appendix C*.



Axial forces – node 9
and 18 totally free

Axial forces – node 9
and 18 totally fixed
horizontally and
against rotation

Figure 4.4: Illustration indicating the distribution of forces in the back column and the crane column. [Prokon output]

Question five effectively asks the experts for their interpretations of fatigue load cycles. If a crane with two wheels per end carriage was to pass over a crane runway girder, how many stress cycles would specific details on the crane runway girder be subjected to? A finite element model of a crane runway girder was created using shell elements in Prokon. The loads were then imposed on the model in steps. Signifying the wheels moving onto, along and then off the crane runway girder. The time dependent stress distribution at the different examined details is presented graphically below. Further information is available in *appendix D.*

For the top flange to web weld: From the graph it can be seen that although the larger stress range cycle [Δ_A] only occurs once there is a considerable contribution by a slightly smaller stress range cycle [Δ_B]. Therefore two stress range cycles were chosen to be correct. Local loading effects are accounted for.

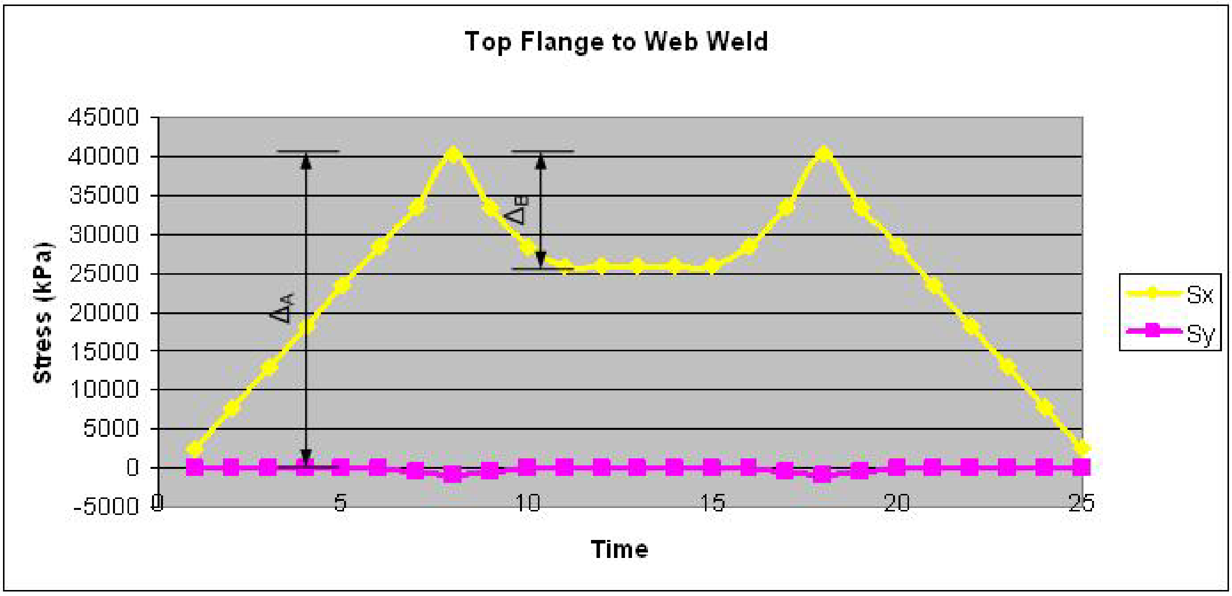


Figure 4.5: The stress distribution in the top flange to web weld as a crane moves across a crane runway girder. This serves as a visual aid to the stress distributions.

For the stiffener toe: A similar result to the top flange to web weld can be found for the stiffener toe. In this case the influence of stress range cycle [Δ_B] is much more prominent. Therefore two stress range cycles were chosen to be correct. Local loading effects are accounted for.

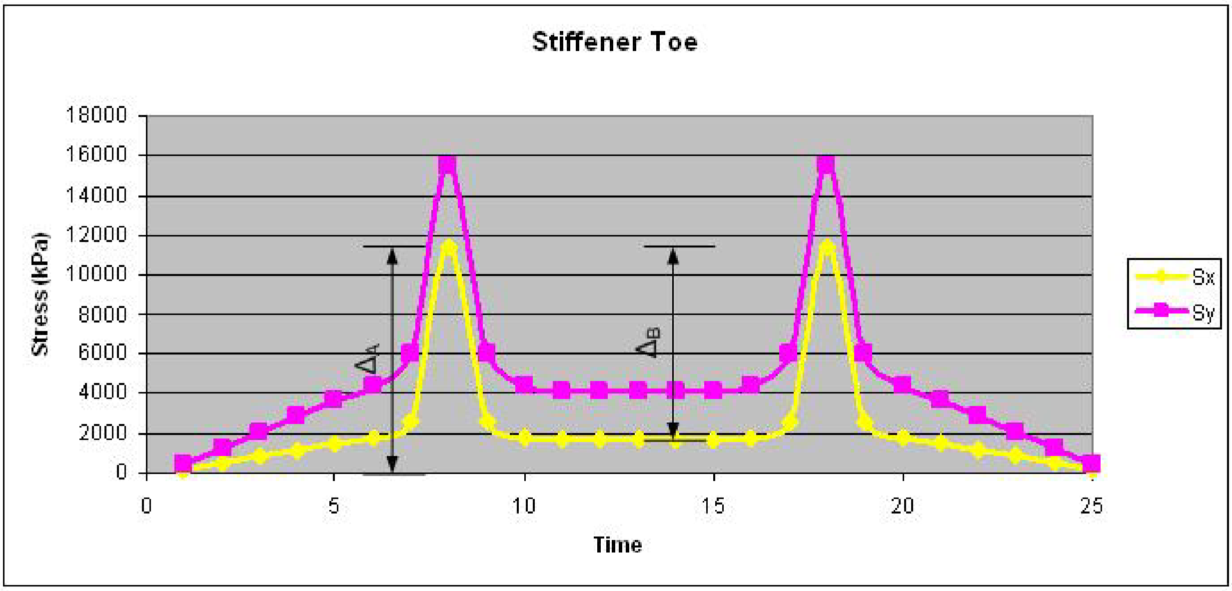


Figure 4.6: The stress distribution in the stiffener toe as a crane moves across the crane runway girder. This serves as a visual aid to the stress distributions.

For the bracket connection: The global loading of the crane takes effect, rather than the local wheel loads. Therefore only a single stress range cycle is assumed for the bracket connection. The two small deviations near maximum stress are due to local wheel load effects taking affect.

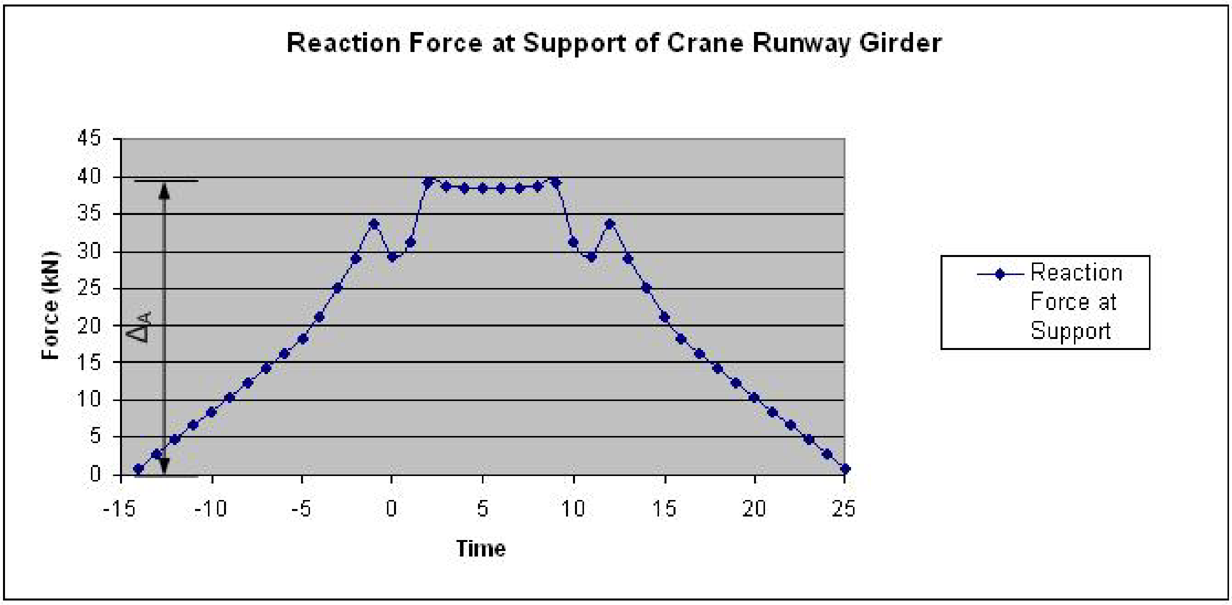


Figure 4.7: The force cycle imposed on the column to bracket connection. The time starts from negative to include the portion of time were the crane is on the previous crane runway girder.

4.3.3 Trial Run second Draft Questionnaire

The first draft questionnaire was complete and ready for use. In order to achieve the most effective questionnaire possible, a few trial run interviews were scheduled using the first draft questionnaire. The intention of the trial run interviews was to obtain feedback on the:

i) Questions included that were deemed unnecessary.
ii) Questions excluded that were deemed necessary.
iii) Seed questions success or failure.
iv) Layout of the questionnaire and flow of the question order.
v) Possible time an interview would take to complete.
vi) Style and approach of the individual questions.
vii) Style and approach of the researcher.

The purpose of the trial interviews was briefly explained to each mock expert before the interview commenced. The mock experts included:

i) Prof. Dunaiski – experienced structural engineer and heads the crane research program at Stellenbosch University.
ii) Dr. Dymond – completed a PhD project related to cranes.

Occasional adjustments were recommended and made to the questionnaire. For example certain sketches had to be added or improved to aid the interpretation of various questions. The mock experts also recommended that the researcher know the questionnaire inside out, in order to be more comfortable in the interviews. This in turn will allow better application of good interview techniques and avoiding of biases.

Although both mock experts seemed relatively satisfied with the layout and detail of the questionnaire, there was a slight issue with the duration of the interview. The survey guides consulted all recommend a short contact session (Hoinville 1977, Morgan 1998]. The concern was enhanced as the experts to be consulted are professionals and their time is valuable. In the trial interviews, the average time was one and three quarter hour. A much shorter interview duration was required.

As a last step in preparing the questionnaire, a contact session with Mr. Erling of the Southern African Institute of Steel Construction (SAISC) was organised. Unfortunately due to travel and basic logistic difficulties involved with scheduling, a meeting could not occur. Instead the questionnaire was e-mailed to Mr. Erling for comment. Mr. Erling did not include any physical adjustments to the questionnaire, but warned of the time constraints. He stated that the questionnaire goes into great detail. All the experts might not be equally aware of each respective issue covered. Additionally Mr. Blitenthall, also of SAISC, stated his satisfaction in the coverage of the questionnaire. A summary of the most important results from the three mock experts includes:

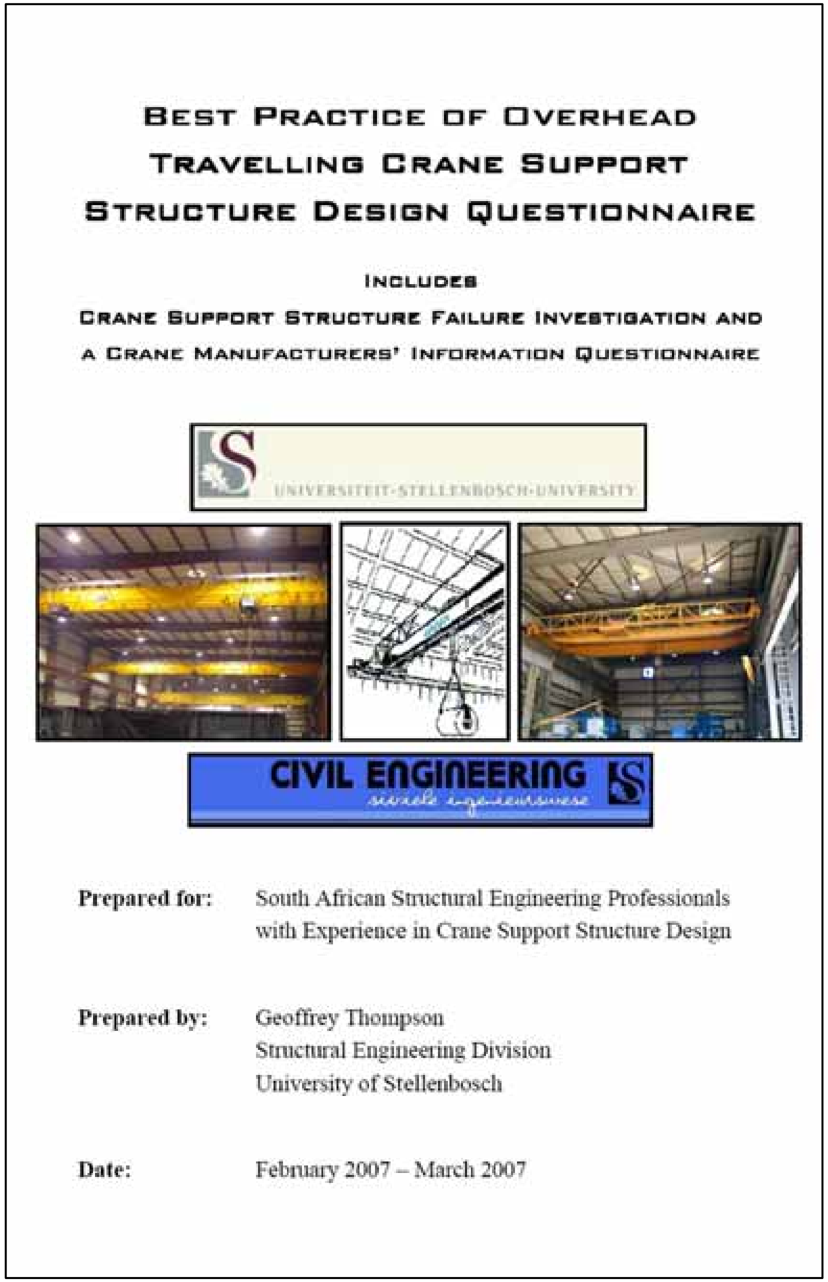
i) The questionnaire is detailed but acceptable.
ii) The seed questions are appropriate.
iii) The layout and flow is acceptable.
iv) Awareness of the duration of the interviews is important.
v) Expert knowledge on the topics included in the questionnaire may be variable.
vi) Know the questionnaire very well in order to be comfortable in the interviews.

With the trial run adjustments made a final product could be compiled and readied for survey use.

4.3.4 Final Questionnaire

The final questionnaire was a 21 page document. The actual questionnaire, in its entirety, can be found in *appendix A*. Questions directed at crane manufacturer's information transfer, the design procedure and a failure investigation were included. The following comments are applicable to the final questionnaire.

An attempt was made to make the document attractive and easy to read. Sufficient space was provided between answers to allow for notes to be made by the expert or by the researcher. An introduction was attached to the front of the questionnaire explaining exactly what the research project was about. The objectives of the study, the basic break down, any limitations and a clause explaining the importance of the expert's true opinion were included in the introduction.



BEST PRACTICE OF OVERHEAD
TRAVELLING CRANE SUPPORT
STRUCTURE DESIGN QUESTIONNAIRE

INCLUDES

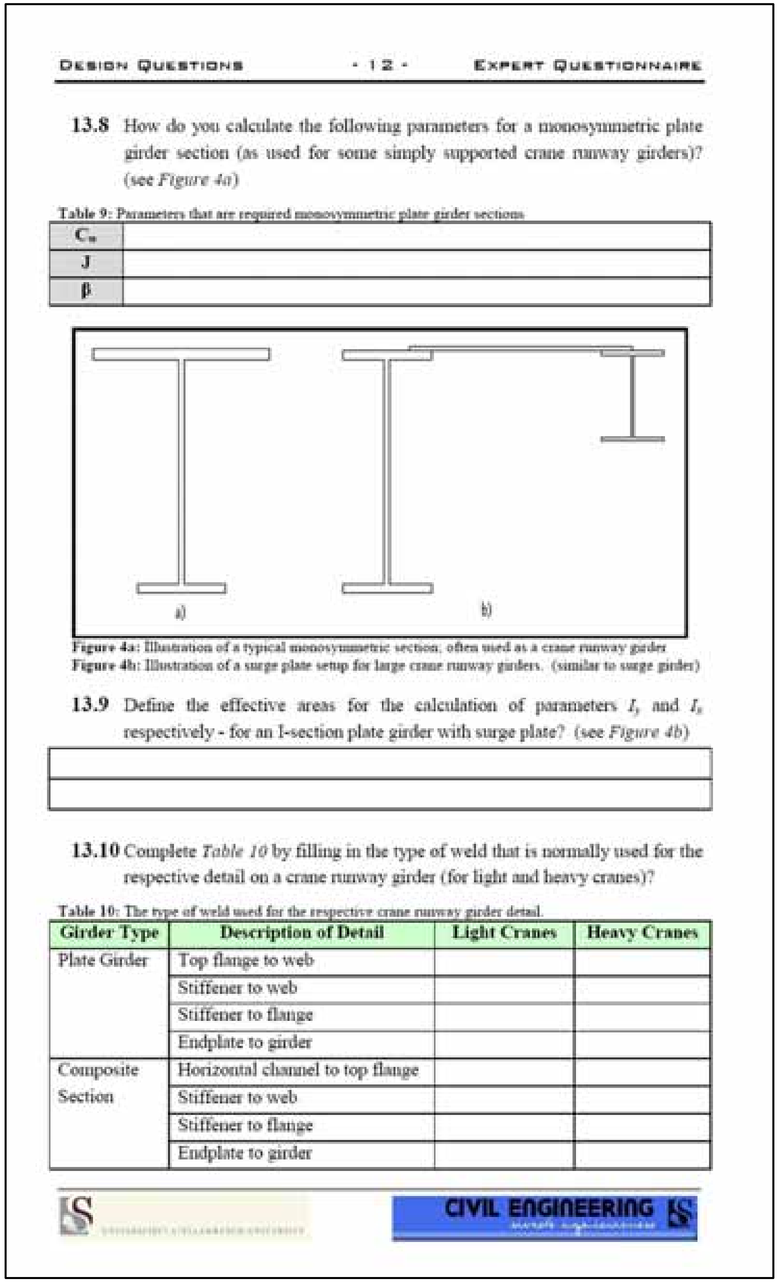
CRANE SUPPORT STRUCTURE FAILURE INVESTIGATION AND
A CRANE MANUFACTURERS' INFORMATION QUESTIONNAIRE

Prepared for: South African Structural Engineering Professionals
with Experience in Crane Support Structure Design

Prepared by: Geoffrey Thompson
Structural Engineering Division
University of Stellenbosch

Date: February 2007 – March 2007

Figure 4.8: Front page of the questionnaire.



DESIGN QUESTIONS - 12 - EXPERT QUESTIONNAIRE

13.8 How do you calculate the following parameters for a monosymmetric plate girder section (as used for some simply supported crane runway girders)? (see *Figure 4a*)

Table 9: Parameters that are required monosymmetric plate girder sections

C_w	
J	
β	

Figure 4a: Illustration of a typical monosymmetric section; often used as a crane runway girder
Figure 4b: Illustration of a surge plate setup for large crane runway girders. (similar to surge girder)

13.9 Define the effective areas for the calculation of parameters I_y and I_z respectively - for an I-section plate girder with surge plate? (see *Figure 4b*)

13.10 Complete *Table 10* by filling in the type of weld that is normally used for the respective detail on a crane runway girder (for light and heavy cranes)?

Table 10: The type of weld used for the respective crane runway girder detail.

Girder Type	Description of Detail	Light Cranes	Heavy Cranes
Plate Girder	Top flange to web		
	Stiffener to web		
	Stiffener to flange		
	Endplate to girder		
Composite Section	Horizontal channel to top flange		
	Stiffener to web		
	Stiffener to flange		
	Endplate to girder		

Figure 4.9: The use of tables and graphics in the questionnaire aid the experts' responses.

Graphics were used to ease the expert's interpretation of complicated questions. Tables were included to make answering certain questions more user-friendly. An added benefit is the straightforward post interview analysis associated with tables. Tabulated responses are generally already in a format that can be combined rather than in prose.

The bulk of the questionnaire was focused on the formal question and answer format. A section on sketched structural details was included towards the back of the questionnaire. Sketches would in this case not be required at random in the document. The details are followed by the failure investigation which is less structured. This portion of the investigation is meant to take on a more informal conversational format.

The principal aim of the failure investigation is to obtain as much information concerning crane and crane support structure failures in South Africa as possible. The intention is to document the failures. It is furthermore intended that the failure mechanisms established during the investigation will provide data which can be used to improve future structure designs. The aim is additionally to find issues and details to avoid during inspection of the failure mechanisms.

4.4 Expert Survey

The development of the questionnaire has been described. The seeded questions have been selected and readied for use. The next stage in the research was the elicitation process. As previously mentioned, this can be compared to performing an experiment. It is therefore vitally important to execute the planned process correctly or the researches results may be negatively influenced.

4.4.1 Expert Selection

The questionnaire has three separate focus subjects. These are crane manufacturer's information, crane support structure design and a failure investigation. Three separate groups were targeted as possible experts. Each group expected to supply information from their frame of reference. The relevance of the questionnaire to each group is described in *table 4.2*.

The selection of crane manufactures was simplified by the fact that there are four main crane manufacturers in the country. Demag, Condra, Verlinde and Morris were therefore contacted. Verlinde were found to outsource their crane designs to Demag, lodging a visit unnecessary.

Table 4-2: The choice of experts and the number of expert interviews targeted.

Expert Group	Comments	Expected Type of Experience	Targeted Number
Crane Support Structure Designers (Structural Engineers)	As the design of the support structure is the main focus of the study, these experts are the most important. All three parts of the questionnaire are to be asked as the designers knowledge should pertain to all topics.	At least: Practical; Reflective Possibly: Philosophy of Design	20 Experts
Crane Manufacturers	These experts will primarily focus on the crane manufacturers information (transfer) and on the failure investigation. The design process will also be investigated, but it is expected that the information attained will not be as critical.	At least: Practical	4 Experts
Crane Users (Industry)	The crane users can not be included in the expert survey. There knowledge would only be valid for maintenance and actual crane use. Unfortunately, due to the need for rationally defendable results the crane users will not be interviewed. It is understood that the information so attained may not be accurate. Certain confidentiality issues may also limit the investigation.	At Least: Practical	0 Experts

A list of designers was more difficult to assemble. Two avenues were used to begin the selection. Firstly, the project supervisor, Prof. Dunaiski, was asked to list a few experts with a sound knowledge of crane support structures design. Secondly the larger engineering companies were also contacted in order to find out who completes their crane support structure designs. The experts found were then asked for the names of other designers they recommend are included in the investigation. Each subsequent expert contacted was again asked for his own recommendations. Resulting from this was the list of designers in *table 4.3*. Note that only those experts that were consulted are included in the table and the targeted number of experts (from *table 4.2*) was nearly met.

A positive result from this process of expert selection was the repetition of recommendations. Confidence in any expert immediately improves when his / her name is mentioned by several other experts. The experts finally consulted all received some recommendations, instilling confidence in the experts.

As may be noticed, Hein Barnard from Morris Cranes is included in the designers list. The reason is that the majority of his experience is in steel structure design. It can also be noted that four of the experts were not seen individually. David Haines and Greg Francis formed one pair and Albert Hafkamp and Matthew Wolstenholme a second pair. When the responses are combined to obtain results, the two pairs will be considered as two individual experts and not four individual experts.

Table 4-3: Experts who took part in the survey.

Crane Support Structure Designers (Structural Engineers)				
No	**Name**	**Years Experience**	**Qualifications**	**Company**
1	Hein Barnard	12	Pr Eng	Morris Cranes
2	Gerrit Bastiaanse	14	Pr Eng	BKS (Pty) Ltd
3	Jim Collins	35	Pr Tech	Walker Ahier Holtzhausen Engineers
4	Alan Davies	26	Pr Eng	Bergstan South Africa
5	Nick Dekker	32	Pr Eng	University of Pretoria Dekker & Gelderblom Consulting Engineers
6	Greg Francis	25	Pr Eng	Holley & Associates
7	Albert Hafkamp	41	NTC V Detail Draughtsman	DSE Structural Engineers & Contractors
8	David Haines	20	Pr Eng	Holley & Associates
9	Bob Harrison	33	Pr Eng	Hatch Africa (Pty) Ltd
10	Wahl Hugo	20	Pr Eng	Africon
11	Will James	45	Pr Eng	LSL Consulting Tekpro
12	Jeff Jane	42	Pr Tech	Retired
13	Tomme Katranas	17	Pr Eng	Africon
14	Geoffrey Krige	34	Pr Eng	Anglo Technical
15	Roy Mackenzie	45	Pr Eng	Mackenzie Macky & Associates cc Consulting Structural Engineers
16	Ferdie Pienaar	30	Pr Eng	Hatch Africa (Pty) Ltd
17	David Scott	42	Pr Tech	Scott Steel
18	Richard Shedlock	20	Pr Eng	R M Shedlock & Associates cc
19	Alwyn Truter	10	Pr Eng	BKS (Pty) Ltd
20	Willem van Schalkwyk	30	Pr Eng	Retired
21	Matthew Wolstenholme	6	Pr Eng	DSE Structural Engineers & Contractors
Crane Manufacturers				
No	**Name**	**Years Experience**	**Qualifications**	**Company**
1	Wynand Andeweg	8	Pr Eng (Mech)	Demag Cranes and Components
2	Marc Kleiner	20	Pr Eng (Mech)	Condra Cranes

It is very important that the experts were selected scrupulously in order to obtain the best results possible. As mentioned the choice of experts made above was in many cases supported by the number of times the experts were referred to by their colleagues. Another important fact concerning the experts was years of experience in the structural field. Looking at the designers alone this totalled 579 years of experience at an average of approximately 27.5 years per expert. These statistics positively support the choice of experts made.

4.4.2 Interview Organisation and Preparation

Each expert was first contacted via telephone. Willingness to take part in the investigation was established. The complying experts were asked for their contact details and invited to recommend any engineering professionals they feel could be included in the study.

The majority of crane support structures, especially higher class crane support structures, are primarily involved in heavy industry and possibly mining. This being said, and realising that large scale industry in South Africa is predominantly found in the Gauteng area, meant that it was not surprising to find that the majority of the experts were based in Johannesburg. It was also understood that for proper application of the questionnaire, the researcher would need to be present during the interview. For this reason two trips to Johannesburg were planned by the researcher. A few experts in Cape Town were also consulted. In some cases the experts were so willing to assist that they accepted meeting on a Sunday.

After the travel dates had been determined an e-mail was sent out with final details. In this way the schedule as shown in *figure 4.10* was compiled. Important information transferred for the interviews is listed below.

i) A meeting time that fitted within the time of travel.
ii) An introduction to the method and aims of the study were explained.
iii) Names of any recommended experts.
iv) Years of experience in the field of structural engineering.
v) Expert's qualifications.
vi) Opportunity was also afforded for any queries the experts had concerning the process.
vii) The questionnaire was attached for the experts to view and possible preparation could be carried out. It was not expected of the experts to prepare in too much detail.

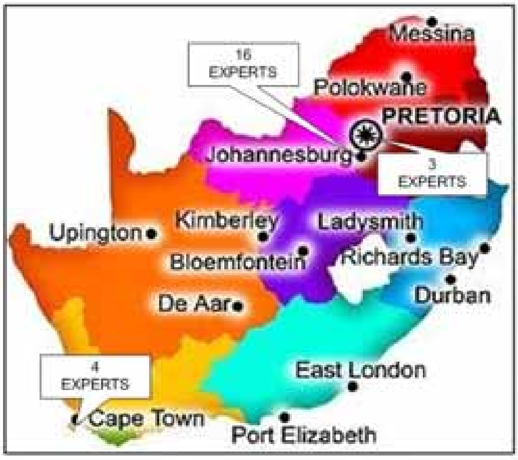
	01-Apr Sunday	02-Apr Monday	03-Apr Tuesday	04-Apr Wednesday	05-Apr Thursday	06-Apr Friday
07:00				Kleiner		
08:00				Kleiner		
09:00			Andeweg			
10:00			Andeweg	Barnard		
11:00				Barnard		
12:00						
13:00						
14:00			Collins	Van Schalkwyk		
15:00			Collins	Van Schalkwyk		
16:00		Jane				
17:00		Jane				

The first set of interviews were completed early in March in Johannesburg. Three trips to Pretoria had to be made.

The second set of interviews were conducted early in April, also in Johannesburg.

The remaining four experts reside in Cape Town and were seen on three separate dates.

All interviews were conducted at the experts offices. This was done to limit the time impact on the experts.



Mr. Davies
19th March @ 09:30

Mr. Hugo
23rd April @ 08:00

Mr. Bastiaanse
23rd April @ 14:00

Mr. Scott
3rd May @ 14:00

	04-Mar Sunday	05-Mar Monday	06-Mar Tuesday	07-Mar Wednesday	08-Mar Thursday	09-Mar Friday
07:00						
08:00				Hafkamp		
09:00		Shedlock	*Mackenzie*	Wolstenholme		James
10:00	Mackenzie	Shedlock	*Mackenzie*			James
11:00	Mackenzie					
12:00		Pienaar				
13:00		Pienaar				
14:00	Harrison		Dekker	Francis		Truter
15:00	Harrison		Dekker	Haines	Katranas	Truter
16:00		Krige			Katranas	
17:00		Krige				

Figure 4.10: Dates and times of interviews with the respective experts.

4.4.3 Interview Proficiency

As preparation by the researcher, literature was consulted to assist in developing interviewer skills. Awareness of biases as described in earlier chapters was also developed. The most important lessons learnt are:

i) Leading the interviewee (expert) – the researcher must ensure that the experts are interviewed neutrally. Good consistent interview techniques should be used.

ii) Listening and notation – paying attention in the interview should take preference over recording the responses. A means of recording the responses was required in order to free the researcher's attention. A digital voice recorder was utilised.

iii) Speed and flow –an attempt to keep the interviews flowing and to a time acceptable to the experts must be made. It is important that the interviewer subtly dictates an appropriate rate. The researcher should additionally implore the experts to keep their answers brief. Moreover the brevity will aid post interview analysis.

iv) Interview skills - good interview skills must be practiced, these include a confident / comfortable attitude, tone and speech tempo. Certain literary guides also mention that sudden movements to make a note or reactive facial expressions can sway an expert from relating their true opinion.

As was stated earlier, the interview process simulates an experiment conducted in ordinary laboratory research. In this case each interview session was unique and could in no way be conducted a second time in case of mistakes. Efficient administration of the interviews was therefore highly important to the studies outcomes.

4.4.4 Elicitation Notes

The interviews were completed with very little incident. The length of the interviews varied from 4½ hours to 45 minutes. The duration of any given interview decreased rapidly if the expert was prepared. In these cases the answers were generally more specific.

In the questionnaire, any assumptions that are made should be clearly spelt out. Sketches should be clearly marked and simply drawn. Experts should be encouraged to give their honest opinion, but at the same time the responses should be focused on the correct topics. As each individual has a different personality, managing the interview is a dynamic task.

Having a researcher present during the survey process is recommended by many survey guides. This recommendation is founded as the lack of a researcher could have resulted in a completely different interpretation of particular questions – influencing the research outcomes.

The order of questions was not discussed in the literature studied prior to completion of the questionnaire. It became clear that in fact the order of the questions is very important. Topics that require the most attention should be moved to the beginning. Any questions that can be answered quickly and to the point can be left to the end. In this way the important questions are covered when the attention of the interviewee is at its highest. Over time as an expert's focus shifts back to their professional work, the speed of the interview would then appear to increase. The experts experience this positively because the tempo appears brisk in order to complete the questionnaire.

4.4.5 Post Interview Duties

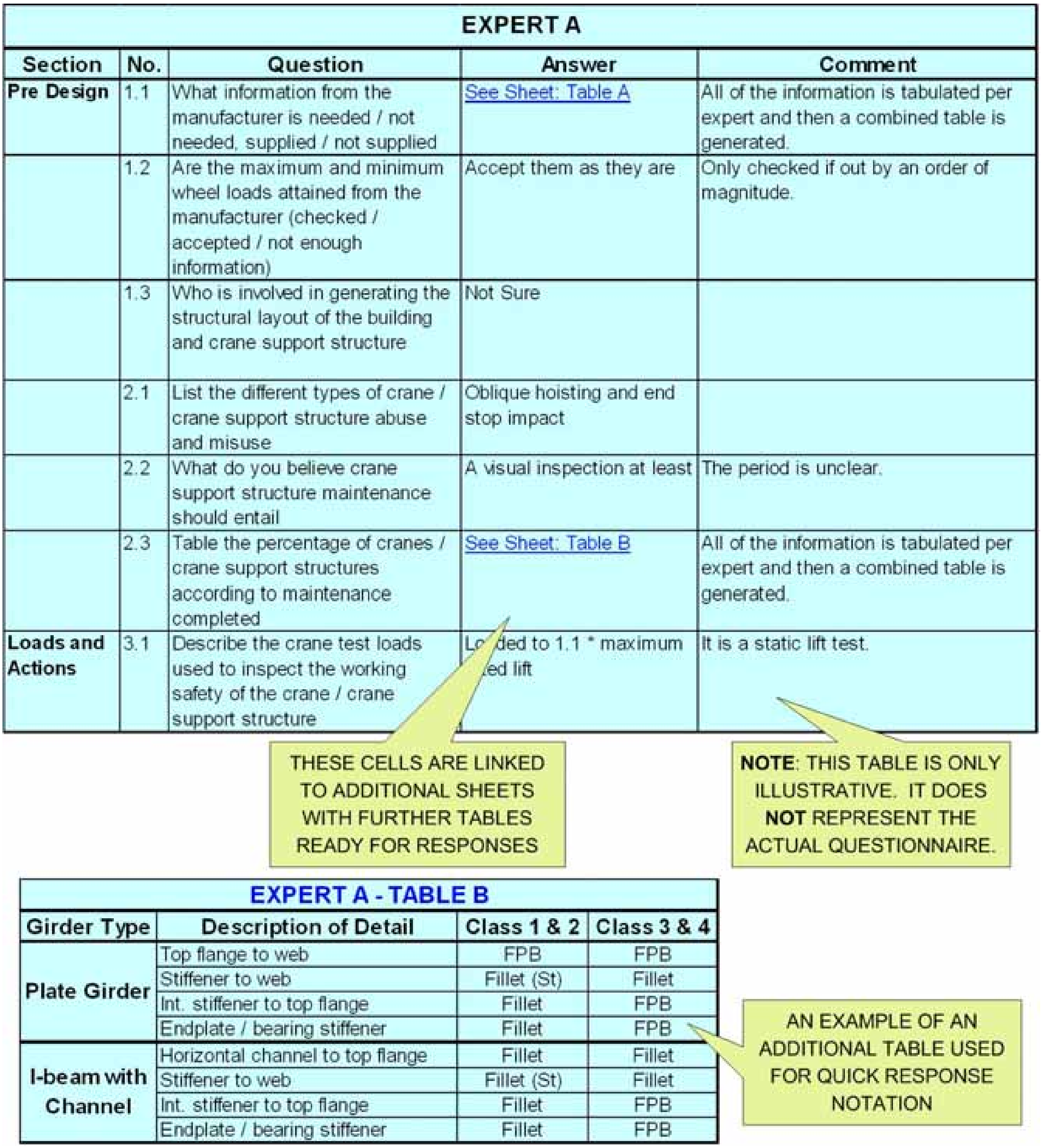
At the completion of an interview it is important to ensure that all information required has been acquired. The planned research progression was also conveyed to the experts. A letter of thanks was later sent out to all the experts. The thank you letter also serves to keep contact with the experts in the event of further communication being required or wanted - remembering always that without the experts this research could not have taken place.

4.5 Post Interview Analysis and Results Preparation

The interviews totalled approximately 50 hours of recordings. In order to obtain good accurate results from the survey, all the interview data needed to be analysed accurately. The analysis is described in this segment. The method of results portrayal as in this thesis is also described. The actual results are however found in *chapter 5* and *appendix B.*

4.5.1 Data Analysis

Each minute of digital recording was reviewed and analysed. The opinions (responses) of the experts were noted down. To ease this process an Excel spreadsheet was setup with all of the questions. Space for the responses and comments was also provided. The setup is described further in the diagram attached.



EXPERT A				
Section	**No.**	**Question**	**Answer**	**Comment**
Pre Design	1.1	What information from the manufacturer is needed / not needed, supplied / not supplied	See Sheet: Table A	All of the information is tabulated per expert and then a combined table is generated.
	1.2	Are the maximum and minimum wheel loads attained from the manufacturer (checked / accepted / not enough information)	Accept them as they are	Only checked if out by an order of magnitude.
	1.3	Who is involved in generating the structural layout of the building and crane support structure	Not Sure	
	2.1	List the different types of crane / crane support structure abuse and misuse	Oblique hoisting and end stop impact	
	2.2	What do you believe crane support structure maintenance should entail	A visual inspection at least	The period is unclear.
	2.3	Table the percentage of cranes / crane support structures according to maintenance completed	See Sheet: Table B	All of the information is tabulated per expert and then a combined table is generated.
Loads and Actions	3.1	Describe the crane test loads used to inspect the working safety of the crane / crane support structure	Lo ded to 1.1 * maximum ed lift	It is a static lift test.

THESE CELLS ARE LINKED TO ADDITIONAL SHEETS WITH FURTHER TABLES READY FOR RESPONSES

NOTE: THIS TABLE IS ONLY ILLUSTRATIVE. IT DOES **NOT** REPRESENT THE ACTUAL QUESTIONNAIRE.

EXPERT A - TABLE B			
Girder Type	**Description of Detail**	**Class 1 & 2**	**Class 3 & 4**
Plate Girder	Top flange to web	FPB	FPB
	Stiffener to web	Fillet (St)	Fillet
	Int. stiffener to top flange	Fillet	FPB
	Endplate / bearing stiffener	Fillet	FPB
I-beam with Channel	Horizontal channel to top flange	Fillet	Fillet
	Stiffener to web	Fillet (St)	Fillet
	Int. stiffener to top flange	Fillet	FPB
	Endplate / bearing stiffener	Fillet	FPB

AN EXAMPLE OF AN ADDITIONAL TABLE USED FOR QUICK RESPONSE NOTATION

Figure 4.11: The use of spreadsheets maximised the speed with which the recorded data could be notated and analysed.

The process of logging all the data from the interview recordings was a long process. Each expert recording taking between two and three times the length of the interview to notate. It was very important to accurately record all of the opinions and loose no information relevant to the study – be it correct or erroneous. The careful approach of the analyst and the methodical layout of the Excel spreadsheets assisted accurate notation of the interview recordings.

4.5.2 Codification of Responses

Expert surveys such as this are primarily focused on combining opinion in order to obtain a single result or a set of results. The individual responses on their own are not very valuable to anyone conducting research. Most of the answers in this survey were unique. Many responses from different experts were similar, but not in a format that promoted combination. This meant that the unique data already notated would have to be adjusted and categorised into a few standard answers. According to literature this process is known as coding.

The coding process followed in analysis, handled the questions one at a time. The answers from all the experts are considered together. Then the following procedure was followed:

i) Expert A is assigned answer 1 (it is simplified to a standard format without losing any important information)
ii) Expert B's response is examined and either assigned to answer 1 or deemed to be an answer on its own – answer 2.
iii) Expert C's response is examined and either assigned to answer 1 or 2 (if this exists) or deemed to be an answer on its own – answer 3 (possibly 2).
iv) Repeat until all the expert responses have been codified.

Generally all the responses would fall into between one and four categories. These categories are coded answers that are ready for combination using proper scoring rules.

4.5.3 Expert Scoring and Utility Values

As has been previously introduced there are several scoring techniques, several of which are described as proper scoring rules. Simply put, each expert is assigned a rating. The rating is relative to the degree of correctness associated with the expert. This can also be seen as the calibration of the expert. The expert rating is calculated using the seed variables. The seed questions are answered by the experts. The expert answers are then compared with the calculated answers and a score assigned to the expert per question. For each expert, the seed question scores are then combined using utility theory. This new combined weight is the experts rating. Normally all the expert ratings are normalised.

Other methods of obtaining expert ratings include assigning equal ratings to all experts, ranking the experts, the “best” expert only technique and expert self rating. Unfortunately these methods were found to be unsuitable for various reasons. Instead the seed questions, experience related ranking and a form of peer ranking were found to be more appropriate. A full description of the method is supplied in *figure 4.12* of the next section. The choice of scoring methods is clarified in *table 4.4*.

Table 4-4: The choice of a scoring method and the assigning of utility values.

SCORING RULES / METHODOLOGY AND UTILITY VALUES					
Scoring Method	**Description**	**Comment on Possible Application**	**Valid**	**Explanation of Utility**	**Utility Value**
Seeded Variables	Experts are scored using responses to selected questions.	Very useful. Possibly the most scientifically based scoring rule. Difficulty in designing good questions, but scoring procedure is very effective to help calibrate the experts and survey.	✓	The importance of this scoring rule, means a high utility should be assigned. Four Questions were found to be useful. The utility assigned here will be split between these questions.	0.5
Expert Self Rating	The experts are asked to rate their own opinion.	Easily influenced by heurisitics and biases. Literature does not recommend its use.	✗	Not applicable to this study.	0
"Best" Expert Only	Not truly a scoring method. Once experts are ranked, the highest ranked expert's opinion is used.	Ranking must be done using another scoring rule. As only one experts opinion is taken, much information is lost. Using weighted averages is definitely much more reliable.	✗	Not applicable to this study.	0
Researcher Rating	The researcher rates or ranks the experts.	Easily influenced by heurisitics and biases. Literature does not recommend its use.	✗	Not applicable to this study.	0
Expert Peer Rating	The experts are asked to rate their peers.	Difficult to directly apply as all experts are not known at the time of elicitation. A variation can be used whereby experts are asked to recommend other designers they regard as good experts in the field. A largely unbiased useful scoring rule.	✓	Due to the possible influence of "cliques" on this scoring method (groups of experts that know one another through previous work or jobs), too great a value should not be applied. After all the expert opinion, not the expert interaction, is being rated.	0.2
Experience Rating	A rating is assigned according to the years of experience in the field of interest.	A good indication of the knowledge base an expert may have. Not too influenced by biases, although experience does not necessarily equate to knowledge.	✓	Too high an influence should be avoided. (experience does not equate to knowledge) Approximately half as important as the seeded variables and equal to the expert rating.	0.2
Equal Ratings to All Experts	Expert opinion is combined equally. (a weight of 1 for each expert)	The most basic method for combination. Does not take account of any differences in experts expertise. Results are not rationally defendable.	✗	Not applicable to this study.	0
Average Scoring	A fixed percentage is added to each individuals score.	Not truly a scoring method. This is rather an averaging value to limit the overall scores of experts. Reduces the variance in the expert ratings by ascribing a fixed "starting score".	✓	A 10% average is applied. Its influence is not large but can take account of some errors due to incorrect interpretation of seeded variables and other ratings.	0.1

Table 4-5: Further division of the utility value assigned to the seed question and the seed questions answers.

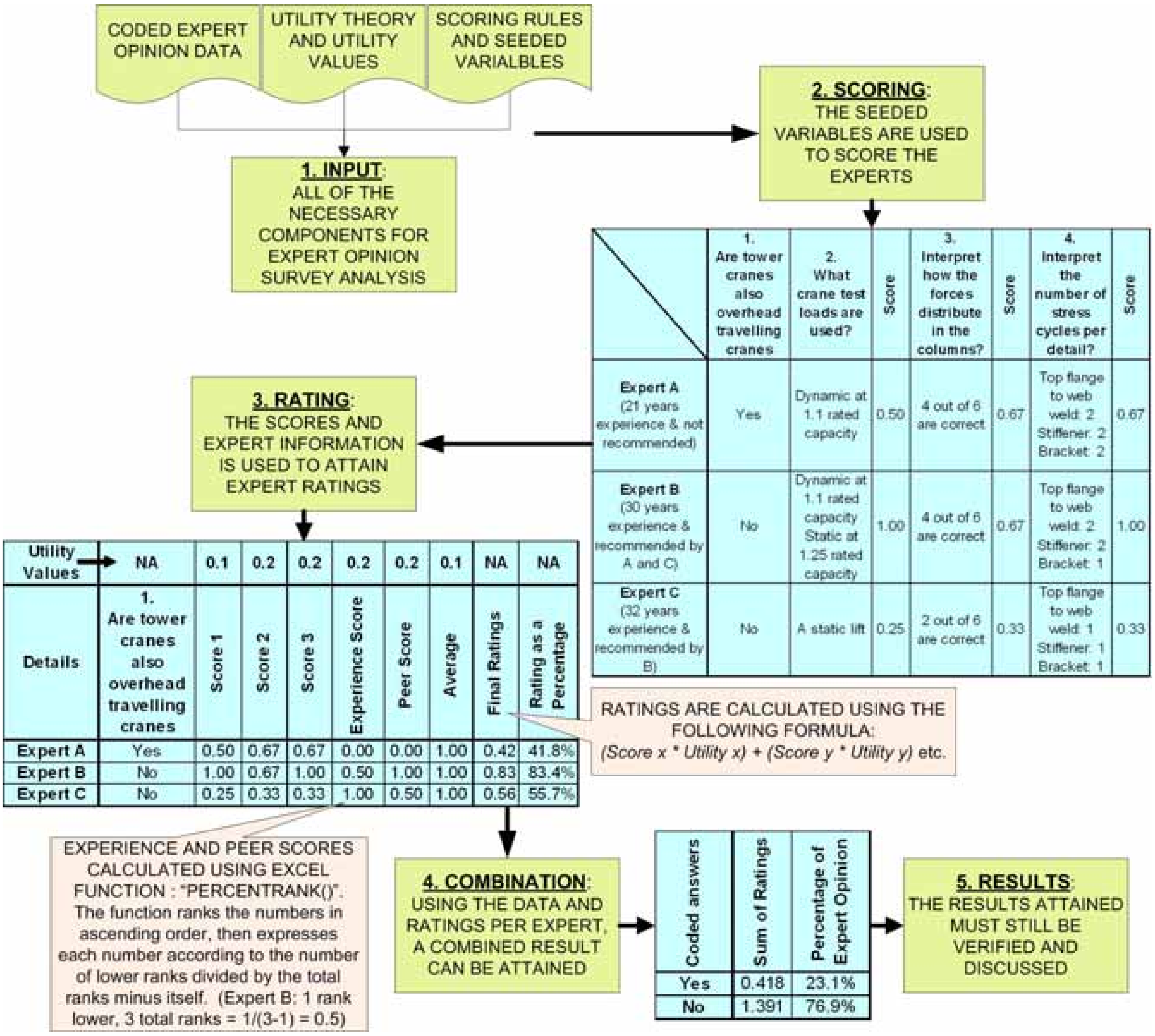
UTILITY VALUES ASSIGNED TO THE SEEDED QUESTIONS				
Question Reference	**Seeded Question**	**Explanation of Utility**	**Scores**	**Utility Value**
Appendix B: Expert Survey Questionnaire. Loads and Actions - 4. Post Construction Test Loads: Question 4.1	Describe the crane test loads used to inspect the working safety of the crane and crane support structure?	The responses to this question were fairly random. Experts with more experience and knowledge of cranes are thought to have a better understanding of the crane support structure. Therefore, although the questions answer is focused on cranes, it is included.	Knowledge of: Dynamic test- **0.25** Static test - **0.25** Dynamic lift at [1.1 * rated capacity] - **0.25** Static lift at [1.25 * rated capacity] - **0.25**	0.1
Appendix B: Expert Survey Questionnaire. Loads and Actions - 7. Load Cases: Question 7.2	For the purpose of a "second order analysis", how is the horizontal notional load calculated and where is it applied to the structure?	The question was unsuccesful. The SANS 10162-1:2005 code specifies that 2nd order effects should be taken into account and that the notional load should be included in all load combinations. Most experts use a linear analysis method and do not account for notional effects on crane runway gantry support structures. Therefore most experts avoided the question.	Not Applicable	0
Appendix B: Expert Survey Questionnaire. Design - 13. Crane Girder: Question 13.8	How do you calculate the following parameters for a mono-symmetric plate girder section (as used for some simply supported crane runway girders)? C_w ? J ? β_x?	The question was unsuccesful. From the trial interviews and literature it was thought that the mono-symmetric section is widely used. This was found not to be the case. It would be bad judgement to rate experts on something they have not been involved in before.	Not Applicable	0
Appendix B: Expert Survey Questionnaire. Design - 18. Crane Column: Question 18.3	Explain what effect the crane load applied to the crane girder has on the force distribution along the two columns? Comment on each scenario as the connections fixity (restraint) is adjusted?	This was a useful question. It demanded some insight into the structure and its performance under loading. Experts often make use of computer software, but a deeper understanding of the structure is demanded from an expert. Therefore this is a good evaluation of expertise.	Six different scenarios are investigated. Each scenario is assigned a score of one sixth if correct. (The questionnaire should be consulted for further details)	0.2
Appendix B: Expert Survey Questionnaire. Fatigue - 22. Load Cycles: Question 22.1	For the example given please calculate the number of stress cycles the top flange to web weld [1], the stiffener toe [2] and the corbel to column connection [3] will be subjected to?	This was a useful question. It demanded some insight into the structure and its performance under repetitive loading. Fatigue is an issue in crane support structure design and the question again focused on interpretation of the subject. Therefore this is a good evaluation of expertise.	Three different scenarios are investigated. Each scenario is assigned a score of one third if correct.	0.2

4.5.4 Combination of Expert Opinion

Once the different scoring concepts had been selected, utility values assigned and the expert ratings calculated - combination of the expert data could be made. Similarly to the calculation of the expert ratings, utility theory is used to combine the expert opinion. The utility value of each expert's response is equated to the expert rating. The use of Excel spreadsheets was again found to be very useful in this combination process.

Figure 4.12 depicts the calculations and steps used to obtain the ratings of each expert and subsequently combine all the expert opinion into useful results. A brief explanation of the figure is provided.

Step one involves attaining the necessary input data in the correct format. Step two scores the experts according to the responses to the seed questions, their referrals and their experience. Step three uses all of the scores per expert to calculate a rating per expert. This is calculated using the utility values assigned to the respective scores. The final combination during step four again involves utility theory using the expert ratings as the utility values and the experts coded answers as the subjects being combined. Step five precedes the results of the next chapter.



	1. Are tower cranes also overhead travelling cranes	2. What crane test loads are used?	Score	3. Interpret how the forces distribute in the columns?	Score	4. Interpret the number of stress cycles per detail?	Score
Expert A (21 years experience & not recommended)	Yes	Dynamic at 1.1 rated capacity	0.50	4 out of 6 are correct	0.67	Top flange to web weld: 2 Stiffener: 2 Bracket: 2	0.67
Expert B (30 years experience & recommended by A and C)	No	Dynamic at 1.1 rated capacity Static at 1.25 rated capacity	1.00	4 out of 6 are correct	0.67	Top flange to web weld: 2 Stiffener: 2 Bracket: 1	1.00
Expert C (32 years experience & recommended by B)	No	A static lift	0.25	2 out of 6 are correct	0.33	Top flange to web weld: 1 Stiffener: 1 Bracket: 1	0.33

Utility Values →	NA	0.1	0.2	0.2	0.2	0.2	0.1	NA	NA
Details	**1. Are tower cranes also overhead travelling cranes**	**Score 1**	**Score 2**	**Score 3**	**Experience Score**	**Peer Score**	**Average**	**Final Ratings**	**Rating as a Percentage**
Expert A	Yes	0.50	0.67	0.67	0.00	0.00	1.00	0.42	41.8%
Expert B	No	1.00	0.67	1.00	0.50	1.00	1.00	0.83	83.4%
Expert C	No	0.25	0.33	0.33	1.00	0.50	1.00	0.56	55.7%

RATINGS ARE CALCULATED USING THE FOLLOWING FORMULA:
*(Score x * Utility x) + (Score y * Utility y)* etc.

EXPERIENCE AND PEER SCORES CALCULATED USING EXCEL FUNCTION : "PERCENTRANK()". The function ranks the numbers in ascending order, then expresses each number according to the number of lower ranks divided by the total ranks minus itself. (Expert B: 1 rank lower, 3 total ranks = 1/(3-1) = 0.5)

Coded answers	Sum of Ratings	Percentage of Expert Opinion
Yes	0.418	23.1%
No	1.391	76.9%

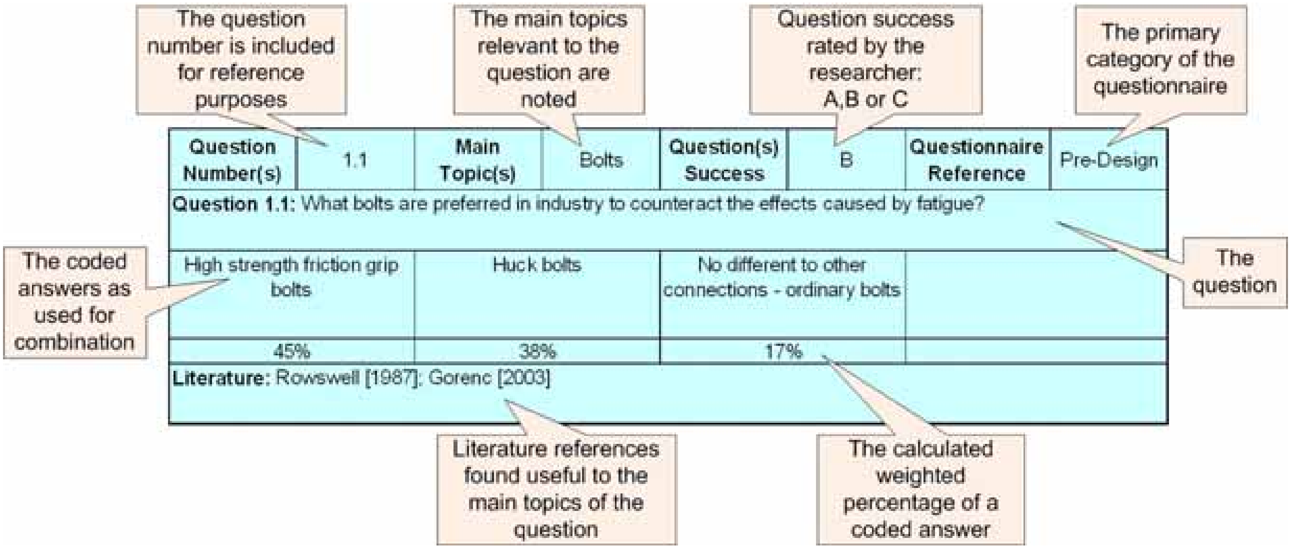
Figure 4.12: The entire scoring, rating and combining procedure as followed in this research.

4.5.5 Results and Verification

The objective of the thesis is to do research to facilitate the compilation of a potential crane support structures design guide. As a result of this, the findings of the expert survey should be structured in a manner which is easy to reference and utilise. Brevity of discussions stemming from the results is also essential as there are such vast amounts of information discussed and covered under this topic. With this in mind the following approach was selected.

4.5.5.1. Tabulated Results for Easy Reference

A table containing the question together with the coded responses is drawn up. Several other useful references are included and described in *figure 4.13*. The percentages of each coded response, as calculated using the expert ratings, are incorporated in the table. Additionally, all references found to have information pertaining to the specific question's subject are inserted at the bottom of the table. The tables as described are provided for each question in *appendix B*.



Question Number(s)	1.1	**Main Topic(s)**	Bolts	**Question(s) Success**	B	**Questionnaire Reference**	Pre-Design
Question 1.1: What bolts are preferred in industry to counteract the effects caused by fatigue?							
High strength friction grip bolts		Huck bolts		No different to other connections - ordinary bolts			
45%		38%		17%			
Literature: Rowswell [1987]; Gorenc [2003]							

Figure 4.13: The table used to make referencing the results more easy. Note that this is just an example and has no influence on the outcome of the research.

4.5.5.2. Approach to the Results and Discussions

In the results and discussions only the results seen as very important are graphically presented. Furthermore the questions are occasionally grouped. Any groups formed consist of questions and responses focused on the same topic. This allows for a more concise formulation of the results and discussions.

It is understood that during codification, the finer details of individual expert opinion can be lost. To avoid this, note was made of additional response information obtained during the coding process. The relevant responses logged during this process are included in the results and discussions chapter.

4.5.5.3. *Structural Details and failure investigation Results*

Structural details are one of the most critical crane support structures design features. Therefore they are handled separately. Practically all examples supplied by the experts are illustrated. Literature comparisons are made and reflective comment given. The concepts observed to work and those that do not are also conveyed.

Failure investigation results were difficult to come by. Three possible reasons for this exist.

i) Experts (people in general) find it hard to point out their own mistakes.
ii) Confidentiality agreements may exist between designers and their clients.
iii) Designers are seldom closely involved in failure events and consequently have little information available other than the mechanism of failure.

The information gathered concerning failure mechanisms is nonetheless tabulated and included.

As far as verification of all the results is concerned, it can be stated that most results were found to be relevant. During the discussions, if differences were found between literature and expert opinion it is clearly stated. Final thoughts on the results are discussed in the form of unresolved issues and telling subjects brought to light by the experts.

CHAPTER 5:

RESULTS AND DISCUSSIONS

What remains to be defined in this thesis, are the results obtained from the research. A large amount of data had to be analysed and processed. As a result it would be difficult to include every last table or detail in the body of the thesis. For this reason the answers and resulting percentages of each question are placed in *appendix B* found at the back of the document. For reference purposes the questionnaire can be found in *appendix A*.

At this stage it is recommended that for the best use of the results, the *appendix B* tables be viewed together with this chapter. The tables provide additional clarity to the results. Furthermore the process as described at the end of the previous chapter will be followed.

5.1 General Elicitation Results

The elicitation process completed as part of the research resulted in the following observations:

i) Time, as expected, was a critical matter during elicitation.
ii) Experts should not be guided, but the answers must be kept relevant to the topic at hand.
iii) Interview skills must be applied to very different dynamic situations. Interview skills are however, gained quickly with experience and interview practice is helpful.
iv) The researcher being present during interviews, markedly influenced the goals of the survey being achieved.
v) Question order is very important. The more important topics should be placed early on in the interview. This was an issue that could not be corrected during the interviews.

The proficiency of the researcher improved and consequently the elicitation process and tempo improved. This being the case it was important not to change any of the questions to improve the results as this reduces the neutrality and fairness of the elicitation process. Even the questions that were known to be problematic were asked in the same manner each time. As a general remark the expert survey contact sessions were quite acceptable and ran smoothly. The methods and approaches used in this thesis were found to be acceptable for future use. The results obtained in this survey will also be shown to be useful and as such can promote the procedures adopted.

5.2 Expert Ratings

To ensure the anonymity of the experts specific details are excluded from this section and the ratings handled in a random group format. As part of the procedure certain results were already conveyed. These included the usefulness of the seeded variables. Notably only three of the five questions were answered in a manner which permitted expert opinion scoring. The questions that were implemented successfully were:

i) Question 4.1 asks for the crane test loads that are used to validate the working order of the crane.

ii) Question 18.1 attempts to understand the flow of forces in a latticed crane column.

iii) Question 22.1 aims to determine the number of stress cycles each of three crane support structure details undergoes for a four wheel crane load cycle. [top flange to web weld; stiffener toe and bracket connection]

The answers to the seed questions have previously been calculated and described together with possible reasons for success or failure of the respective questions. The graphs in *figures 5.1* to *5.3* shows the answers which were obtained for determination of the experts' seed question scores.

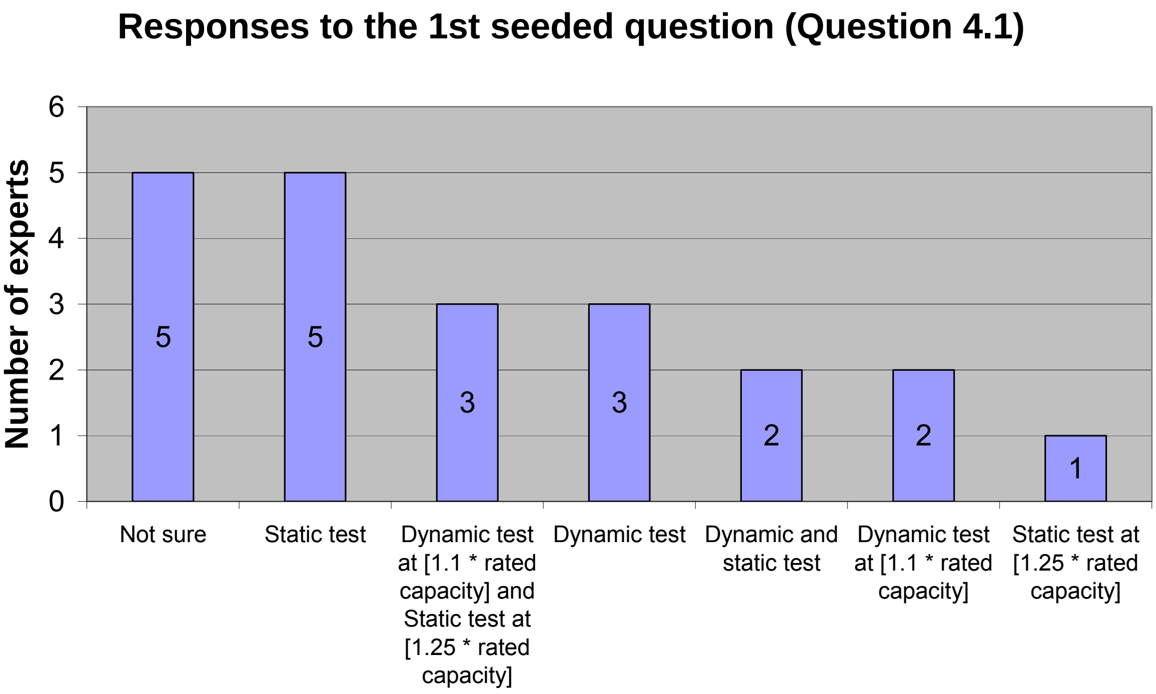
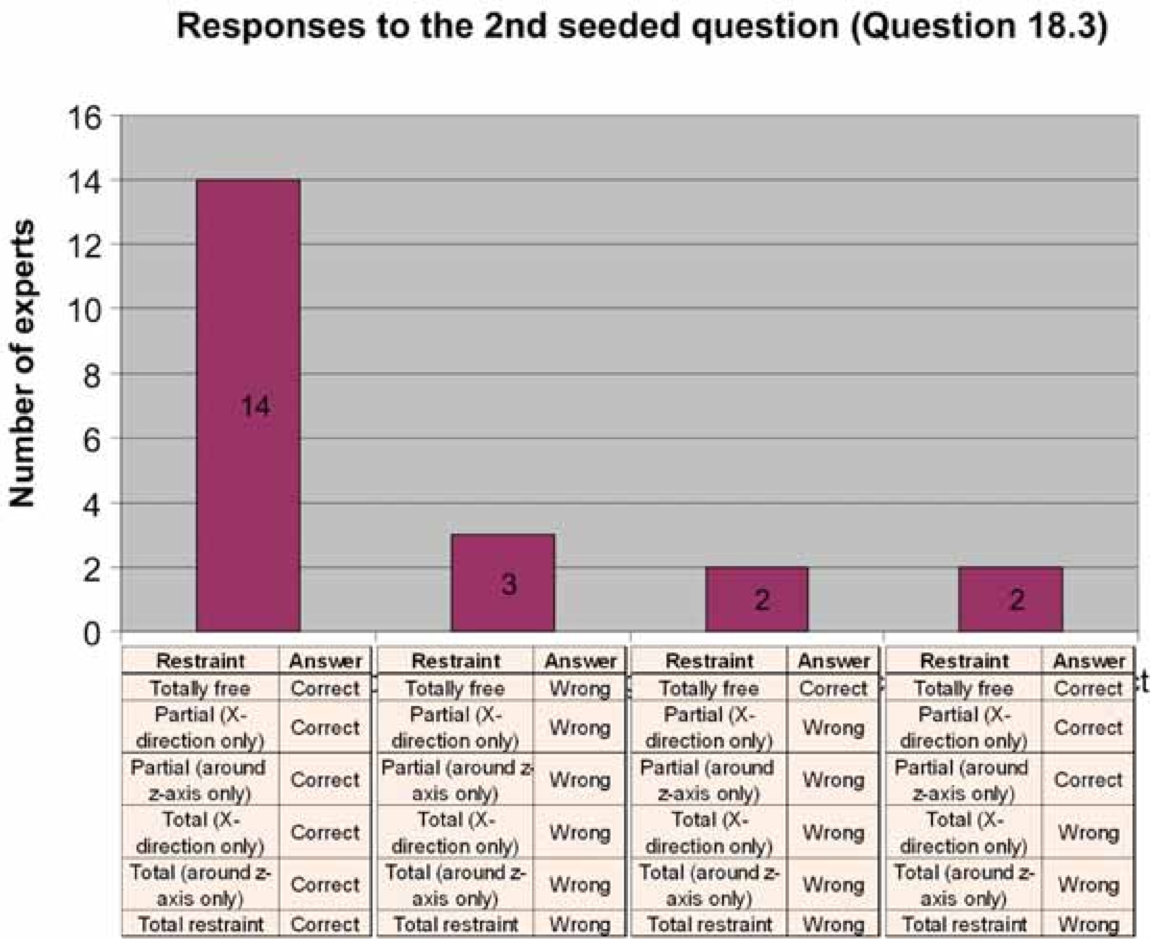


Figure 5.1: Question 4.1 is the first seed question and the results used for rating the experts are supplied.



Restraint	Answer	Restraint	Answer	Restraint	Answer	Restraint	Answer
Totally free	Correct	Totally free	Wrong	Totally free	Correct	Totally free	Correct
Partial (X-direction only)	Correct	Partial (X-direction only)	Wrong	Partial (X-direction only)	Wrong	Partial (X-direction only)	Correct
Partial (around z-axis only)	Correct	Partial (around z-axis only)	Wrong	Partial (around z-axis only)	Wrong	Partial (around z-axis only)	Correct
Total (X-direction only)	Correct	Total (X-direction only)	Wrong	Total (X-direction only)	Wrong	Total (X-direction only)	Wrong
Total (around z-axis only)	Correct	Total (around z-axis only)	Wrong	Total (around z-axis only)	Wrong	Total (around z-axis only)	Wrong
Total restraint	Correct	Total restraint	Wrong	Total restraint	Wrong	Total restraint	Wrong

Figure 5.2: Question 18.3 is the second seed question and the results used for rating the experts are supplied.

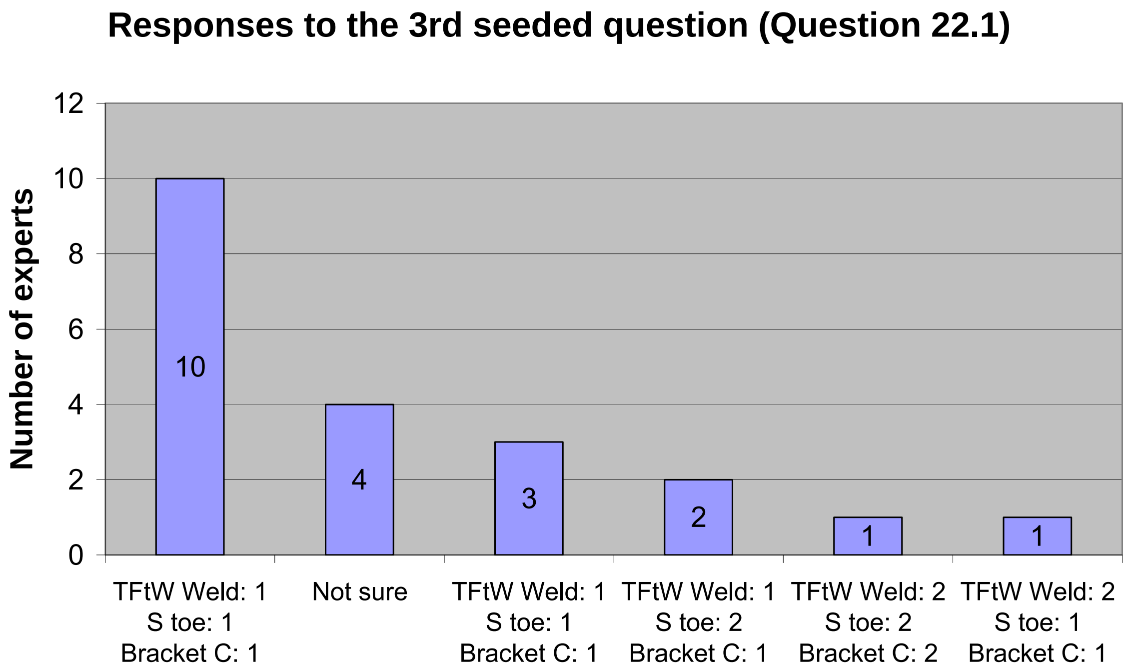


Figure 5.3: Question 22.1 is the third seed question and the results used for rating the experts are supplied.

The expert rating calculation employs the seed variable scores, the expert experience and the number of recommendations an expert received. The following rating spread was obtained using procedures previously described.

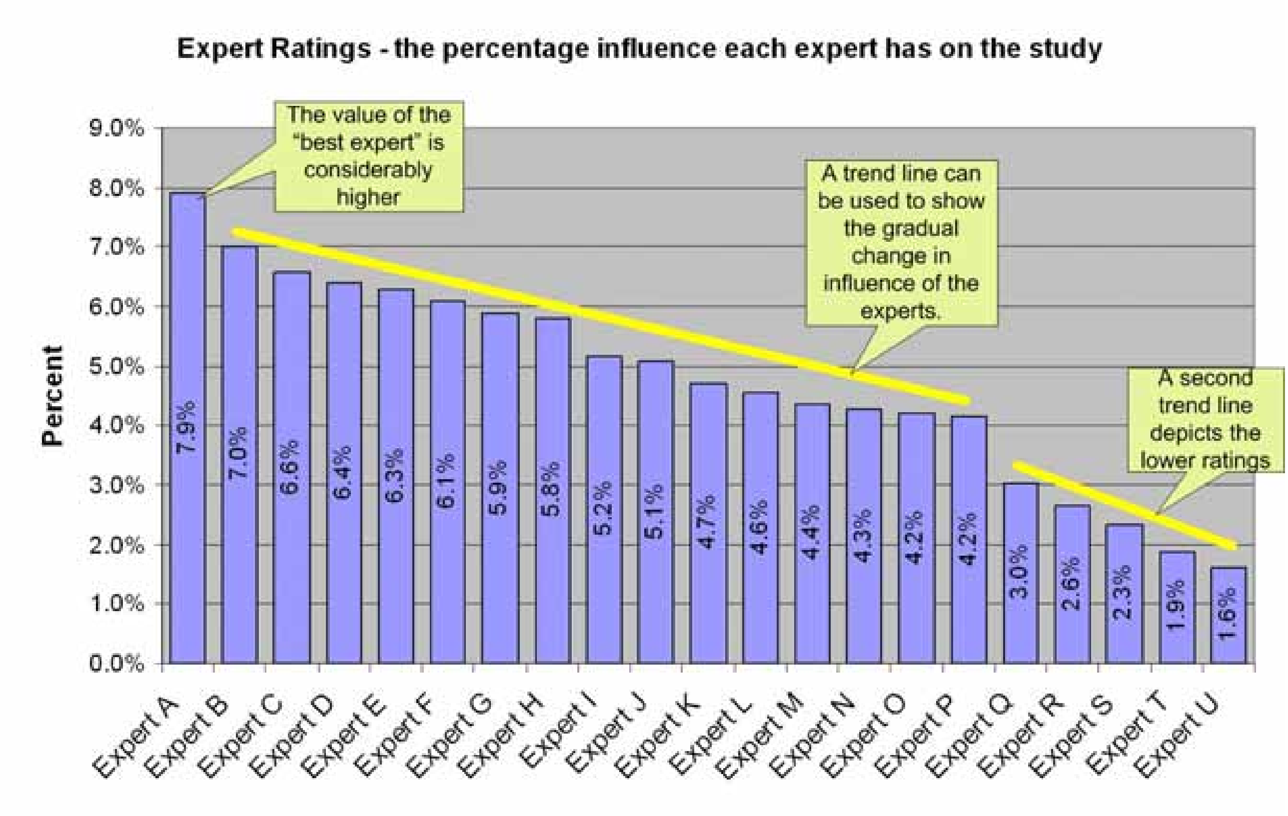


Figure 5.4: The spread of ratings according to their percentage influence on the study.

The graphic provides a good visual indication of the ratings. The spread is acceptable and one can see that the value of influence of any one expert does not differ too significantly from another. Statistically the mean and median values are also found to be very similar, 4.8% and 4.7% respectively.

There is a clear distinction between the experts that have a sound knowledge and good experience, compared with the experts that are either relative newcomers to the structural field or whose structural knowledge does not extend to crane support structures. The less knowledgeable (experienced) experts have values on the tapered lower end of the ratings. It is possible that the lower ratings occur due to differences in practical versus theoretical knowledge. The seed questions in this case were slightly more theoretical.

According to Cooke's (1991) "classical method" the lower scoring experts can be removed from the combined result. For the purpose of this qualitative study, which faces challenges in basic assessment of the experts, all of the expert's responses are included.

It is intended that the experts with greater know how of crane support structures influence the final results more. This has been successfully achieved and the ratings are understood to be as accurate a representation of the varying level of expertise as could be obtained. Consequently it remains appropriate to use all of the ratings to combine the expert opinion in order to obtain rationally defendable results.

5.3 Formal Questionnaire Results

The results pertaining directly to the questionnaire will now be discussed.

5.3.1 Crane Manufacturer's Information and Pre-design Specifications

Issues concerning the information transferred from the crane manufacturers to the structural designers and the reliability of this information are investigated in this section. Possible crane expansions and upgrades also form part of this section.

5.3.1.1. Information Transfer

The very first question concerned the transfer of crane data from the crane manufacturer to the support structure designer. This was previously described as a vital subject to the entire design. As a simple example the travel and hoist speeds are investigated. These parameters are increasing with technological advances and as a result the burden placed on the support structure also increases. (These parameters are required by certain international codes and in the proposed SANS 10160 loading code) In order for the structural designer to make provision for this and other similar issues, crane details must be forwarded in a timely manner.

As the information transferred is imperative to the rest of the design and in essence all other survey questions asked, the full set of combined results is presented. As a general comment, several experts stated that hardly any information is readily supplied, but that most of the information is obtainable by a phone call to the crane manufacturer.

Table 5-1: Information transferred from the manufacturer to the support structure designer.

QUESTION 1.1 - Information related to the crane is listed in the table. What information from the manufacturer is normally "Not Supplied - Needed", "Not Supplied - Not Needed", "Supplied - Needed" or "Supplied - Not Needed", by the support structure designer? Assume SABS 0160-1989 is the relevant loading code.

Information	**Not Supplied Needed**	**Not Supplied Not Needed**	**Supplied Needed**	**Supplied Not Needed**
Nominal weights of crane and hoist load				
Weight of crane bridge	0.0%	0.0%	**100.0%**	0.0%
Weigth of crab	0.0%	0.0%	**100.0%**	0.0%
Weight of hoist load	0.0%	0.0%	**100.0%**	0.0%
Crane Geometry				
Span of crane bridge	0.0%	0.0%	**100.0%**	0.0%
Minimum distance (hoist to rail)	4.2%	6.3%	**82.4%**	7.1%
Minimum distance between wheels of different cranes on the same runway	5.8%	0.0%	**94.2%**	0.0%
Number of wheels	0.0%	0.0%	**100.0%**	0.0%
Wheel spacing	0.0%	0.0%	**100.0%**	0.0%
Rail				
Rail type	23.4%	13.1%	**58.7%**	4.7%
Rail to runway attachment (clips)	30.5%	**66.5%**	3.0%	0.0%
Travel and hoist speeds				
Long travel speed (crane bridge)	0.0%	6.1%	**53.4%**	40.5%
Cross travel speed (crab)	0.0%	17.7%	**41.8%**	40.5%
Steady hoisting speed	0.0%	17.7%	34.7%	**47.6%**
Hoist type and characteristics				
Type of load lifting mechanism	0.0%	13.0%	**53.6%**	33.4%
Hoist load free to swing	0.0%	6.4%	**69.1%**	24.5%
Design life in terms of total hoists	30.7%	**31.9%**	21.4%	16.0%
Wheel and wheels drives				
Drive mechanism (independent / coupled / synchronized)	8.4%	**59.6%**	19.6%	12.4%
Behaviour of drives (smooth / sudden)	8.4%	**56.0%**	27.5%	8.1%
Number of driven track wheels	8.4%	**46.1%**	29.2%	16.3%
Guidance means				
Guide rollers present (or not)	0.0%	9.5%	**87.4%**	3.0%
Clearance between rail and wheel flange	17.6%	30.1%	**43.4%**	8.9%
Buffers				
Buffer type	26.7%	26.6%	**43.6%**	3.0%
Height of the buffer above the rail	9.7%	2.3%	**84.9%**	3.0%
Buffer characteristics (degree of plasticity; hydraulic information)	28.2%	**51.0%**	15.2%	5.7%
Other				
Storm brake information	**48.1%**	28.3%	20.6%	3.0%

Remarks concerning *table 5.1* include the following:

i) There is relative consensus that all weights and crane geometry are supplied and needed. This is quite clear and it should only be noted that the geometry often originates directly from the client.

ii) Over 80% of opinion expects the manufacturer to at least specify a minimum rail size.

iii) The rail clips are something that most designers specify themselves.

iv) Speeds (accelerations) are supplied by the manufacturer – though they are not yet needed for design (according to SABS 0160:1989).

v) Design life in terms of hoists or more specifically a duty cycle analysis is not readily provided. This makes design for fatigue difficult unless the information can be obtained elsewhere (from history or the client). The crane is also designed for fatigue. The lack of this information is therefore also the crane manufacturer's problem. It is therefore the client's responsibility to specify the number of lifts and at what capacity. Either the designer or manufacturer can assist in determination of such values if required.

vi) Opinion varied greatly concerning the wheel drives and technical crane information. Most of the cranes come in a standard form (Fixed-Fixed; independent, electronically synchronised and smooth drives). If unsure, the manufacturer should be able to clarify.

vii) Though the guidance means are normally specified, convincing opinion is not available concerning the wheel flange tolerance which is later described to be very important to the horizontal loads.

viii) Ordinarily information concerning the crane buffer is supplied. The runway end stops and end stop buffers are left to the support structure designers.

ix) Relative consensus concerning storm brakes is that the information is not supplied, but is needed for outdoor gantries. Storm brakes are themselves a topic discussed later.

Dymond [2005] found that problems exist concerning the time at which information made available to the support structure designers is released. This is as a result of the manufacturers not wanting to complete an accurate design and release the information until they have officially been awarded the contract. This problem is heightened by the fact that the crane is usually one of the last items to be installed during construction. This being said, the experts stated conclusively that sufficient information can be obtained for standard cranes in catalogues or past experience. It is only the really large (higher class) special order cranes that truly present a problem, and these are not particularly common cranes. As a last resort, even for the special cranes, experience and a conservative approach should be sufficient until further information is released. It is important for the structural designer to clearly indicate what specifications have been used for the design in the event of late information transfer.

5.3.1.2. Reliability of Wheel Loads

Opinion results indicated that the loads and information from the manufacturers are commonly regarded as reliable. "Best Practice" would however promote a simple calculation to check the order of magnitude of the maximum and minimum wheel loads. Note that the answers will never be identical because the crane manufacturers do a more detailed calculation which includes additional variables.

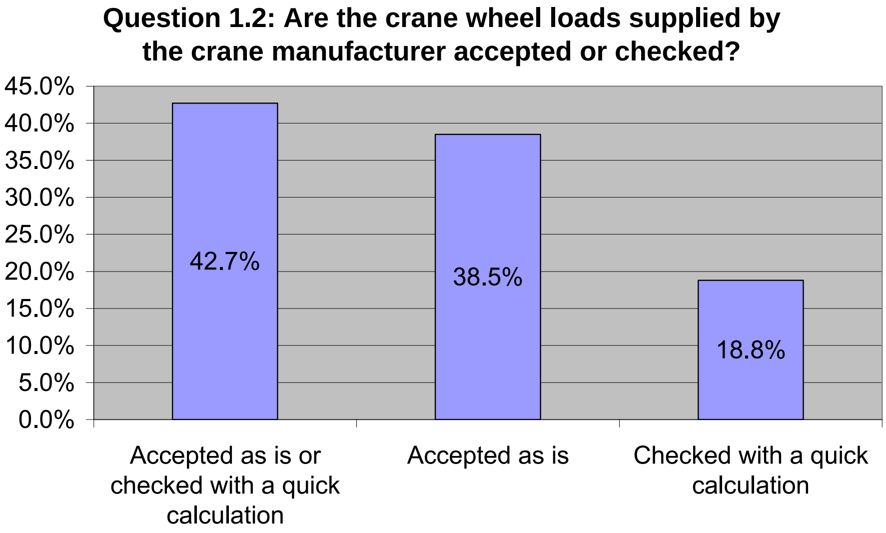


Figure 5.5: Indication of the degree with which the experts trust the wheel loads supplied by the manufacturers.

5.3.1.3. Structural Layout

A clear indication was found that the client, with the likely aid of a process engineer, specifies the structural layout. In some unusual instances an architect or the structural draughtsman could also be consulted. If the structural designer feels it necessary to adjust a structural facet (column placement was mentioned several times), he is advised to let his request be heard, noted and confirmed by the client. This is primarily for legal reasons. Opinion advocates the early involvement of the structural designer in generating a structural layout. This will help obtain a reliable and economic layout more quickly. Note that on smaller crane setups, the structural designer may be given the responsibility of the entire layout and design process.

5.3.1.4. Crane Expansion, Alterations and upgrades

Crane expansions, alterations and upgrade are all possible. In most instances the designer would not know, at the time of design, of a possible crane upgrade at a later stage. This type of upgrade would only surface if the crane related process develops.

Adjacent bays and more commonly the lengthening of the building are relatively simple to facilitate in design. The end frames are designed as any other frame only with additions for the end stops and sheeting, gables etc. All possible expansions, alterations and crane upgrade must be viewed and the most conservative situation designed for. “Best Practice” recommends enquiring about possible expansions, alterations or crane upgrade prior to design.

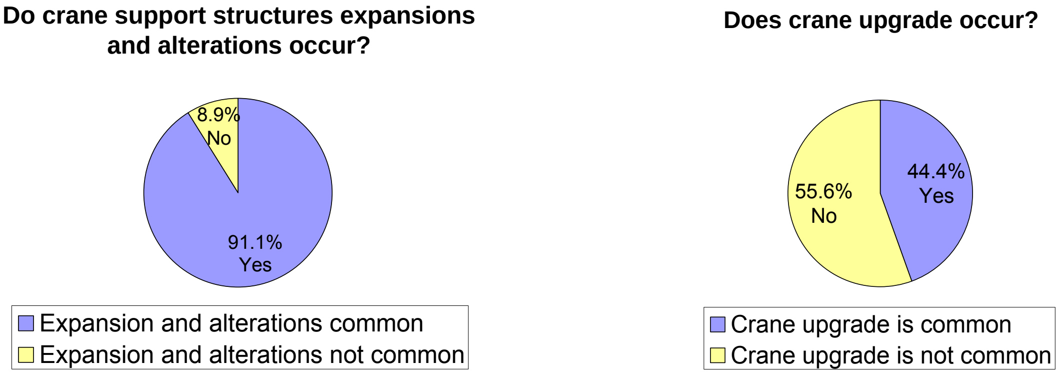


Figure 5.6: The pie graphs show the experts opinion on the occurrence of crane upgrade and expansions.

In the event of a crane support structure being subjected to a crane upgrade that was not planned, a helpful tip is to increase the crane wheel spacing to reduce the forces on any one column or crane runway girder.

5.3.2 Maintenance and misuse

Maintenance of crane support structures was not found to be a subject well covered by literature. The failures and problems that have developed in the crane industry could be seen as an indication that support structure maintenance should receive more attention. As part of the investigation into maintenance, an enquiry into the different forms of crane and support structure misuse was made. This information is graphically presented in *figure 5.7.* Note the large variety of misuses mentioned. During the interviews it was difficult for the experts to specify and recall all forms of misuse. Many experts emphasised that there were too many issues to mention them all. The fact remains that misuse and lack of maintenance are a serious problem.

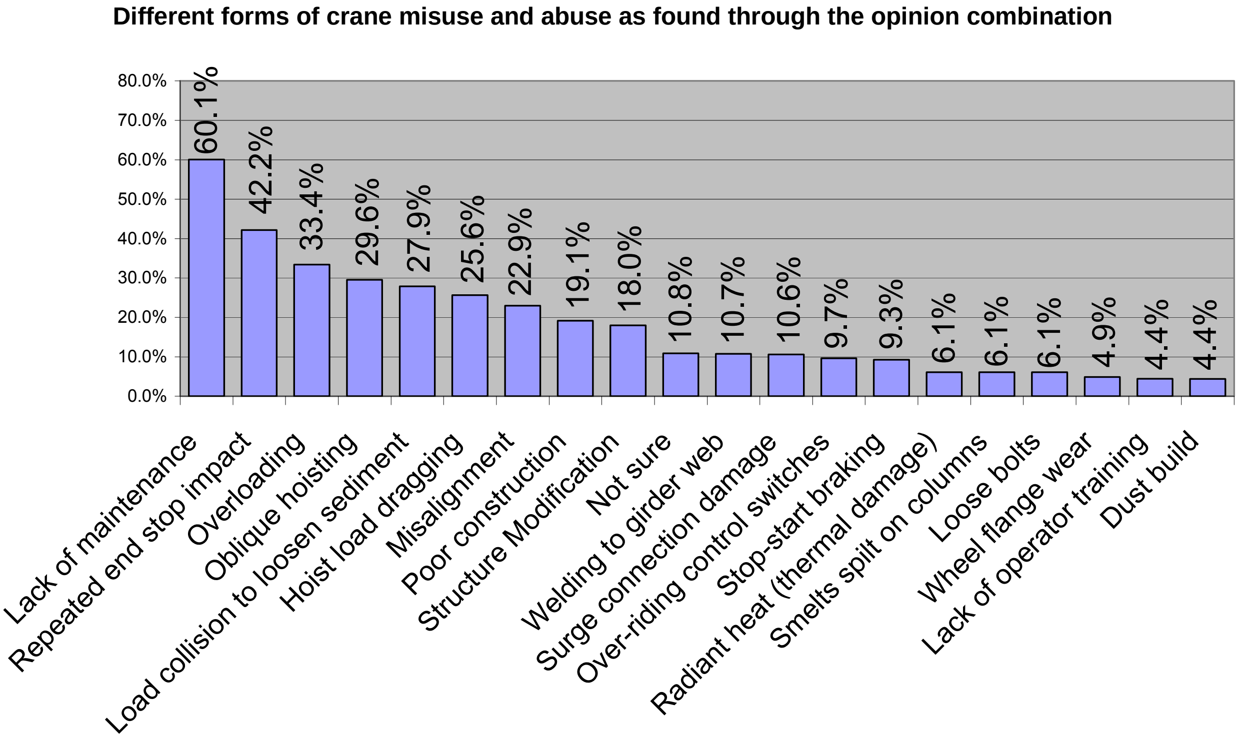


Figure 5.7: The different forms of crane and support structure misuse in South Africa. The values indicate the percentage of experts that mentioned that type of misuse or abuse.

Literature indicated that these subjects were two of the most common causes of crane support structure failure. As can be seen in *figure 5.7*, opinion supports this fact. Many experts reiterated that the bigger picture would also prove misalignment and lack of maintenance to be the chief cause of many other misuse issues. Especially if it is considered that surge connection damage, loose bolts and wheel flange wear can in fact be grouped under lack of maintenance and misalignment. Literature supports misalignment being the cause of many problems.

As further input into the lack of maintenance issue, the experts were asked to give a best estimate of the degree of misalignment and lack of maintenance experienced in industry today. *Figure 5.8* clearly shows that the support structure is more neglected than the cranes. According to expert opinion only 10.8% of support structures are routinely and correctly maintained. Cranes are commonly maintained by the crane manufacturers and not the client, and as such the equipment is often better kept. The fact that the cranes consist of working machinery also means that different laws and guidelines (codes) are applicable.

Results concerning misalignment were also concerning. The opinion estimate indicates that over 50% of rails and crane girders are badly aligned. Only 26.5% of crane runways are understood to be well aligned. These estimates are based on conditions five years post commissioning.

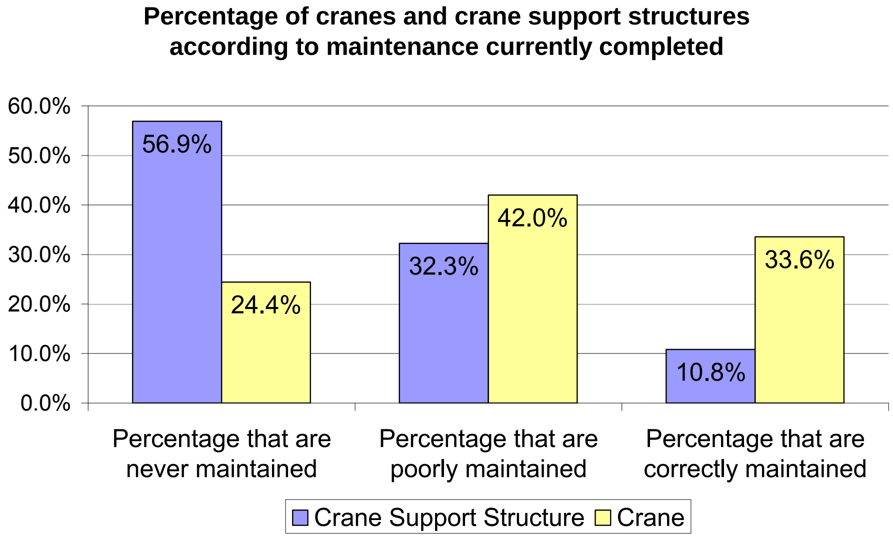


Figure 5.8: Values of the degree of maintenance completed on cranes and their support structure. The values are not precise, but give a good indication that problems do exist.

5.3.2.1. South African Maintenance Guide

Very importantly, every expert (100%) stated that there is no crane support structure maintenance guide available in South Africa. The closest thing to such a guide is the Occupational Health and Safety Act. According to this act, which was introduced in an earlier chapter, all structures must be inspected annually.

5.3.2.2. Proposed procedures for maintenance

According to the combined expert opinion, a basic inspection guide is put together in *table 5.2*. Many experts were adamant about the development of a formal maintenance guide which should be enforced - possibly by law. History of maintenance actually completed on structures was found to be useful and the lack thereof a clear problem. The majority of the experts also stated that a large percentage of failures (local and global) could be avoided if routine maintenance was enforced.

Furthermore the crane support structures are being kept in a working order, but not through preventative maintenance. Reactive repair work is completed only when the cranes functionality is impaired (the crane is unable to function and operation is halted). The downtime of a crane is so costly, that crane operators do not want to break for maintenance. However, if routine maintenance is applied, the downtime incurred during repair will ordinarily be avoided completely. The snow-balling failures of other elements due to problems like misalignment will also be minimised.

Table 5-2: Items included in an expert opinion maintenance program together with the frequency of inspection. Percentage of combined opinion that included that type of maintenance is in [ ] brackets.

Number	Type of Maintenance to be Performed	Part of Which Inspection
1	Visual inspection (crack initiation and general structure) [86.7%]	Regular check
2	Bolt (tight and present) check [53.7%]	Regular check
3	Rail clips check [24.2%]	Regular check
4	Painting [6.0%]	Regular check
5	Rail and wheel alignment to tolerances [67.8%]	Detailed check
6	Loaded structural behaviour check [12.9%]	Detailed check
7	Rail check [10.4%]	Detailed check
8	Vertical bracing check [6.3%]	Detailed check
9	Wheel flange tolerance check [6.1%]	Detailed check
10	Buffer inspection [3.1%]	Detailed check
11	Operation and safety control [2.7%]	Detailed check
12	None Destructive Testing [4.3%]	Occasional check

12 Items are included in *table 5.2*. This is a relatively comprehensive check list for the crane support structure and does not differ too greatly from the inspection example in AISE Technical Report No. 13 [2003] or the AS1418.18.

5.3.2.3. Frequency of inspection

The frequency of inspection postulated by the experts varies. For all cases other than the None Destructive Testing (NDT), the time periods lay between one month and two years, according to the crane class. NDT is recommended by a very small fraction of the group and together with this recommendation is a repetition period of ten years for light duty cranes and five years for heavy duty cranes.

After careful consideration of the periods suggested by some of the experts and those found in literature, it becomes clear that the class of crane should dictate the period between inspections. As with NDT the breakdown is made into class one and two cranes (light duty) and class three and four cranes (heavy duty). Accordingly the detailed inspection should be completed once bi-annually for light duty and once every six months for heavy duty cranes. The detailed check should be completed by a professional structural engineer. The regular check to be completed between detailed inspections can be conducted by trained on site personnel. Again it is emphasised that a maintenance program, covering similar concepts as in *table 5.2*, be enforced by law in order to improve the reliability of the structures.

5.3.2.4. Additional Maintenance Guidelines

A few additional tips that are focused on "best practice" during maintenance are:

i) After maintenance or repair, ensure that the crane is correctly setup again (wheels of the correct size, surge connections correctly constructed, etc.).

ii) When installing a walkway at crane level or a process is changed on the ground, column lacing or more importantly structural bracing is sometimes removed. This places the entire structure at extreme risk. A check for this issue should be included in a visual inspection.

iii) Misalignment can be caused by the runway, rail or wheel flanges being misaligned. The columns can also affect the alignment. A small deviation at ground level, results in a large deviation at crane girder level (especially for outdoor cranes). Therefore be aware of settlement and creep of concrete foundations and columns.

iv) Adjustments and retrofit should not only repair the structure but correct the problem from occurring again. This is a very important and logical approach that is not always administered.

v) Application of any maintenance procedure should include documentation and guidance on what must be changed or corrected. Fulfilment of the adjustments can then be checked during subsequent inspections. This is similar to the approach laid out in the OHS Act.

5.3.3 Crane Classification and Load factors

The aptness of the classification model as used in South Africa and the load models dynamic and horizontal load factors are investigated here.

5.3.3.1. Loading and Design Codes

Designers in South Africa design using the SABS 0160:1989 loading code and the SANS 10162-1:2005 steel design code. The survey research indicates that the classification process as prescribed by these codes is acceptable. In fact 82.3% of opinion states this. Many experts are aware of the simplicity of the load model used in South Africa, but feel that the loads obtained are acceptable.

5.3.3.2. Crane classification

The process of crane support structures design begins with crane classification. The survey shows that the classification is most commonly prescribed by the client. The structural designer may review the classification and make recommendations if necessary. Usually this is not required.

5.3.3.3. Dynamic and horizontal load factors

Questions concerning the crane load factors, which are based on the crane classification model, were asked. Again it was found that the factors, although simplistic, are acceptable. The majority of the experts employ these factors as they have worked for many years (*figure 5.9*). Expert opinion unanimously stated that the loads calculated using the factors are not the direct cause of problems - the structural details designed are the main cause of problems, especially when associated with a lack of maintenance. It should consequently be noted that the factors are considered to be acceptable for maintained structures. A badly aligned rail for instance can result in forces that exceed those designed for using the present loading model. Again it becomes clear that maintenance and alignment of crane support structures is highly important.

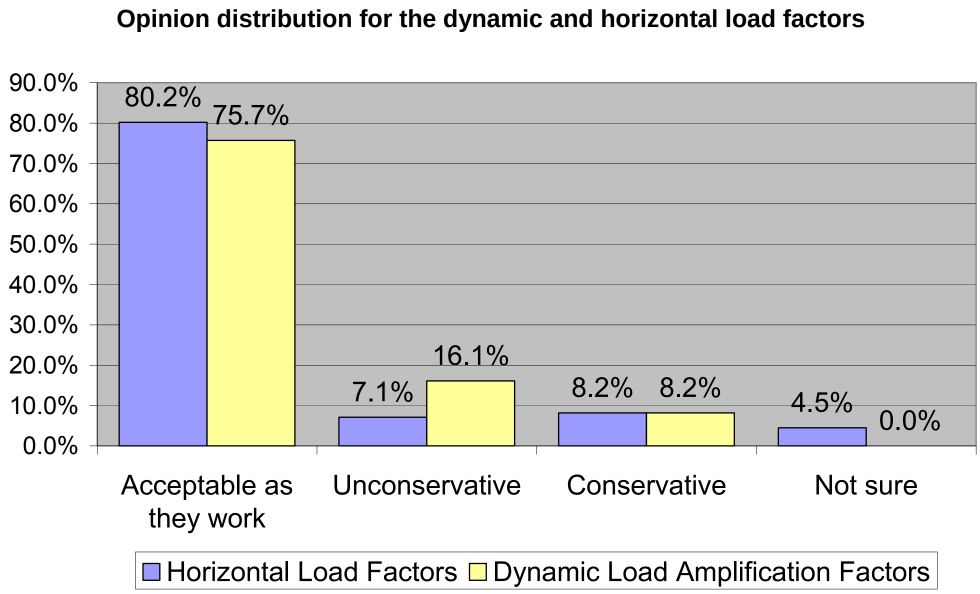


Figure 5.9: Expert opinion distribution for the acceptability of the load amplification factors.

The entire classification and loading model appears to be considered acceptable by opinion. Certain experts do feel that to change any one component of the loading model would consequently require the complete recalibration of the whole load model. This would require much work to implement.

Research on a full scale crane setup at the Stellenbosch University Structural Laboratory was also completed and showed little difference in the factors required to those presently in existence. [De Lange 2007]

Lastly the increase in factor values according to the class of crane was questioned. 91.2% of the opinion agreed with the increase. Many did state that mathematically it does not make sense. A crane of a given load is capable of imposing loads relative to the vertical load. The class, therefore, should have no influence. The same experts in opposition stated that from a reliability and probability point of view, the chances of a crane of a higher class, being used more frequently at a higher percentage of rated capacity, does stand a greater chance of being subjected to relatively larger loads. For this reason the increased factors account for this in an indirect manner.

Additionally, as “best practice” the factors on class four cranes are often increased by the experienced designers in order to ensure the entire structure can withstand the heavier loads and duty cycles these structures are subjected too. This could possibly warrant the increase of the class four factors in the loading code in order to avoid inexperienced designers from under-designing the support structure. For further information on what magnitude of increase is used, structural designers specialising in heavy duty crane structures should be contacted.

5.3.4 Load Cases and Load Combinations

Load cases and combinations form the basis of this section.

5.3.4.1. Multiple Crane setups

Questionnaire question 9.1 focused on the number of cranes to be used in combination when analysing the loads generated by multiple crane setups. This proved to be a contentious subject which, during discussion, had few clear cut answers. Expert opinion supports this fact as the majority (71.3%) is found to simply apply the code.

What the question really tries to address is the degree to which crane loads are able to influence one another. Furthermore it enquires as to the probability of more than one crane simultaneously being used and causing a load? These are questions which only intense statistical investigation and research could answer. As a means of clarifying the suitability of the SABS loading code without conducting this research, other codes were found to compare well.

Engineering judgement must still be applied when selecting the influence of loads in multiple crane buildings. Moreover every design should be handled uniquely and interpreted conservatively.

The proposed SANS 10160 revises the number of cranes in multiple crane setups to two for all horizontal forces. This is possibly more conservative but is stated to be considered as a maximum. "Best practice" suggests that due to the unpredictability surrounding the selection of the number of influential cranes, the code should be used as a starting point and conservative yet logical adjustments made from there, if required.

5.3.4.2. Unusual Load Cases

The regular load cases for industrial buildings with cranes include dead and live loads, wind and crane horizontal and vertical loads. The experts were asked if any other unusual load cases exist. Just fewer than 50% of experts suggested that no further load situations need be investigated. This response must be clarified to the extent that standard load situations were not listed. Therefore it is unclear if the experts view thermal expansion loads as a standard or special load case.

Summarising the important responses, only end stop impact and thermal forces seemed appropriate. Earthquake loading was expected to be mentioned here, but was regarded as unnecessary by all the experts. The reason for this is that in South African conditions most industrial steel buildings are ductile enough to handle seismic accelerations. The buildings mass and height is not normally very large and the earthquake zones in South Africa are not considered to be high risk areas. Therefore designs are not checked for earthquakes and the cranes and rails are not designed to account for seismic movements.

Thermal issues normally pertain to deflections. Guidelines to the maximum building length have been included in an earlier chapter and most often are able to account for thermal concerns. It is certainly good practice to investigate the thermal effects, though the designers did not seem to find their influence to be critical. In cases were thermal processes are being conducted and repetitively influence the structure, thermal expansion forces can be investigated for fatigue effects.

End stop impact is a serious problem. Many failures occur due to weak end stop design or detailing. The forces are simple to calculate and one should certainly approach the design conservatively. When designing, take note that the buffers may be removed or hydraulic buffers not maintained. Therefore the robustness of the physical end stop becomes vital. Furthermore many crane users have been described to misuse the end stops, making impact a repeated load case and not an accidental load case as previously thought. “Best practice” recommends conservative end stop design.

5.3.4.3. Load Combinations

Load combinations are open to a fair amount of interpretation. Nonetheless, over 95% of the opinion regards the SABS 0160:1989 load combinations as acceptable and sufficient. It was conceded that accurate interpretation and sound engineering judgement are required in order to apply the load combinations successfully.

Another factor that assists load combination analysis is the power of computer software. No combinations need to be ruled out and all can be analysed very quickly and easily. After the analysis of all combinations has been completed it becomes necessary to select the critical combinations for any given structural element. Intuition and experience are required to select the critical combinations. Envelopes are available which plot the maximum moments or shear forces of all the combinations analysed. The danger is that for design the maximum forces and moments must be used from one load combination, not simply the maximum moment with maximum shear and axial forces for any combinations. Care should therefore be exercised and the envelopes only used as a help.

Understandably a design using the maximum values from the envelopes may result in a more conservative design, but if sufficient care is not taken the opposite may occur and the buildings reliability will decrease.

The experts were also asked to list the combinations that they investigate. Due to time constraints in the interview, this question was often not well answered. The question could definitely have been structured differently in order to obtain better results. Several structured questions focusing on specific interpretation would have served this purpose. The results, nonetheless, are listed according to the combinations the experts mentioned were critical and are tabulated below.

Table 5-3: Different approaches to crane related load combinations.

Number	Critical Cases Included by the Experts	Ultimate Limit State Load Combination	Notes on the Combinations
1	Crane Vertical Dominant	1.2DL + 0.5LL + 1.6CV + (0.8 or 1.2 or 1.6)CH	If the crane vertical load is considered to be a live load, then the LL factor should not be 0.5 but 1.6. Wind combination factor is 0, is this acceptable?
2	Crane Horizontal Dominant	1.2DL + 0.5LL + 1.6CH + (0.8 or 1.2 or 1.6)CV	If the crane horizontal load is considered to be a live load, then the LL factor should not be 0.5 but 1.6. Considering the LL is actually a roof load a partial factor of zero is also possible according to the code. Wind combination factor is 0, is this acceptable?
3	Wind Normal Dominant	1.2DL + 0.5LL + 1.3WL + 0.8CV + 0.8CH	Should 0.5*LL be included, or should LL's combination factor be considered to be 0?
4	Wind Uplift Dominant	0.9DL + 1.3WL	
All combinations that can be generated for the given load cases should be investigated. Thermal affects included. The use of computer software makes this possible.			

Although no consensus can be obtained from the answers the following points can be made which link closely with the notes in *table 5.3*.

i) Application of the code formed a part of every experts answer. There is no problem with the combinations laid out in the South African code.

ii) Various interpretations of the code are possible. (Some ambiguity exists)

The most important issue is the correlation between vertical and horizontal crane loads. This influences both the crane girder design and the structural analysis. The conservative approach would be to fully correlate the two loads. The calculation procedure in SABS 0160:1989 certainly indicates that the values are fully correlated (the horizontal loads calculated from the vertical loads). A topic brought up by several experts was that the horizontal loads are point in time or instantaneous loads which do not necessarily occur simultaneously to the vertical crane loads. But considering that the forces are generated on account of the vertical loads from the crane, the forces may be seen to occur simultaneously. To conclude, the forces are at least partially correlated and for this reason factors of 1.2 or 1.6 should be prescribed.

As stated previously it is difficult to obtain any form of consensus from such variable interpretations. Considering that all experts were comfortable with the code and the specific interpretation of its guidelines they make use of, no further comment is to be given. “Best practice” recommends very careful application of the code. If in doubt of any aspect, use the more conservative approach. Furthermore the following literature is referred to in case of difficulties:

i) Southern African Institute of Steel Construction – Design of Heavy Industrial Buildings Course Notes; Crane Loading. [2007]
ii) Southern African Steel Construction Handbook; Cranes. [2006]

The same situation occurred during consideration of the serviceability limit states load combinations. Consequently exactly the same results were attained and the same guidance can be supplied from the results. The code should be carefully interpreted for serviceability limits states and the resulting analysis compared with the deflection limits provided as a recommendation at the back of the SANS 10162-1:2005 steel design code. The same literature can be referenced for further guidance.

5.3.5 Force Application and Eccentricities

The horizontal and vertical crane forces must be applied to the crane runway girder for girder analysis and design. The forces must also be applied to the structural analysis model. The subject of force application and eccentricities covers these two separate domains.

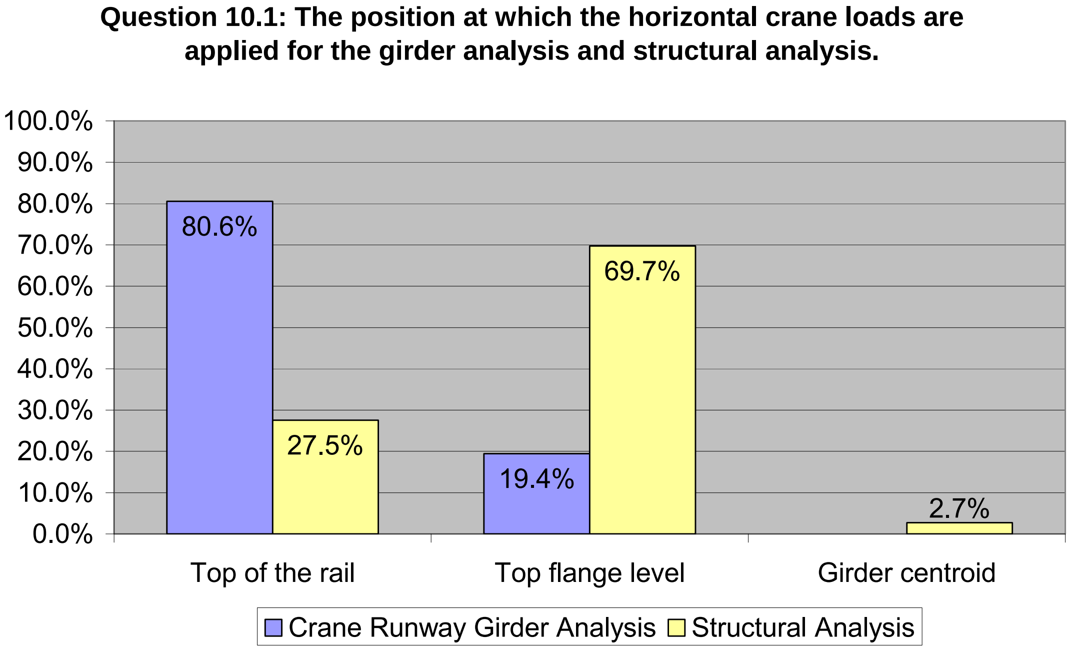


Figure 5.10: The placement of the horizontal crane loads for crane runway girder and structural analysis respectively.

5.3.5.1. Crane runway girder force application

Firstly for the crane runway girder the horizontal wheel loads are imposed on the top of the rail at the interface between the wheels and rail. The friction between these two surfaces usually transfers the force into the rail and the rail then distributes the force slightly and imposes this force on the girder. The horizontal element of this force is then split into a couple at top and bottom flange level. The calculation and description of this was given in the earlier chapters and is known as the twin beam theory. [Gorenc 2003]

The vertical wheel loads also travel from the wheels to the rail and then into the crane runway girder. This line of action is never exact and will always involve some form of eccentricity. It is therefore bad practice to assume a perfectly centred wheel load on the crane runway girder or rail. Two possible vertical load eccentricities were recommended by the experts. The first is as in the SABS codes, a quarter of the rail head width either side of the crane girder web centreline. The second is the thickness of the crane girder web either side of the crane girder web centreline. This is similar to the approach found in the Australian Standards, only AS1418.1 recommends three quarters of the girder web either side.

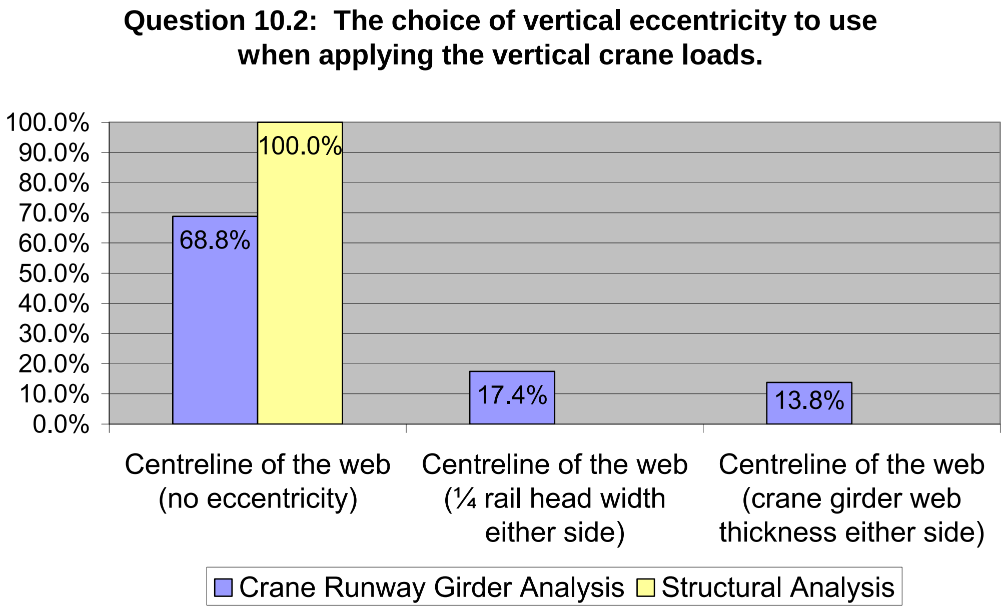


Figure 5.11: The distribution for the eccentricity applicable with the vertical crane load.

The number of experts applying vertical eccentricity in the design of the crane runway girders is astoundingly low. With all of the failures and uncertainties surrounding the rotation of the top flange, most experts surprisingly still do not apply any eccentricity during design. The Eurocode, the Australian code and the proposed SANS 10160 code make eccentric application of the vertical crane load compulsory when analysing the crane girder. “Best practice” should re-emphasise the compulsory application of the eccentric vertical crane load. In this case the twin beam theory can again be used to handle the torsional actions by means of a horizontal couple. Over and above this the horizontal crane force must also be resisted by the girder flanges. The use of the twin beam theory is illustrated in *figure 5.12*.

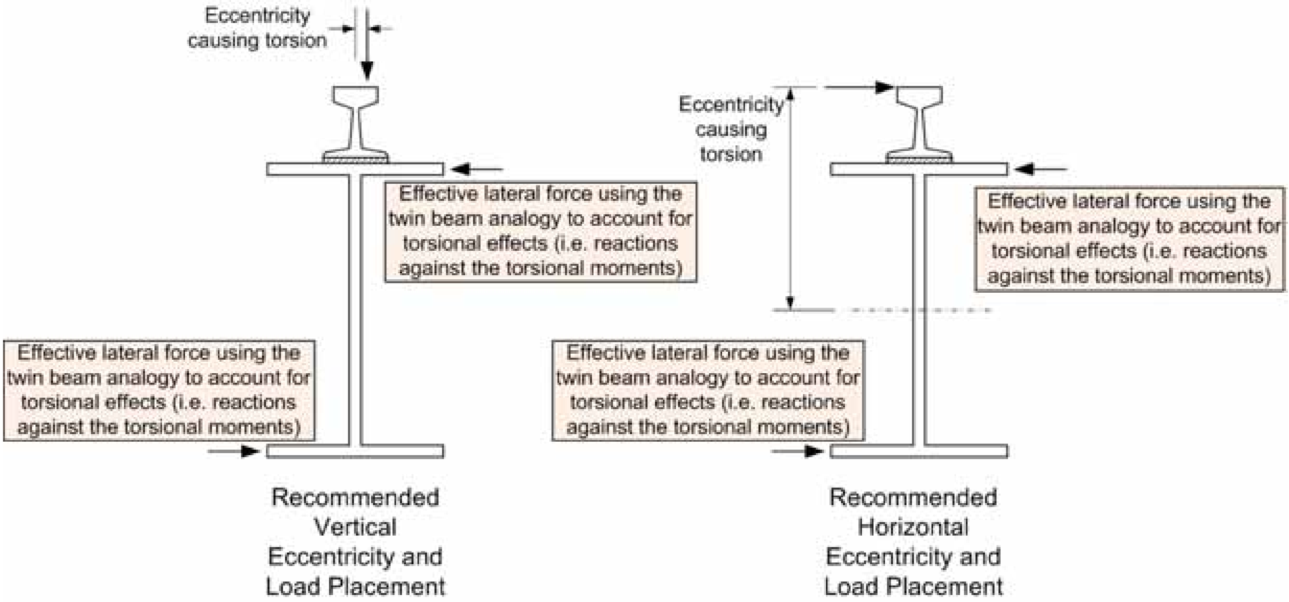


Figure 5.12: "Best practice" must include a recommendation for crane application which includes eccentricities.

5.3.5.2. Structural force application

The analysis of the structure is less sensitive to the placement of the crane vertical and horizontal forces. The vertical forces can be placed at crane girder (column cap), crane girder top flange or crane rail level. When analysis software is used, the position is based on the closest and most appropriate node. The horizontal forces can be placed at crane girder (column cap), crane girder top flange or crane rail level. Opinion clearly favoured the crane girder top flange as this is the level of the surge connection which resists and transfers, to the structure, the largest part of the horizontal crane loads. Both of the structural applications supplied by the experts were found to be acceptable (see *figures 5.10* and *5.11* for opinion results).

5.3.6 Deflection Limits

According to 85.4% of expert opinion, the deflection limits as found in Annex D of SANS 10162-1:2005 are acceptable. They are occasionally found to be the critical design criteria.

The experts commented that when a really large structure is within deflection tolerances, the structural movement may still become large enough to trouble the public or building employees. Accordingly, in really heavy duty structures (generally class three or class four cranes) the deflection limits should possibly be made more stringent. This would be in keeping with the international tendency of reducing relative deflections of heavy duty crane buildings and girders for structural reliability reasons. Moreover, the SANS variation in lateral deflection limits according to capacity should perhaps be changed to consider crane class as the defining variable instead. International codes differentiate the deflection limits according to crane class and not the cranes capacity. This is simply a suggestion made by several experts to improve the deflection criteria.

Additional to those deflection limits recommended by the code, several experts recommended a relative rail to rail deflection limit of 10mm. This is a limitation which Gorenc [2003], in connection with the Australian Standards, also stipulates. The reason explained for its application is to reduce the "jamming" of the crane between the rails. The 10mm would normally be within the wheel flange tolerances and therefore wheel flange contact and its associated skewing forces would be, at least partially, avoided. It is acceptable to recommend this as "best practice". More will be said on skewing and rail "jamming" at the end of this chapter.

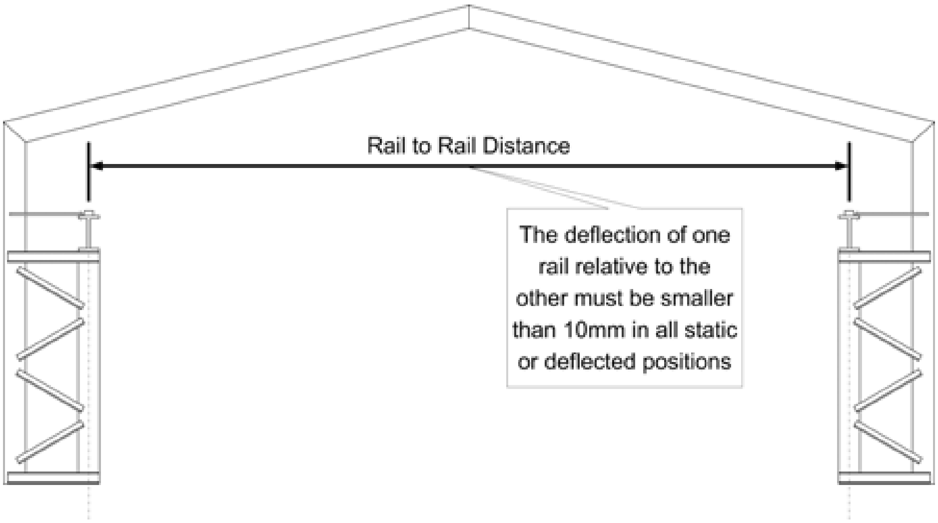


Figure 5.13: An additional deflection limit recommended by the expert survey.

5.3.7 Structural Analysis and Design

With the advances in technology and adjoining computer hardware and software, many structural analysis and design packages have been created and put on the market. Most commonly these programs are variants of the finite element model. Each program has its own unique implementation method, input process and graphical outputs. Certainly efficiency varies and all programs will have limitations. Nonetheless, in order to be a competitive structural designer today, computer software must be implemented skilfully and accurately. At the same time designers must ensure that they understand the concepts applied in finite element modelling and that they are able to interpret the results accurately. Blind application of a program often can lead to gross errors.

5.3.7.1. Structural Analysis

Many different packages are on the market today, Prokon, Master Series, Robot and Framework ver9.4 being but some of these. Framework ver9.4 is free software available on the internet, which is developed by the Delft University in Netherlands. The students take part in constant improvement of the software. The reliability of this software has not been tested by Stellenbosch University, though it was regarded by a few experts as efficient.

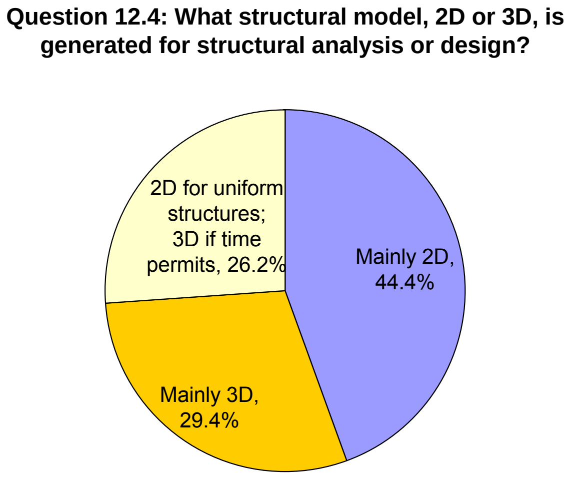


Figure 5.14: The choice between 2D and 3D models for structural analysis or design purposes.

5.3.7.2. Analysis Model

Further enquiry into the structural analysis and design was made. Firstly the type of model was investigated. As *figure 5.14* suggests, most experts make use of the less complex 2D model. This is because the simplicity reduces the chance of errors. In cases where the design is not symmetrical or uniform, a 3D analysis may however not be avoidable. If a crane support structure were to be analysed for dynamic or seismic effects, a 3D model would be recommended.

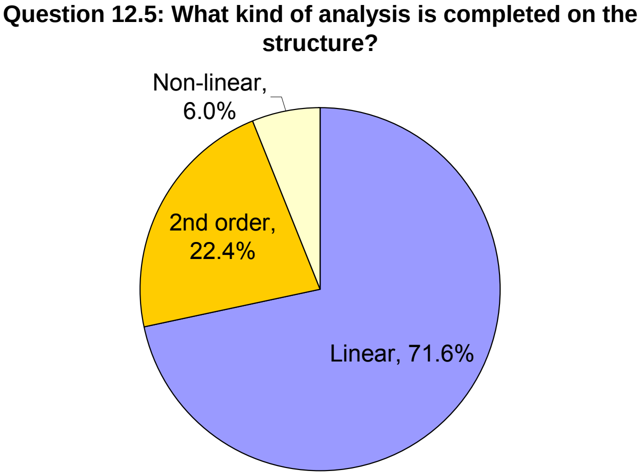


Figure 5.15: The expert opinion selected analysis type.

5.3.7.3. Analysis Type

As can be seen from *figure 5.15* most experts use a linear analysis. This unfortunately is not what the SANS 10162-1:2005 steel design code stipulates. The structure is subjected to large horizontal loads and the deflections and sway are important parts of the design. For this reason the SANS 10162-1:2005 recommends that notional loads be applied and second order effects be investigated. The notional loads are understood to account for poor construction and pre-camber of columns; the second order effects then induce a starting horizontal sway. This in turn results in the large vertical crane forces acting eccentric to the centreline of the column.

Due to the codes requirements for analysis, “best practice” must recommend applying second order effects on cranes. With today’s computers, the implementation of this analysis is no more difficult than a linear analysis.

5.3.7.4. Crane Runway Girder Analysis

The girders analysis was viewed separately. Over 62.0% of opinion tended towards analysing these generally simply supported elements with hand calculations. The analysis is of course not complicated, even if the previously defined load eccentricities are included. Excel spreadsheets can be used to simplify and speed up the analysis process.

5.3.7.5. *Crane Runway Girder Design*

Prokon does have a crane girder design section of which the reliability is unclear. It handles both the analysis and design of crane girders. The experts felt much more comfortable using their own design spreadsheets, as this ensures that the beams are designed as the designer desires. If software applications are used for design, possible program short comings should be investigated prior to a designer accepting any given design. In other words the program should first be validated by the designer. In fact "best practice" recommends this with all structural software.

5.3.7.6. *Connection Design*

Computer software is still not commonly used by the designers for connection design. Practically all of the experts make use of simple, detailed, hand calculations and sketches (77.7% of opinion). Excel spreadsheets can be used to enable quicker calculation. Once the spreadsheet has been formulated, it is much easier and quicker to use. Finite element models of connections are never required. Note that the ordinary connections as well as surge connections, bracing and any other crane support structure connections are included in this discussion.

Furthermore connection design not only requires a lot of attention to specific details, but as a "best practice" recommendation, it is very important to keep all connections symmetrical and aligned. Connection eccentricities should be avoided at all costs. A sketch explaining this is shown in *figure 5.16*. Furthermore, ensure that all connections given to the drawing office are clear sketches, with as little interpretation required by a draughtsman as possible. The connections on crane gantries are, due to fatigue, one of the most critical parts of the structure. Sufficient care, in designing the connections, must therefore be taken.

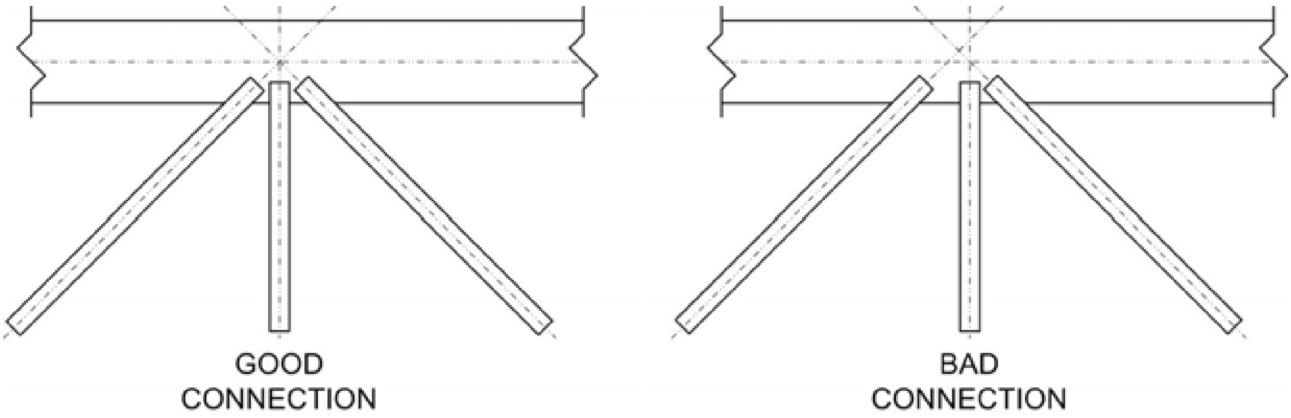


Figure 5.16: Sketch showing an acceptable connection and an eccentric connection that is to be avoided.

5.3.8 Crane runway Girders

Expert opinion and related literature both stipulate that simply supported beams are preferred to continuous beams for crane runway girders. The continuous or semi-continuous girders have been known to be more problematic. This is mainly as a result of the fatigue cycles the girders are subjected to and the fact that the stress distribution in the girder is inverted at continuous runway supports. "Best practice" therefore recommends simply supported beams for all cranes (i.e. both light and heavy duty). The only case when a continuous girder must be considered is for cantilever portions at the end of a structure or for runways that in fact only consist of two short spans. In both cases one crane girder profile can be used and a splice, in any form, is not required.

5.3.8.1. Crane Girder Sections

Any beam section can be used. Expert opinion suggested the use of the same crane girder sections as related literature. These comprise of the following sections. A guide to opinion recommended safe working capacity boundaries is provided in the brackets:

i) Universal section (<10 tons)
ii) Horizontal channel on a universal section (10 – 25 tons)
iii) Plate girder section (25 tons until horizontal loads become too large)
iv) Mono-symmetric plate girders section with a thicker top flange (25 tons until horizontal loads become too large)
v) Plate girder section with surge girder (anything larger)
vi) Plate girder section with surge plate (anything larger)

Due to the twin use of a surge plate as a walkway, the surge plate section is more frequently used and preferred by the designers. Proper walkway design criteria must be investigated and regular maintenance must be applied to keep the dust build up to a minimum.

5.3.8.2. Crane Girder Alignment

Many forms of adjustment can be included on crane girders. In many instances it becomes necessary to allow for adjustment both laterally and vertically in order to obtain a centred and aligned crane rail. Sketches with all of the adjustable details prescribed by the experts are discussed towards the end of this chapter.

The use of packing (vertical and horizontal) is described by most experts as the most acceptable. The use of slotted holes however, resulted in more contention. Some designers say slots can be used and others rather avoid slots because of associated problems previously experienced. The best summation of opinion is that slotted holes can be used as long as they are routinely maintained and the correct bolts are used. The bolts depend largely on the type of connection. Either a fixed connection (bolted tightly) or a loose connection (used to keep an element in place but allow some movement) is required. If a rigid connection is wanted the slots must have HSFG's or Huck bolts.

Designers should be aware of the unified effect of runway girders, the surge plate (truss) and the auxiliary girder section. When the crane runway girder is loaded the auxiliary girder is simultaneously "dragged" down by the deflection of the whole compound section. For this reason similar movements must be facilitated in the auxiliary girder as in the crane runway girder.

Many experts also commented that accurate and careful alignment during construction can, in ideal cases, lead to rail clip adjustment being sufficient for alignment at later stages in the buildings life. Furthermore larger bolt holes and packs at the column base and modern laser equipment for alignment are helpful in attaining an accurate alignment during construction.

"Best practice" associated with these adjustable connections involves routine maintenance which in order to uphold the reliability of the connections and structure must be completed. Additionally the correct details must be used. Examples of good details are provided later in this chapter.

5.3.8.3. Crane Runway Girder intermediate Stiffeners

90.0% of expert opinion indicated that crane runway girders should be designed to include intermediate stiffeners when required. These stiffeners are designed according to ordinary stiffener design procedures. The only difference is that due to fatigue effects, the stiffeners are stopped short of the bottom flange. The gap is usually around 50mm. The SASC Handbook [2005] recommends a gap of four times the web thickness.

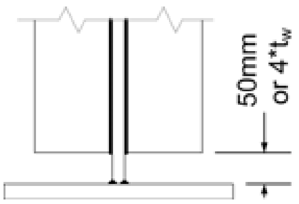


Figure 5.17: The application of the gap between the bottom flange and the intermediate stiffeners.

5.3.8.4. Crane runway girder stub stiffeners

The more contentious issue is whether the shorter “stub” or “fillet” stiffeners should be included in crane runway girder design and if so, for what purpose?

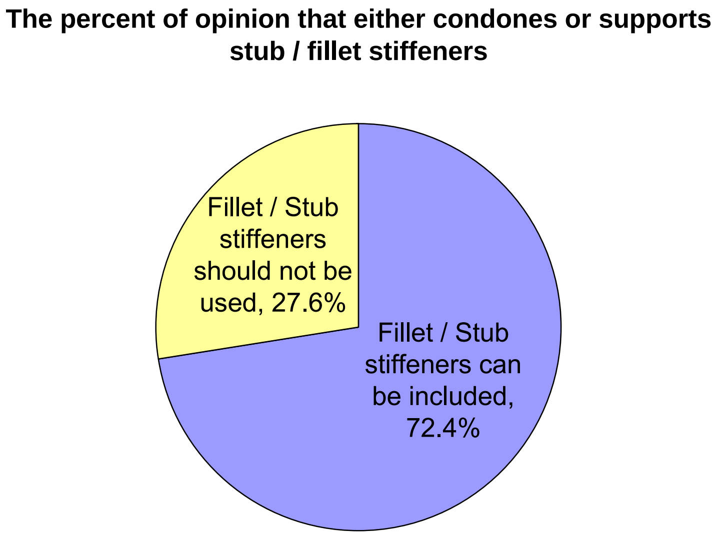


Figure 5.18: Opinion results in a larger percentage of experts using the short stub / fillet stiffeners.

According to *figure 5.18* it would appear that intermediate stiffeners may be used with stub stiffeners staggered in between. One use of the intermediate stiffeners and the main reason for the stub stiffeners is to prevent or reduce the top flange rotation. More will be said on the causes and effects of top flange rotation later in the chapter, but for now it can be assumed that the stiffeners do assist in reducing this rotation.

The design of the short stiffeners is not well defined. It is generally a simple geometric design, rather than one related to forces. The best available information on the stub stiffeners is found in the SASC Handbook [2005]. Furthermore guidelines elicited during the expert survey include using a depth of 25% the girder depth. The breadth is subsequently calculated according to the SASC Handbook or alternately specified to be two thirds the flange width.

Spacing of the intermediate stiffeners is calculated according to the code (SANS 10162-1:2005). The stub stiffeners are then generally placed at a geometrically equal spacing between the intermediate stiffeners. Always on both sides of the web and normally only one or two pairs between intermediate stiffeners.

Very importantly, designers must ensure that the stiffener cope at top flange level is well clear of the top flange to web weld. A sketch of a stiffener cope is supplied in the details section of this chapter. This is to prevent any increased stresses surrounding the top flange to web weld. Also the depth of the stub stiffeners must be sufficient to ensure enough length along the web for proper transferral of the forces. Otherwise the danger of simply moving the rotation to the stiffener toe to web connection arises.

5.3.8.5. Crane Runway Girder Section Properties and Design

The mono-symmetric section properties calculation has already been explained in the seed questions procedure. Expert opinion indicated that the section is not often used. A few experts did state that an increased top flange width can create more space for the rail clips and stiffener connections. The designer can also limit the excess steel on the less stressed bottom flange.

The surge girder and surge plate sections must also be investigated. The associated girder design method described by most experts involved two separate designs - one for a horizontal section and one for a vertical section. A variety of girder section separations were described during the interviews. The expert defined sections are supplied with their corresponding opinion percentages in *figures 5.19* and *5.20*. For clarity the sketch as in the SASC Handbook is included in *figure 5.21*.

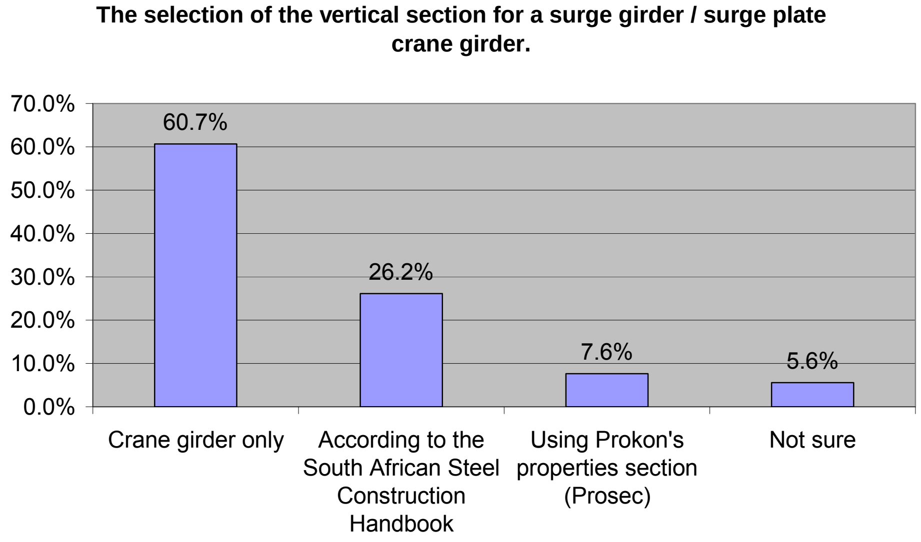


Figure 5.19: Different methods of defining the crane girder with surge plate / surge girder vertical section.

"Best practice" should recommend something similar to SASC Handbook. The main difference is the auxiliary girders inclusion. Only if it is compact enough is it completely included. If a vertical truss is used for instance only the top element of the truss can be included. Note that this is assuming a rigid connection between the surge plate and its lengthwise supports. When designing the horizontal section, HSFG's must be used at the surge plate interfaces to form a rigid connection.

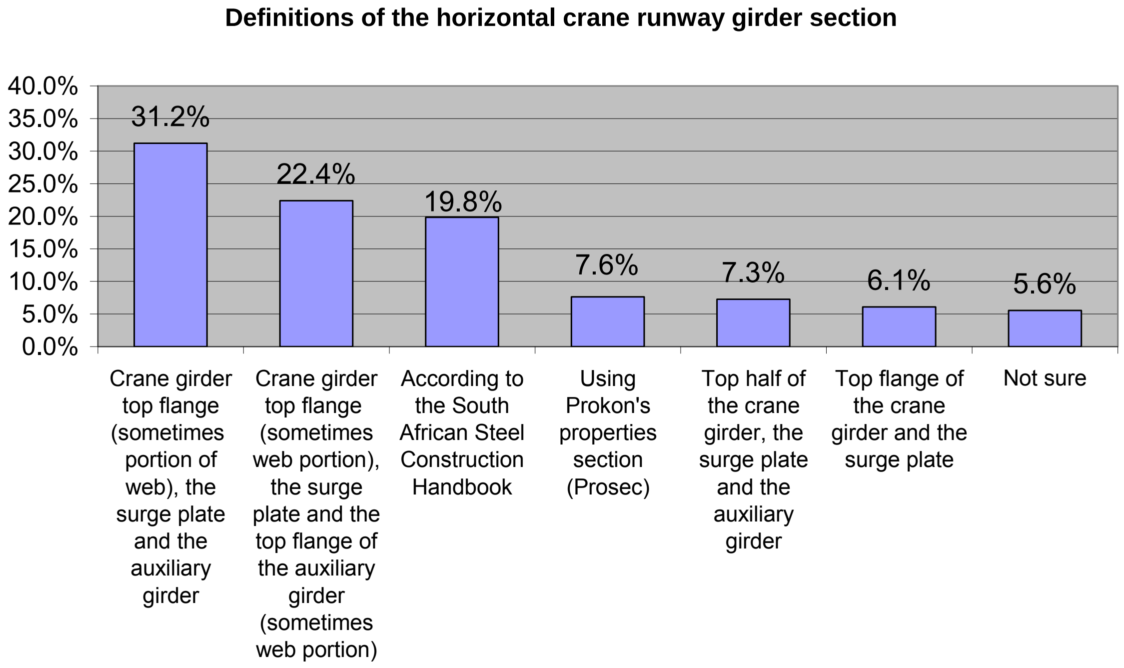


Figure 5.20: Different methods of defining the crane girder with surge plate / surge girder horizontal section.

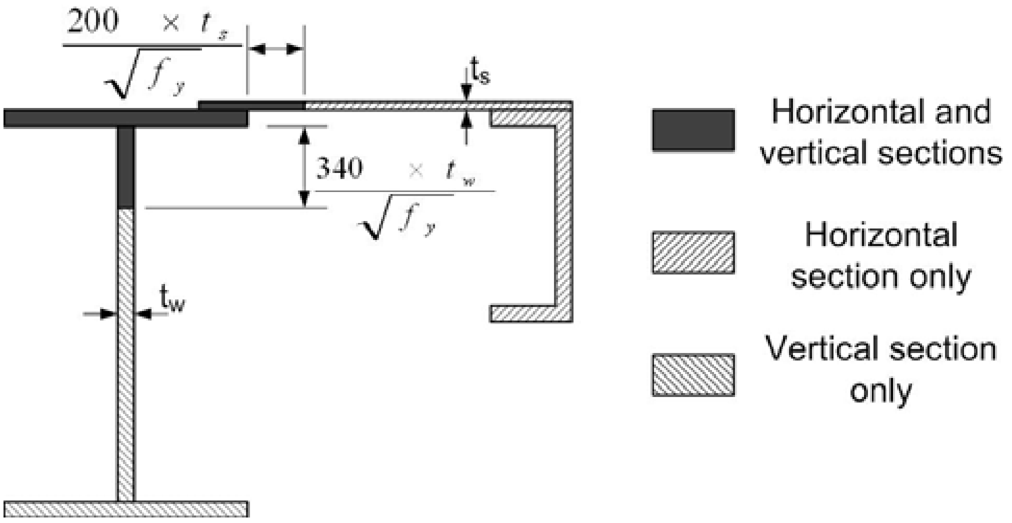


Figure 5.21: The split in horizontal and vertical sections according to the SASC Handbook [2005].

Figure 5.19 shows that opinion primarily uses a more conservative vertical section than literature recommends. The horizontal sections prescribed by opinion, *figure 5.20*, are acceptable as long as the surge plate connections are correctly and efficiently made.

Finally, in design, the two separate sections are designed and then checked using the dual axis moment combination formula.

$$\frac{M_{ux}}{M_{rx}} + \frac{M_{uy}}{M_{ry}} \leq 1.0 \qquad (\textit{Equation 5.1})$$

Lastly, it is stated that the crane runway girder sections are designed as beams and not as beam columns. The axial forces are generally small enough that they can be ignored.

5.3.8.6. Crane Runway Girder Welds

Two tables have been constructed, *table 5.4* and *table 5.5*, of which the first focuses on class one and class two cranes, whilst the second looks at class three and class four cranes. Each table shows the six different types of connections listed by the experts. The bold percentage indicates the majority for each detail. Each table looks at a plate girder section and a universal section with a horizontal channel. The endplate details can vary therefore for this occasion a bearing stiffener endplate was selected. Comments are provided subsequent to each table.

Table 5-4: The various connection methods and their opinion percentages for class one and class two cranes.

Girder Type	Detail Description	Class 1 & 2					
		FPB	Fillet	Fillet (St)	NA	Bearing	HSFG
Plate Girder	Top flange to web	**67.5%**	25.6%	0.0%	6.9%	0.0%	0.0%
	Stiffener to web	0.0%	**75.7%**	19.8%	4.4%	0.0%	0.0%
	Stiffener to top flange	23.9%	**57.9%**	0.0%	4.4%	13.8%	0.0%
	Endplate to girder (bearing stiffener)	31.5%	**64.1%**	0.0%	4.4%	0.0%	0.0%
I-beam with Channel	Horizontal channel to top flange	12.5%	**66.9%**	16.2%	0.0%	0.0%	4.4%
	Stiffener to web	0.0%	**80.2%**	19.8%	0.0%	0.0%	0.0%
	Stiffener to top flange	23.9%	**62.3%**	0.0%	0.0%	13.8%	0.0%
	Endplate to girder	25.0%	**75.0%**	0.0%	0.0%	0.0%	0.0%

Clearly even with light duty cranes, the top flange to web weld must be a full penetration butt weld. This is the most important detail on a crane runway girder. A few experts recommended using a full penetration butt weld for the top flange and continuous fillet for the bottom flange. This is a very dangerous thing to do. Firstly both flanges are highly stressed and secondly in South African industry, the designer can never be certain that the crane runway girder will be installed the right side up. For this reason a FPB weld must rather be used for both flanges. The SASC Handbook [2005] also recommends the use of the FPB weld for these details. The stiffeners are generally fillet welded all around to the web and top flange.

Table 5-5: The various connection methods and their opinion percentages for class three and class four cranes.

Girder Type	Detail Description	Class 3 & 4					
		FPB	Fillet	Fillet (St)	NA	Bearing	HSFG
Plate Girder	Top flange to web	**100.0%**	0.0%	0.0%	0.0%	0.0%	0.0%
	Stiffener to web	6.8%	**88.8%**	4.4%	0.0%	0.0%	0.0%
	Stiffener to top flange	38.9%	**47.3%**	0.0%	0.0%	13.8%	0.0%
	Endplate to girder (bearing stiffener)	46.5%	**53.5%**	0.0%	0.0%	0.0%	0.0%
I-beam with Channel	Horizontal channel to top flange	0.0%	38.0%	4.4%	**46.4%**	0.0%	11.2%
	Stiffener to web	6.8%	42.5%	4.4%	**46.4%**	0.0%	0.0%
	Stiffener to top flange	19.7%	29.5%	0.0%	**46.4%**	4.4%	0.0%
	Endplate to girder	26.0%	27.6%	0.0%	**46.4%**	0.0%	0.0%

Complete consensus is reached regarding the top flange to web weld. Responses from the experts went even further to say that the flange to web welds and the other welds on a crane runway girder should all be over-designed. The severity of the loading and the number of problems that occur related to girder welds is so high, that to put extra material on the welds is well worth it. The structures will be more reliable and failures will be reduced. Although the expert opinion shows a slight tendency to fillet weld the top flange to the stiffener, perhaps a conservative approach should be applied to this connection too. Failures have occurred at the stiffener to top flange connections and the FPB weld would again reduce the risk of failure.

To conclude the crane runway girder welding, it is thought that supplying a standard weld for all crane support structures could be the most reliable answer. Accordingly heavy duty cranes will automatically have the most suitable welds used and the lower class cranes deal with a conservative approach which is not completely uncalled for.

5.3.9 Crane Rails

Rails are generally prescribed by the crane manufacturer according to the wheel loads and wheel size selected. The structural engineer is then commonly left to decide on the rail clips used and the performance of rail – be it continuous or discontinuous.

5.3.9.1. Crane Rail Clips and rail performance

The responses received concerning rail clips included a straight weld between the rail and the top flange for extremely light cranes, a welded block which is bolted to the top flange or specialist manufactured rail clips (e.g. Gantrex or Gantrail). The welded square bar is not recommended even for extremely light cranes. The stresses in the welds are often too large and the welds tend to fail. A basic welded block which is bolted to the top flange is a much better solution for light cranes.

On heavy duty cranes it is expensive, but recommended to utilise the patented rail clips. At such a critical interface between the structure and the crane a rail clip that works well and allows for the correct movements is very valuable. The rail clips selected by the designer are also influenced by the performance required from the rail. Either a continuous or discontinuous rail is required. The expert survey resulted in the following.

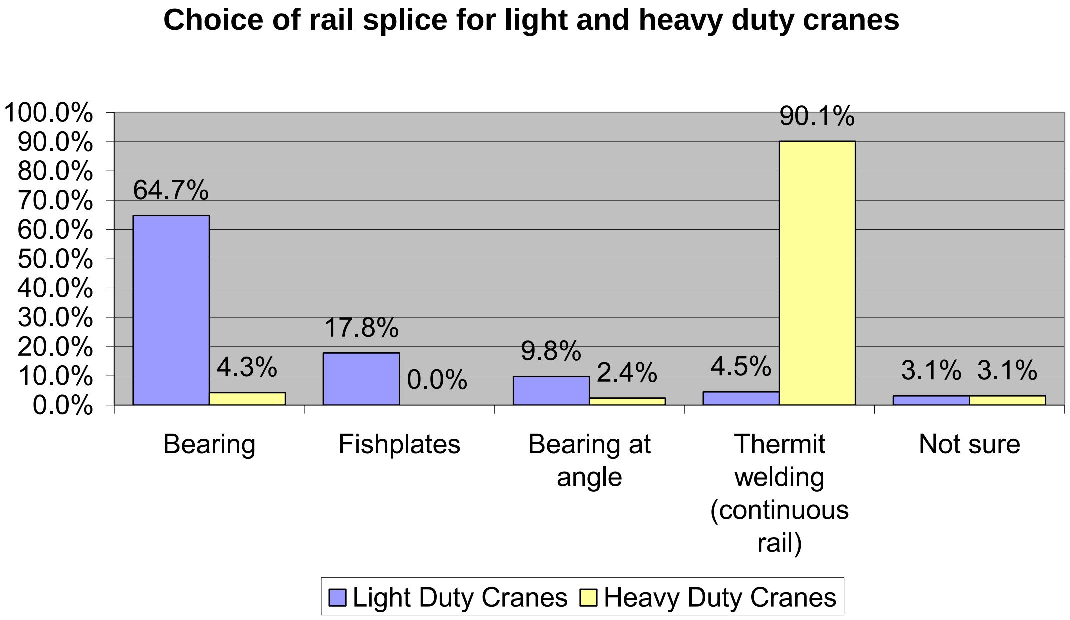


Figure 5.22: Selection of rail splice for light and heavy duty cranes. This choice influences the performance of the rail (either continuous or not)

Opinion results in light duty cranes using a discontinuous rail. Rail joints are avoided and the rail simply bears against the adjacent rail section. The rail sections are usually butted up against the end stops in order to reduce the chance of rail gaps forming. Rail clips close to the ends of adjacent rail sections helps to reduce relative lateral movement of the rails. *Figure 5.23* illustrates this approach.

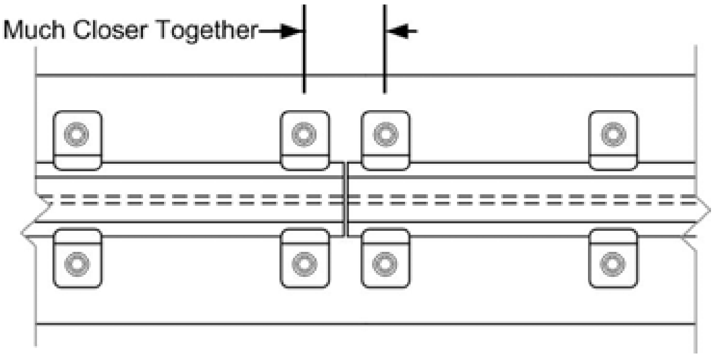


Figure 5.23: The use of rail clips to reduce the relative lateral movement of a discontinuous rail.

For heavy duty cranes expert opinion tends strongly towards a fully continuous rail. Thermit welding is commonly used to achieve this continuity. Space is provided between the end stops and the rail to allow for thermal expansion. The rail clips (usually patented) play an important role in the functioning of this type of rail. Movements in the lateral and vertical directions must be restrained but "float" allowed in the longitudinal direction. Accordingly "Best practice" can recommend a fully continuous thermit welded rail with proper patented rail clips for use on heavy duty crane gantries.

A last comment on rails and clips is focused on hook bolts which are used in Australia. One of the experts recommended these for cranes of a small capacity. Bolt holes, as with fish plates, are drilled in the rail web. The hook bolts then grip on the top flange and bolt through the crane rail. Pairs are required in order not to pull the rail over. Again an illustrative sketch is provided. Gorenc [2003] also recommends these rail clips as an option for light duty cranes.

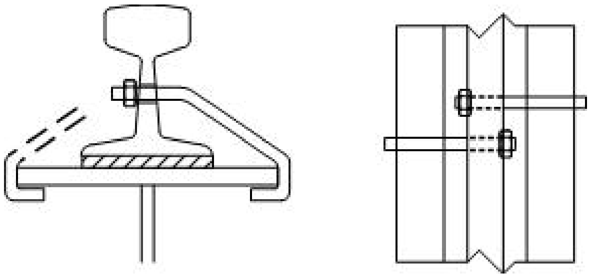


Figure 5.24: The hook bolt rail clips, for use on light duty cranes only.

5.3.9.2. *Elastomeric Pads*

Elastomeric pads were discussed in the introductory chapters of the thesis. Various positive influences were ascribed to the use of an elastomeric bearing pad. When the experts were asked to give their opinion on the use of an elastomeric pad, the same subjects were raised by many of the experts. The most important four subjects were: reduction of impact loads, reduction of top flange wear, spreads the wheel loads and smoothes the movement of the crane. It can be clarified that though many subjects were mentioned, the experts all said they were not convinced of the actual influence of the elastomeric pad.

The experts were subsequently asked to state whether or not elastomeric bearing pads are used on light and heavy crane gantries respectively. The following opinion results were obtained.

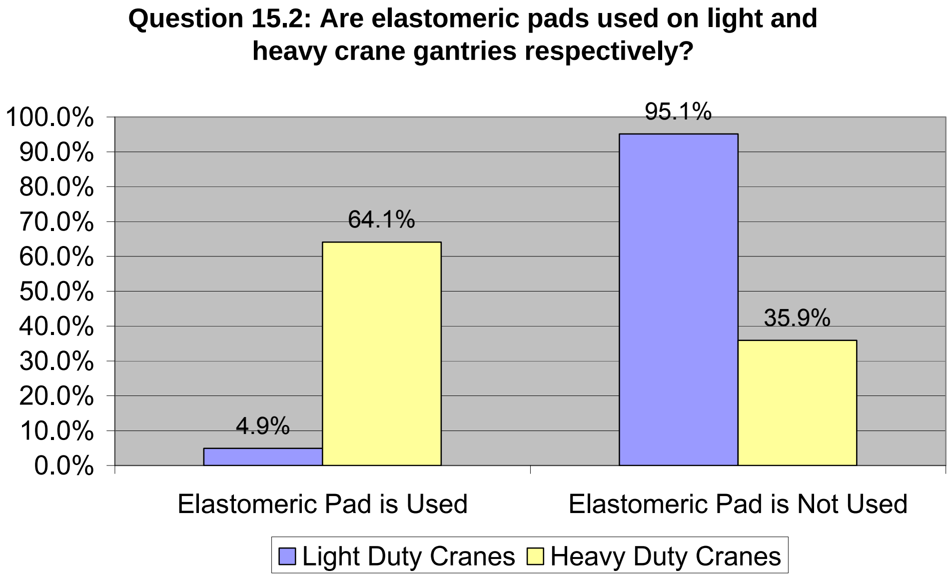


Figure 5.25: The use of elastomeric pads as a percentage of the expert opinion.

From *figure 5.25* it can clearly be deduced that light duty cranes do not require elastomeric pads. They are simply seen as additional to design. The heavy duty cranes make better use of the pads, and in general if the pad is not used, a steel wear plate is used instead. The wear plate is usually just a 5mm plate attached in a simple fashion to the top flange. It prevents wear on the top flange of the girder due to the arched curve beneath many rails.

"Best practice" should recommend the use of elastomeric pads or at least a wear plate on heavy duty cranes and either a wear plate or nothing at all beneath the rail of a light duty crane. Included or not, elastomeric pads do not influence the design of crane runway girders or rails at all. 87.9% of opinion supports this fact. The effects are simply seen as supplementary to the design and it is expected that the influence is only positive.

5.3.10 End Stops

Crane end stops are designed in a variety of ways. The survey detected that most experts were troubled by the maintenance performed on the end stop buffers (ensuring the buffers are present and working) and therefore design the end stops conservatively. This is also influenced by the small financial impact a conservative end stop design will have on the whole structure. The details used for end stop design are included in the details section of this chapter.

The buffer attached to the end stop plays a very important role in reducing the crane impact forces. The buffers are usually made of materials with excellent energy absorption characteristics. The crane itself is also often fitted with buffers. The joint action of two buffers colliding would therefore reduce the impact forces dramatically. For this reason the experts were asked which end stop buffers they prefer to use for light and heavy crane gantries respectively. The following results were obtained.

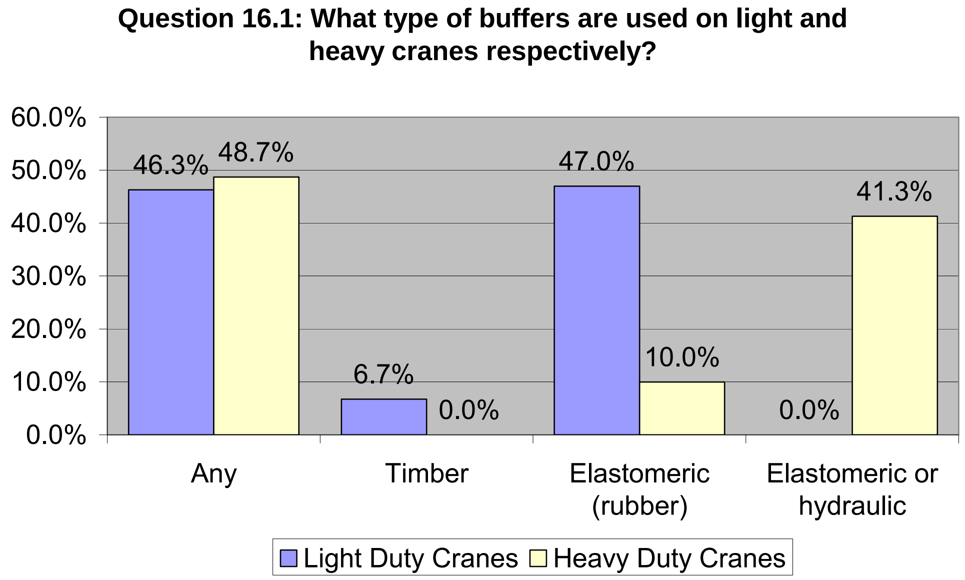


Figure 5.26: The selection of buffer type according to expert opinion for light and heavy duty cranes.

"Best practice" looks to use elastomeric buffers on light cranes and elastomeric or hydraulic on heavy cranes. Note that the hydraulic buffers have the best energy absorption properties, but the elastomeric buffers cost less and are more reliable given poor maintenance.

5.3.11 Bracing Systems and Expansion Joints

As was found in the literature studied earlier, the longitudinal bracing system is normally placed as close to the centre of the building as possible. This allows for equal expansion in both directions away from the centre of the building. 85.0% of expert opinion suggested this to be the optimal solution. "Best practice" can quite simply recommend this.

5.3.11.1. Bracing setups

The bracing system on a portal frame structure is normally only placed in the frame of the building. This means that the crane runway girders and wheel loads are eccentric to the plane of the bracing.

According to the experts, ordinarily, this eccentricity needs to be accounted for. The most common solution is to use a horizontal truss, much like a surge girder, in the braced bay of the structure. This will transfer the forces from the crane runway to the building bracing system. If the eccentricity is small enough and a successful check is made of the columns ability to handle the torsion imposed upon it, then no horizontal truss is required. If the columns are found to be sufficient, the possibility exists that the longitudinal forces causing the torsion will in fact disperse to more than one column. The design should not be made with this assumption in mind.

In buildings with a latticed column the bracing system of the crane and the structure are made separate. The bracings are typically placed in the same bay. This is to avoid blocking a second bay as the placement of the bracing is often influenced by the processes applied in the structure.

5.3.11.2. Continuity Plates

Due to the distance the end stop impact forces must "travel", from the end stops to the crane bracing system, a "continuous path" must be constructed along which the forces can "travel". In lighter cranes with smaller forces, the transfer is assumed to be made from one crane runway girder to the next through the cap plate bolts. In the event of larger forces, a continuity plate is used. Over 90.0% of the opinion stipulated the use of cap plate bolts or continuity plates. No other option is recommended. Note that according to literature web plates are especially troublesome. It is a positive that virtually no experts recommended web plates.

5.3.11.3. Structural Expansion Joints

In the event of the structure becoming extremely long (from literature approximately 100m is the limit) structural expansion joints may be required. In these cases the bracing systems must be placed equally spaced throughout the length of the building in order to minimise the total thermally induced deflections. The expansion joints are then situated between the braced bays. Furthermore the results obtained from the experts were no different from those previously found in literature.

Structural expansion joints are accounted for in three ways: Double columns (64.4% of opinion), slotted holes in the cap plate (10.2%) or accepting that the construction of simply supported beams allows for sufficient expansion (18.9%). The final portion of opinion indicates that no structural expansion joints are required (16.7%). All literature indicates that no expansion joints may be needed for small buildings, but if the length of the building exceeds approximately 100m, the designer must start to look at structural expansion and thermal effects. “Best practice” should accordingly also recommend thermal expansion joints in buildings over 100m. Perhaps the most comprehensive result is that slotted holes may be sufficient for light gantries. On the larger gantries additional details such as slotted holes will only serve to further complicate the column cap detail, consequently double columns would be preferred.

5.3.11.4. Rail Expansion Joints

All of the rail expansion joints cited by the experts were formerly introduced earlier in the thesis.

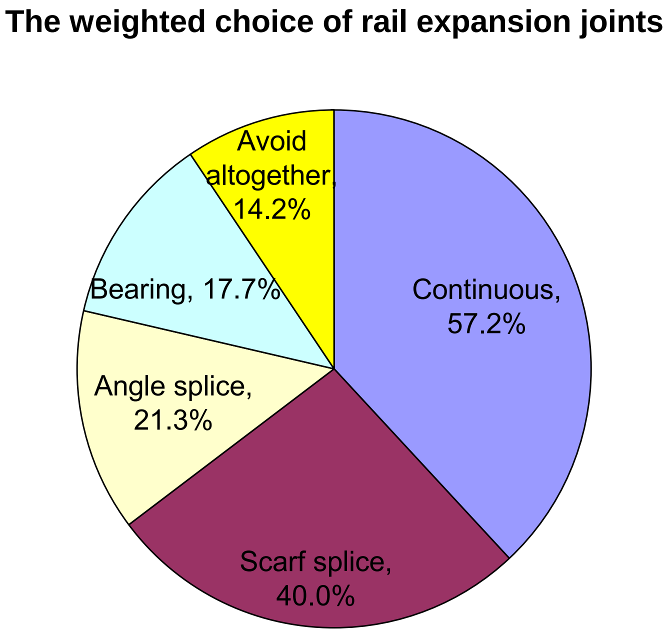


Figure 5.27: The choice of rail expansion joints is highly debated. Several responses were received.

Firstly, before the choice of rail expansion joint is described, note that it is of vital importance that the structural and rail expansion joints are not situated near one another. The failure to apply this would results in large gaps in the rail and the crane and structure would suffer as a result.

The angled rail splice (30° - 45°) is both recommended and disliked by certain experts. It can therefore not be recommended as “best practice”. Failures were mentioned concerning its use. The failure mechanism is thought to be caused by the point of the angle catching the wheel flange and damaging the rail and the crane wheels as a result. For this reason the scarf splice is preferred (*figure 2.23*).

Gantries with a fully continuous rail do not have rail expansion joints even in very long buildings (up to 500m). The conservative approach and one possibly to be prescribed by “best practice” is the use of a continuous rail in any structure that requires expansion joints.

A complication is found with the use of elastomeric pads and expansion joints. The rail movement at an expansion joint is necessary and causes wear. The pad is supposed to reduce this wear, but when a crane moves past a joint in a discontinuous rail, the one section of rail deflects downwards on the pad. The crane then bumps into the next section of rail which has not yet deflected downward. In these cases the use of a steel wear plate is preferred as the relative deflection is less. Continuous rails do not show this problem and can be comfortably used with elastomeric pads.

5.3.12 Crane Columns

The experts mentioned the column types introduced in chapter two of the thesis. “Best practice” is easily assessed to use the bracket on a portal frame for light duty cranes and a latticed column for anything to large for this setup. A guide was provided by one of the experts and since no other information on the subject has been found, these guidelines are supplied.

i) The spacing of the crane leg to the back leg on latticed columns should be around height over seven (h/7) to height over nine (h/9). The height refers to the crane rail height.

ii) The angle of the lacing on latticed columns should be around 30°.

iii) Portal frame columns with a bracket should be designed according to the tonnage of the crane and the columns ability to handle the eccentric loads imposed on it. If the column section becomes too large, rather use a latticed column.

5.3.13 Outdoor Cranes and Storm Brakes

The subject of storm brakes is one which few experts were aware of. No standard brake “concept” is available and perhaps because of the limited application of such brakes, the design thereof is not well known. Indoor cranes that can be shut off from the outside by doors should not require storm brakes. The crane gears and power drives switching off are able to hold the crane in place.

It is the outdoor cranes that are exposed to extreme storm wind conditions that are more commonly at risk. Failure events, sometimes catastrophic, caused by the lack of storm brakes during wind gusts have been documented. Therefore further investigation into the subject was warranted.

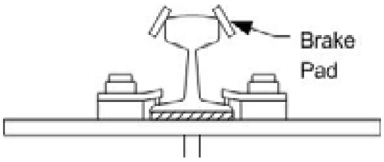


Figure 5.28: Example of the positioning of the brake pads on one type of storm brake.

The crane manufacturers interviewed had examples of storm brakes that involved a type of brake shoe which pinches the rail (*figure 5.28*). The friction produced is expected to restrict movement of the crane. The brakes details are not entirely understood. What is known is that the normal braking facilities (crane gears and power drives) are not sufficient to hold the crane in place. Cranes under storm wind loads have overcome the friction of the rail to wheel contact and skidded into the end stops - either damaging or running straight off the gantry. The "best practice" recommendation made here is to ensure that the crane manufacturers include a good quality storm brake on the crane. Be aware however, that some storm brakes, those that grip the rail, can cause rail damage. This is however not a reason to neglect a storm brakes inclusion. The rails should simply be inspected more carefully.

Another expensive alternative storm brake concept is the use of a fixed pin. The pin sits on the crane and when in the parked position can be electrically dropped into a hole in the crane runway girder. This would prevent any movement of the crane even under intense wind loading. The pin must be electrically inserted. Previously a person was expected to climb up on the gantry to insert the pin or tie down the crane with a physical chain. This had to be done as the storm winds increased and was very dangerous. Considering the storm brakes available, the electrical fixed pin appears to be the most reliable choice.

Outdoor crane supporting structures are furthermore similar to their indoor counterparts. The main structural difference is the lack of a roof system which helps to prop the columns and generate the portal frame action. The outdoor gantries are therefore supported on cantilever columns. The forces and moments on the columns and the foundations are therefore often much larger than for covered building columns. Relative deflections also increase as result of the roof system not joining the two columns. Special attention during design should therefore be afforded to these concepts.

A few additional tips on outdoor gantries include:

i) Pools of water forming on elements and the consequent corrosion must be avoided.
ii) Thermal effects are often more pronounced on outdoor gantries.
iii) The end stops should always be conservatively designed. Failures occur too frequently and as previously mentioned the costs of a conservative end stop design are minimal.

5.3.14 Unusual Structural Layout

The unusual structural layout encountered in the questionnaire involved unequal crane runway spans. Clearly if there are large differences in span length, the girders designed will differ considerably. The experts were asked how they solve this problem.

Firstly it can be commented that this problem is encountered on a fairly regular basis. Around 95.0% of expert opinion recommended "fish bellying" girders deeper than the rest or alternatively, placing a haunch on the shallower beam. The choice is made according to the design that will require changing (adding a haunch or "fish bellying") less girders.

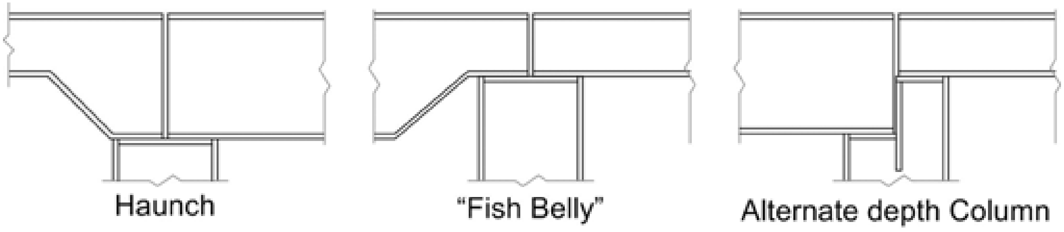


Figure 5.29: Various methods of adjusting the girder depths. Detailed illustrations are available later in the chapter.

MacCrimmon [2005] recommends that "fish belly" girders be used, but his primary recommendation involves designing a column that ends at two heights. This was not mentioned as an option by the experts and for this reason no clear decision can be made as to which is the better option. Another option involves the one girder resting partially upon the adjacent deeper girder. This is not recommended due to trouble in construction and maintenance.

Occasionally different crane girder runway spans are encountered on either side of a gantry. In this event, the experts recommend that the column causing the difference in span, be removed. If this is not done, an unsymmetrical runway will result, generating variable wheel loads. Although it is possible to design a variable span runway, it is not recommended as it negatively influences the crane and gantries performance.

5.3.15 Fatigue

Fatigue design in South Africa is completed using the SANS 10162-1:2005 steel design code. The method applied in this code was described earlier in the thesis. The experts were asked to state there opinion on the efficiency of the SANS fatigue section. Over 50 % of opinion stated that the code was not favoured, but that other international literature was preferred. This literature includes the British [BS 1055], Australian and European codes.

The present South African fatigue design methods are similar to that found in other international standards. It is recommended that which ever fatigue code is preferred, be used by the designer.

5.3.15.1. Fatigue tips

Fatigue as a concept elicited a great number of opinions of which the most important are listed below:

i) Fatigue is a serious problem with crane support structures. The designers must therefore make use of conservatively designed fatigue resistant details or a thorough fatigue check must be made. “Best practice” promotes a combination of the two approaches.

ii) Similarly the details must be fatigue resistant. In other words the details must be selected specifically to reduce possible fatigue damage. Most experts consider this the most important part of fatigue design. (e.g. The top flange to web weld must be a FPB weld and the surge connection must allow for movement due to cyclic loading)

iii) A problem with fatigue design is that it is not particularly accurate. The number of cycles is an estimate and the fatigue performance of different details also varies considerably. Therefore, although fatigue calculations can serve as a good design check, the details are more important.

iv) Most often only class three and class four cranes are subject to fatigue related problems.

v) Expert opinion recommended regular inspection of the details listed in *figure 5.30*

vi) Over 70.0% of opinion suggests that no further investigation of any structural elements is required. The number of cycles becomes too few on elements other than the crane runway girders.

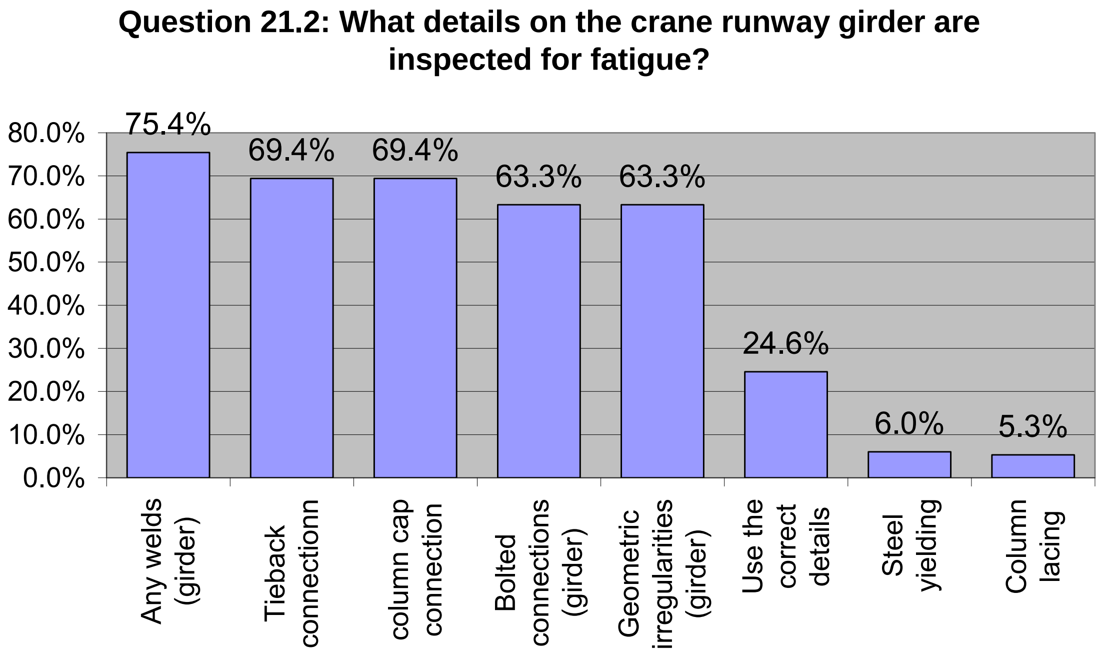


Figure 5.30: The details on the crane runway girder that require a fatigue check.

5.3.15.2. Stress and load cycles

Once the details and extents of the fatigue design procedure have been investigated, it becomes necessary to look into another of the slightly ambiguous fatigue subjects - stress and load cycles.

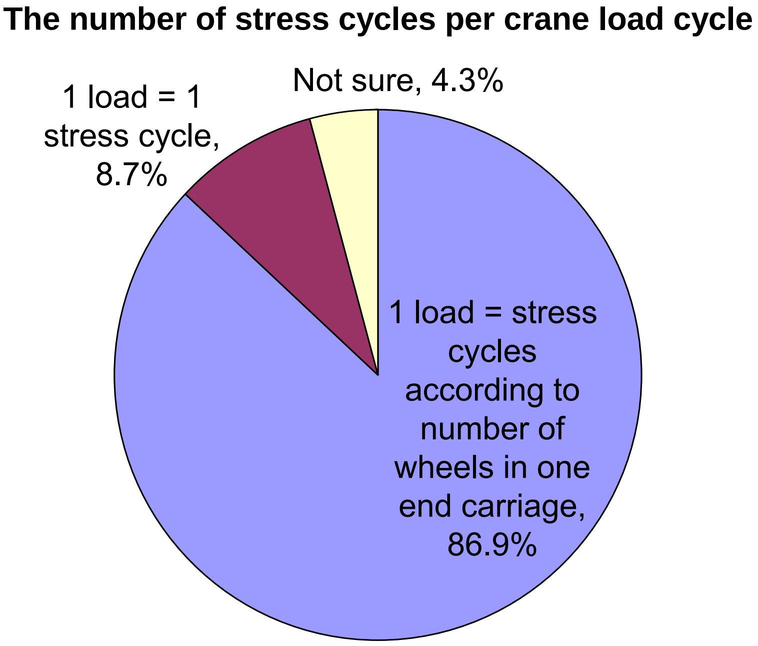


Figure 5.31: The difference between the number of load cycles and stress cycles experienced by a crane girder detail.

According to fatigue design in the Advanced Structural Steel Design Course Notes [2006], each time a crane passes a detail on a crane girder, one load cycle is completed. The load cycle is then multiplied by the number of wheels in one end carriage to attain the number of stress cycles a detail is subjected to. This calculation is most often followed to determine the stress cycles and is the more conservative approach.

As the research conducted to develop the fatigue seed question indicated, different crane runway girder details are subjected to varying stress cycles. *Figure 5.31* shows that 86.9% of the expert opinion agrees that one load cycle can amount to more stress cycles. Due to the relative consensus obtained between opinion and the numerical model, "best practice" recommends designing the crane runway girder details for a number of stress range cycles equal to the number of load cycles multiplied by the number of wheels on one end carriage of a crane. Furthermore details associated with the columns and bracing systems can be designed for the number of load cycles. The analysis described in *appendix D* supports this statement.

For instance when designing a steel mill ladle crane which either runs full or empty, some designers only analyse the full stress cycles and ignore completely the lower stress range of an empty ladle. According to fatigue theory, the smaller effect of the empty ladle should be combined with the larger full ladle stress cycles using a cumulative damage formula. The topic of cumulative damage has been described previously. The expert survey revealed no definitive answer regarding cumulative damage analysis, but "best practice" should remain conservative and include a proper cumulative damage assessment.

5.3.15.3. Duty Cycle Analysis

Duty cycle analysis, or load spectrum analysis, should be investigated and supplied by the client. The expert survey results furthermore reflect that the duty cycle analysis should include the load cycles and the capacity of each lift. For example: 2 000 000 lifts at 50% of capacity and 500 000 lifts at 90% of capacity. It is much more difficult to arrive at specific values for class one and class two cranes as their use is generally more unpredictable. Fortunately these structures are less likely to suffer from fatigue problems.

The movement of the crane can be included in the duty cycle analysis if known. This could influence the gantry design, but it is unreasonable and possibly dangerous to include this in design as processes and equipment positions can change. “Best practice” strictly opposes the use of crane movement in the structure for design.

5.3.15.4. Summary for Fatigue

Finally, when dealing with crane support structures and fatigue, these points should be remembered:

i) The use of the correct details is the most important part of any fatigue design.
ii) The analysis should be completed including all stress cycles and the cumulative effects.
iii) Use conservative detail designs. For example do not design crane runway girder welds to near to the design limit, rather tend to be conservative.
iv) Make sure the steel used is good quality material. Due to the manner in which fatigue manifests itself, bad quality materials or poor welding results in a greater chance of crack initiation from the microscopic flaws in the material. Implementation of quality control specifications is therefore important in crane support structure construction.

5.4 Details, Sketches and Commentary

The results and discussion thus far have been based on the expert opinion as obtained from the survey. The majority of the combined expert opinion was found to correspond to literature. In the cases where literature and opinion differed, alternative solutions were supplied. The notes and comments previously explained in this chapter require several detail sketches for further clarification.

The concept of “best practice for crane support structures design” also requires some good details which a designer can use as a guideline in design. This section of the results and discussions is possibly the most critical part of the “best practice” research, especially when the previously handled discussions on fatigue are reviewed. Note that due to the slight differences in detail sketches supplied by experts a weighted combination of opinion could not be made. Fortunately the experts do not disagree on many details.

Additional to the difficulty of combining details, some experts were not willing to supply designs, due to proprietary reasons. It is their designs that work, and they should be consulted personally if the designs are required. Fortunately this was not a common problem.

5.4.1 Latticed Columns

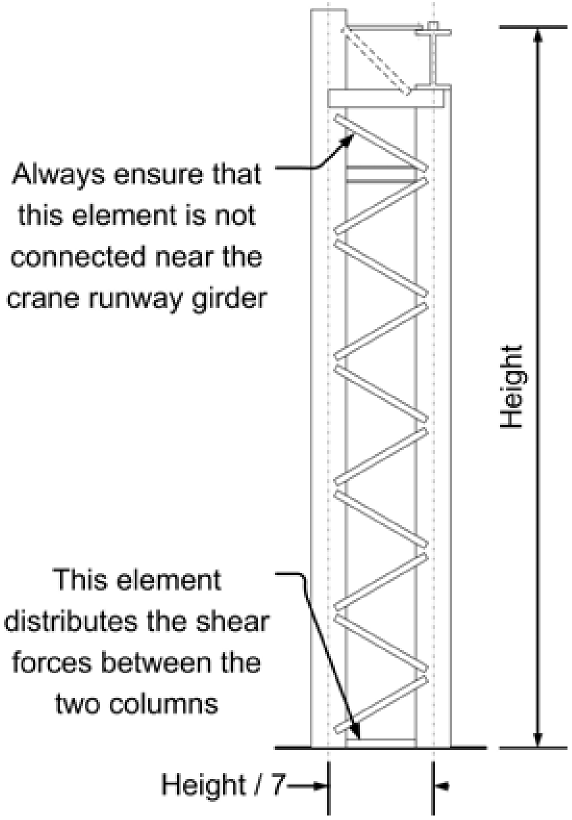


Figure 5.32: Latticed column with the targeted height to width ratio and the direction of the top lacing element.

Latticed columns are usually used for heavy crane gantries. The column acts as a truss which then connects to the roof system creating the needed structural stability in the lateral direction. The performance is similar to the standard portal frame with the foundations fixed against rotation. Horizontal lacing elements can also be included in the truss. Furthermore it is important to note:

i) The lacing and column are normally fully welded and prepared as a unit before being taken to site.

ii) The angle of the lacing should be approximately 30° (45° is still acceptable).

iii) The uppermost diagonal lacing element is always placed in the direction shown. It should not be placed near to the crane column cap.

iv) The lacing in all cases is on both sides of the column.

v) The width ratio is illustrated on the sketch and should be approximately height over seven to height over nine.

vi) The column legs are both orientated with the strong axis in the longitudinal direction, providing as much stability longitudinally as possible.

5.4.2 Crane Runway Girders

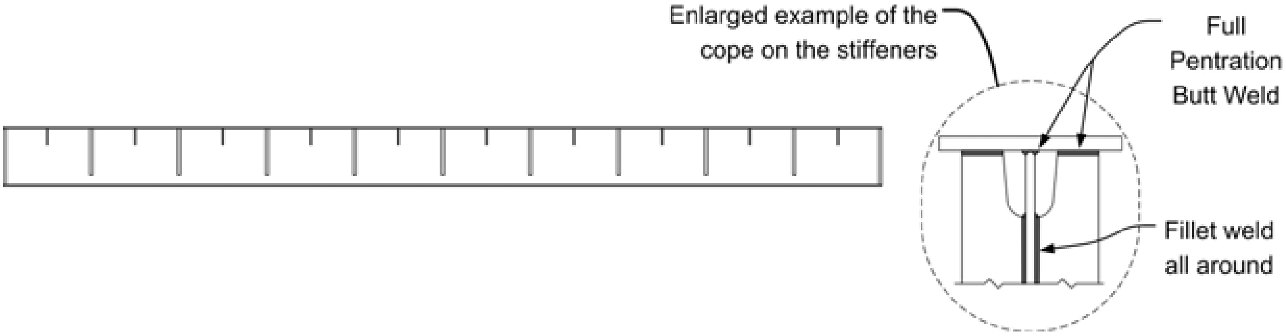


Figure 5.33: The modular layout of the crane runway girder indicating the welds and cope that should be associated with all crane runway girders.

It is recommended by some of the experts that a modular layout is effective. This means to geometrically divide the girder span into equal sections, usually eight or ten segments. The stiffeners are then placed according to the minimum design spacing, but in keeping with a geometric modular layout. The stub stiffeners are then placed equally between the intermediate stiffeners (one or two per segment). The rail clips are also spaced according to this modular layout. Not only does this process serve simplicity, it also tends to look good.

5.4.2.1. Crane Runway Girder Welds

The welds applicable to the different class crane runway girders can be found in *table 5.4* and *5.5*. It is stated that the top flange to web weld is always a full penetration butt weld. It is emphasised that “best practice” recommends that the bottom flange to web weld should also be a full penetration butt weld.

5.4.2.2. Stiffeners

The cope is made well clear of the top flange to web weld. The cope in *figure 5.33* is the best example available and is recommended by “best practice”. If another cope is used it should still provide ample clearance around the top flange to web weld and avoid sharp corners if at all possible.

5.4.2.3. Variable Depth Girders

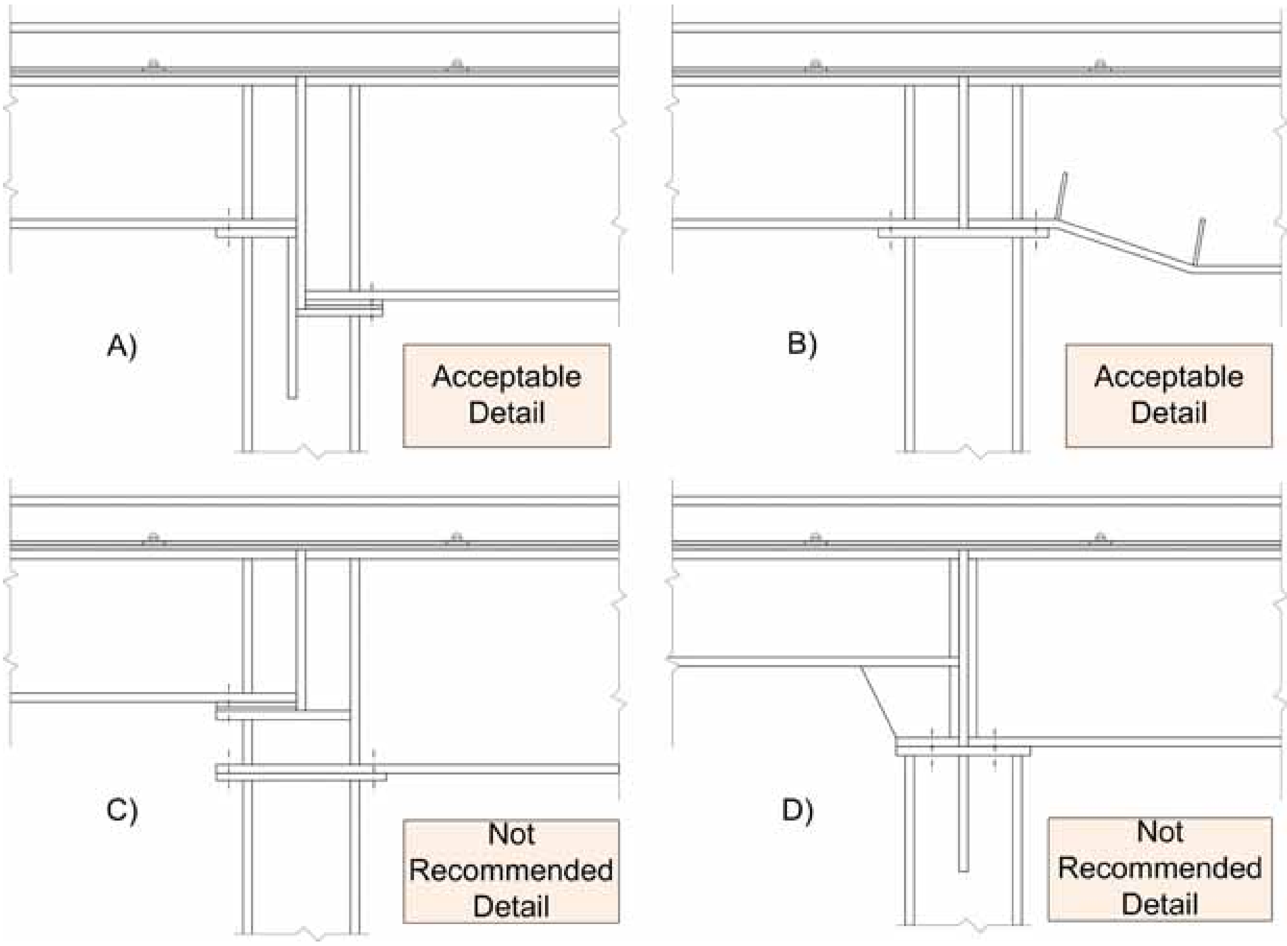


Figure 5.34: Acceptable and problematic methods of dealing with different depth girders. [MacCrimmon 2005]

The expert survey responses described detail B) and D) above being used in South African industry. After comparing this with literature it was found that the haunched girder in D) is not recommended, in part due to the reduced fatigue resistance of this detail. Detail A) was described to be acceptable according to the literature.

Detail C) was also found to be troublesome. The smaller beam sits upon the larger one and it is difficult to construct, repair or replace. The recommended details to handle different depth girders are A) and B). It is therefore satisfactory that detail B) was most popular amongst the expert opinion.

Take note that the column cap to crane girder details in *figure 5.34* are for slightly lighter cranes. Added facility for nib plates and continuity plates should be made for heavier gantries. These concepts will be discussed in the next section.

5.4.3 Tieback and Column Cap Connections

The entire region at which the crane runway girders, the columns and the roof system meet is a very interesting and complex connection. Multiple connections are required compensating for movements under variable repeated loading and lateral and vertical adjustment must often be facilitated. The tieback connection at the crane runway girder top flange level resists the large surge forces and is possibly the most critical detail of all. The details related to the column cap and girder to girder connections are also crucial. A few of the recommended details from the experts and literature are included along with details that should never be used for crane support structures.

5.4.3.1. Light Cranes

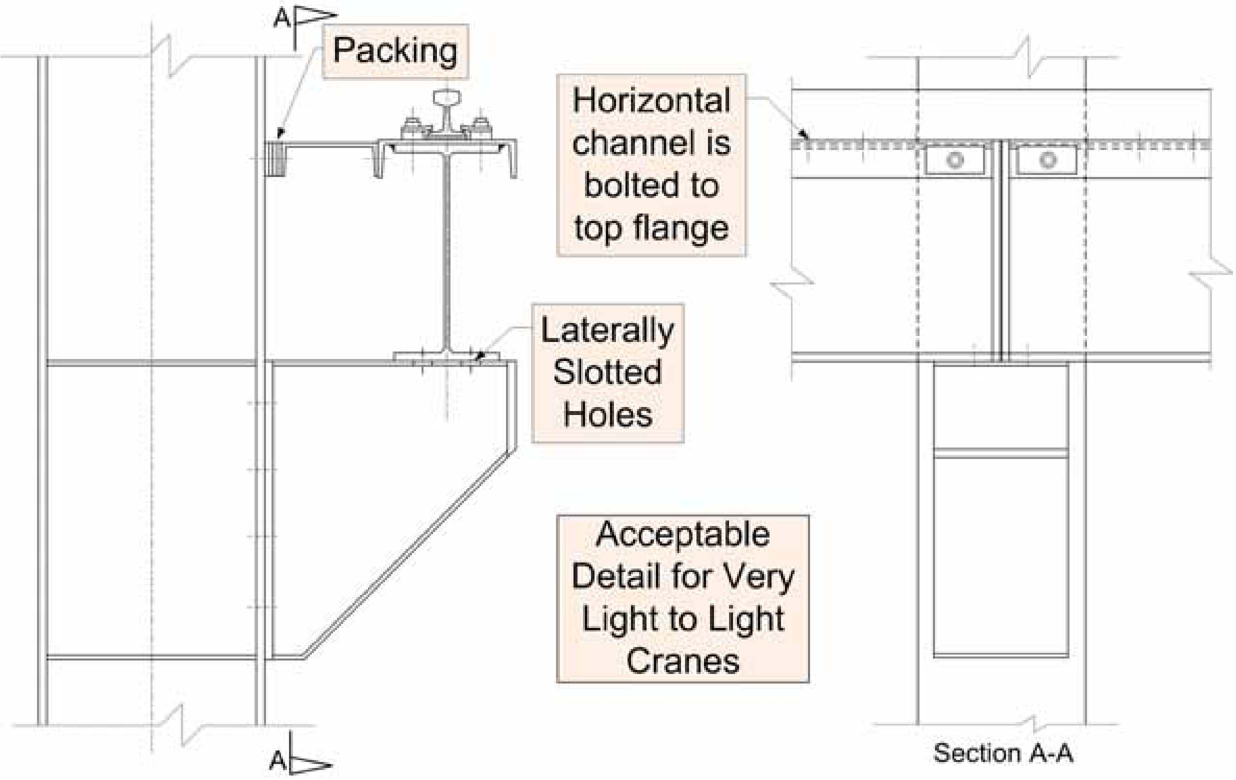


Figure 5.35: A bracket connected to the portal frame column as a light crane setup.

Figure 5.35 is an example which is acceptable for light cranes. The tieback is provided for illustration purposes and is not recommended for medium (large class two) cranes. For extremely light cranes (class one or small class two), which are this details only application, the horizontal channel will most commonly be unnecessary. A universal section alone will most likely be sufficient. The bracket in *figure 5.35* is cut from a section similar to the portal frame column it is connected to. It is bolted to the portal frame. The required stiffeners on the columns and bracket should be placed according to regular design principles.

For such light crane setups, the bolts in the column cap will be sufficient to ensure continuity of the longitudinal forces. Laterally slotted holes in the column cap and packing at the tieback connection allow for good alignment of the girder and rail. The tieback element is a channel section. Single bolts at each end of the channel connect the column to the crane runway girder. This allows for some movement of the connection as it is pinned. Maintenance on these bolts must be performed.

As stated previously the welded block rail on the top flange is not recommended. It should only be used for light, low duty, cranes and perhaps in combination with a dual span continuous runway girder. If possible try to avoid it altogether.

5.4.3.2. Light to Medium Cranes

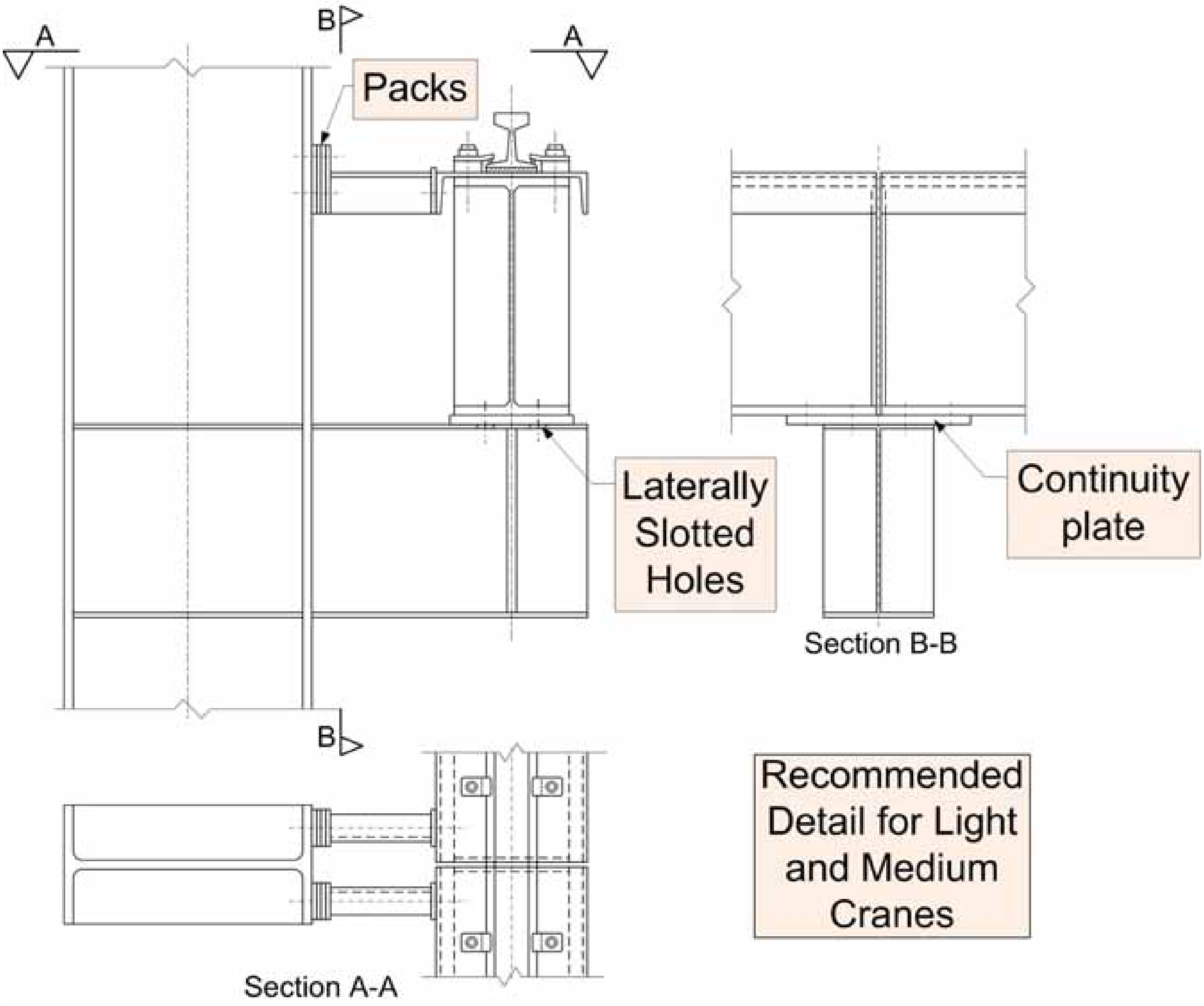


Figure 5.36: A light to medium crane setup recommended for use. [SASC Handbook 2005; Expert Opinion]

The setup in *figure 5.36* is a used fairly often for light and medium cranes. It incorporates the continuity plate and shows an alternative tieback connection. This setup could also be employed without the horizontal channel on the top flange. The rail clips and rail, is a much more efficient choice than a welded square bar. Note again that the connections at the tieback are made with only one bolt in order to affect pinned connection. Slotted holes are again included together with packing to allow for lateral alignment.

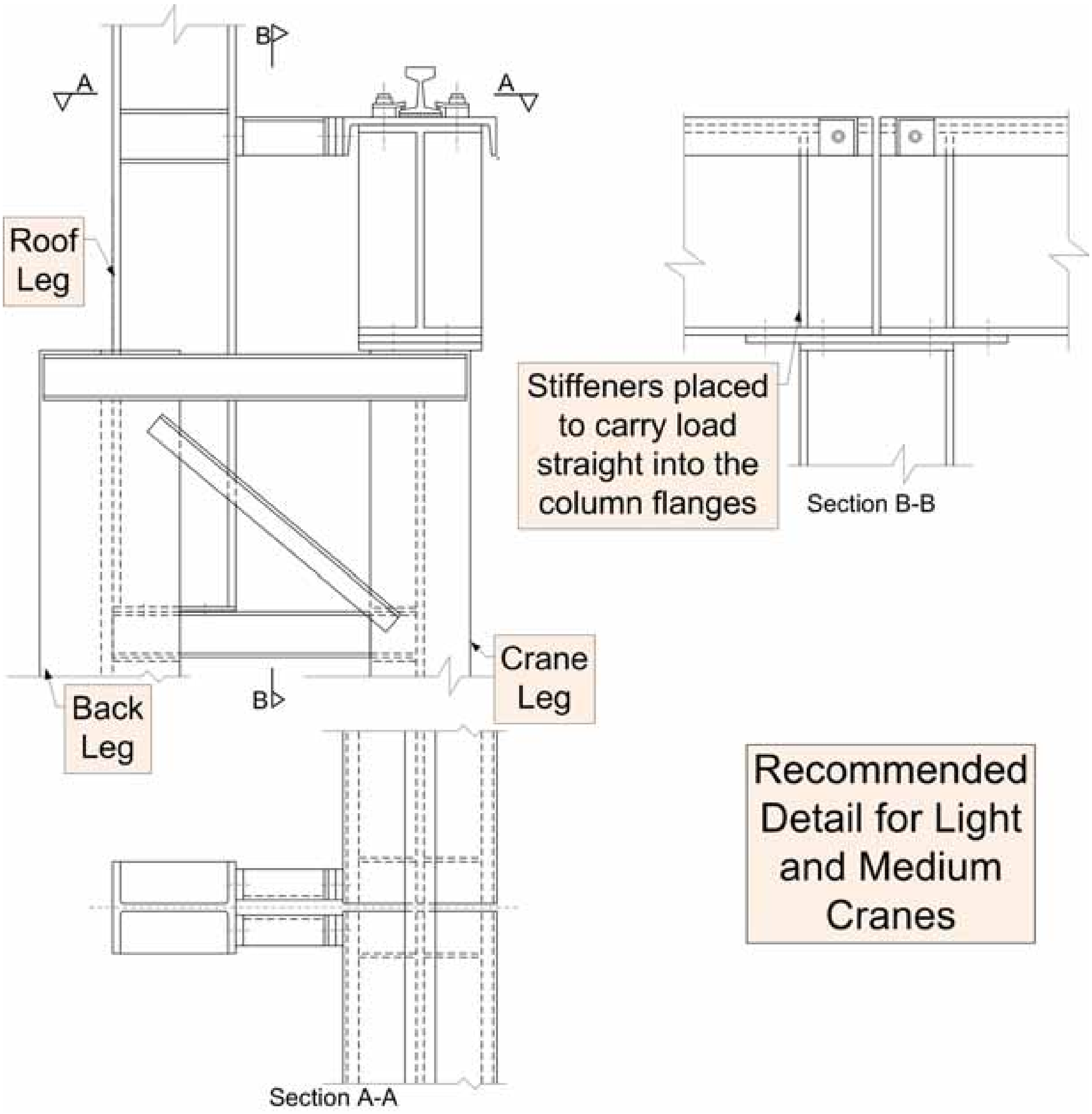


Figure 5.37: A detail using a split column that is appropriate for medium sized cranes.

Much of the information supplied in the previous sketches is still applicable to the medium to heavy crane details. *Figure 5.37* is the first example of a latticed column and comprises a medium duty crane girder and tieback detail, with a heavy crane column setup. Some points to note are:

i) The diagonal bracing starts at an angle that is away from the crane runway girder.

ii) The end bearing stiffeners are placed in line with the crane column flanges as this is the stiffest portion of the column.

iii) The roof column is often separate to the back leg, requiring a good rigid connection.

iv) The roof column is bolted to the back leg (bolts not shown on the sketch) and to the I-section spanning between the crane and back leg. Creating a moment secure connection.

5.4.3.3. Heavy to Very Heavy Cranes

Three heavy to very heavy crane support structure details are illustrated. The surge girder (truss), the surge plate with an auxiliary girder and the surge plate combined with an auxiliary truss are depicted with commentary.

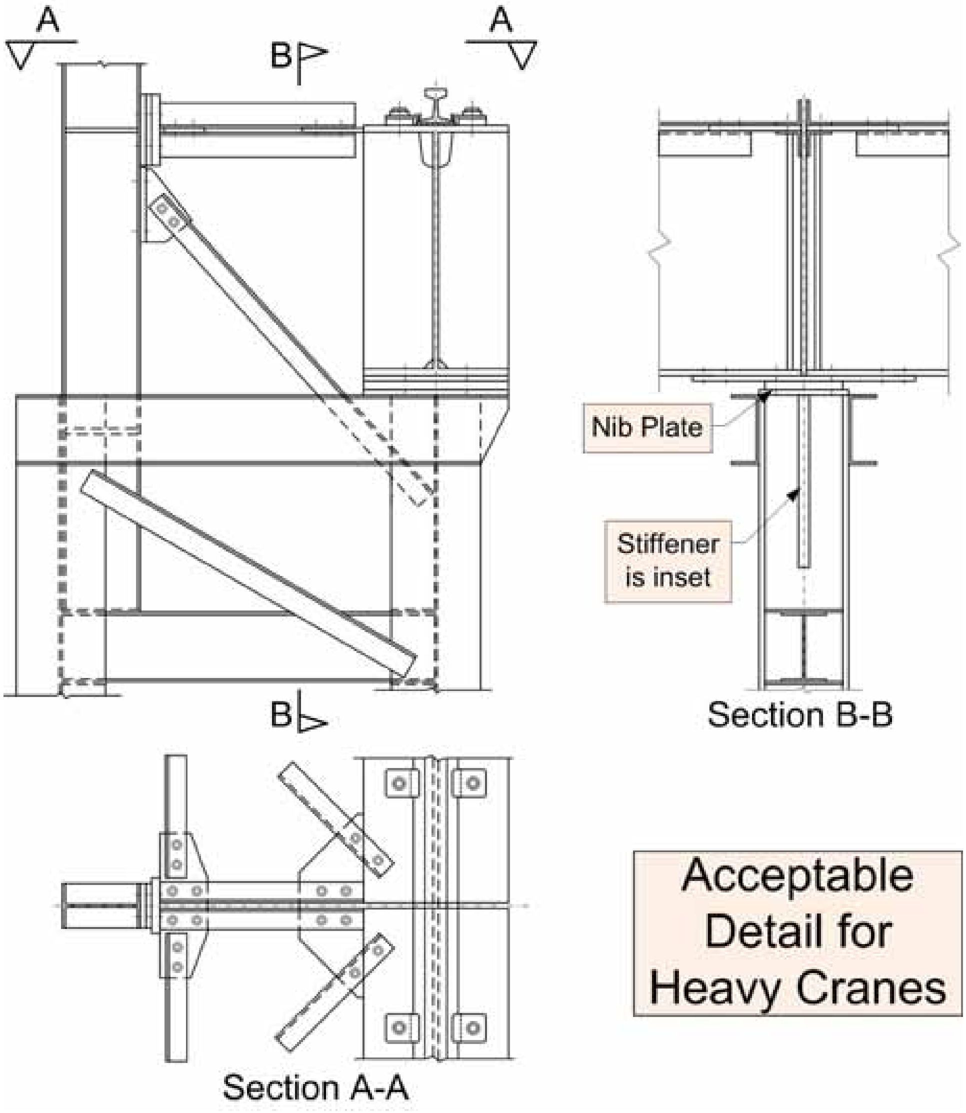


Figure 5.38: A heavy support structure detail making use of a surge girder (horizontal truss).

The following points can be noted when considering *figure 5.38*.

i) The lacing from the roof leg to the crane leg is diagonal away from the crane girder rail.
ii) The surge girder is less popular amongst the experts as it does not double as a walkway.
iii) The crane column bearing stiffener is set into the crane column. In other words a cut is made in the crane column web and the stiffener is welded into the cut. This improves the bearing capabilities of the column.
iv) Packing and slotted holes allow for alignment of the crane runway girders.
v) The rail clips will allow for finer alignment changes.
vi) According to the experts the surge girder is most commonly bolted and not welded.

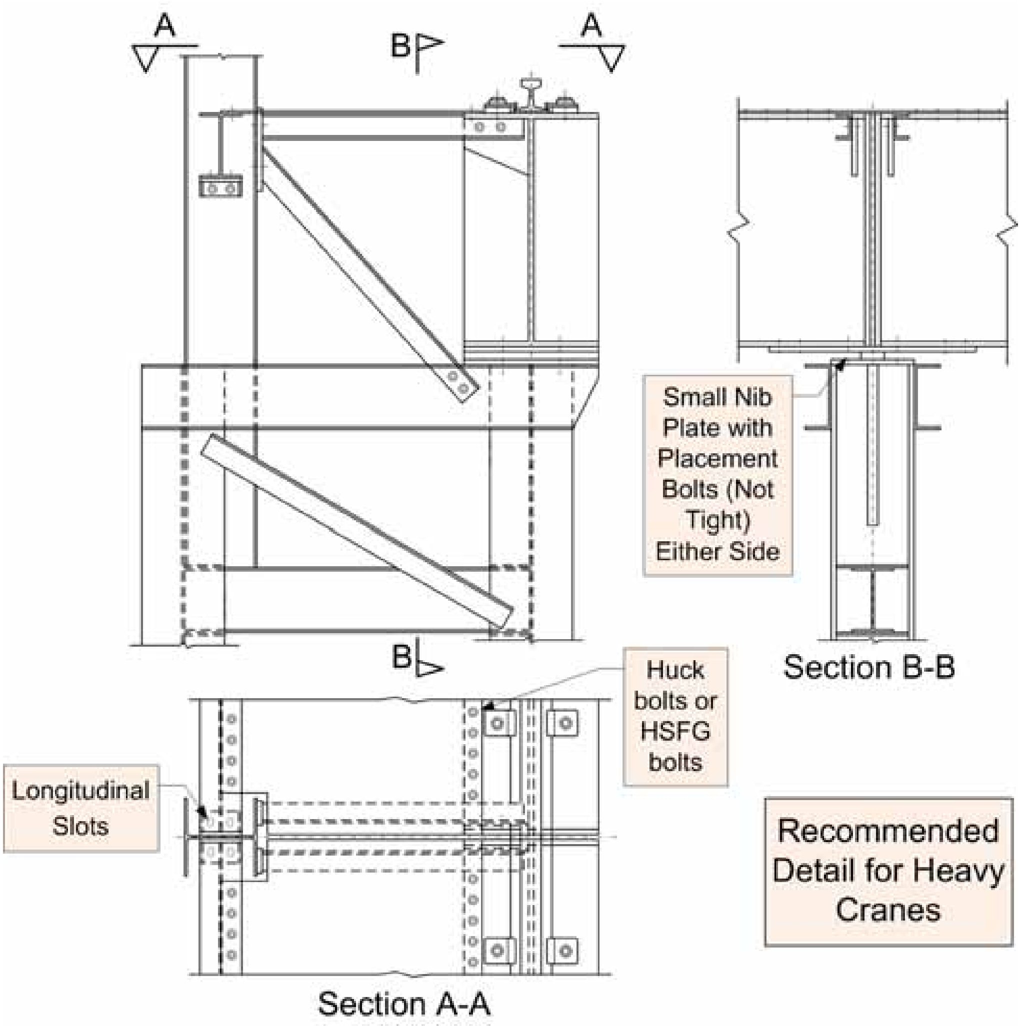


Figure 5.39: A heavy support structure detail making use of a surge plate resting on a bracket.

Figure 5.38 and *5.39* are very similar. The surge plate is supported by the crane runway girder on the one side and the auxiliary girder on the other. Both connections on the surge plate are made using Huck bolts or HSFG bolts thus creating a compound section. HSFG's and Huck bolts withstand fatigue loading better and normal bolts would not enable the compound action of the section.

The continuity plate in *figure 5.39* is a useful good detail proposed by the experts. The nib plate, which helps reduce eccentric loading in the crane column, is small enough to ensure the girders are simply supported. The bolts adjacent to the nib plate are simply placement bolts. They are hand tight so as not to carry any load due to crane girder movements. The continuity plate must be a flexible plate that easily follows the crane girder movements without becoming heavily stressed. The continuity plate bolts (HSFG or Huck bolts) are placed clear of the column cap to keep the connection neat and avoid contact.

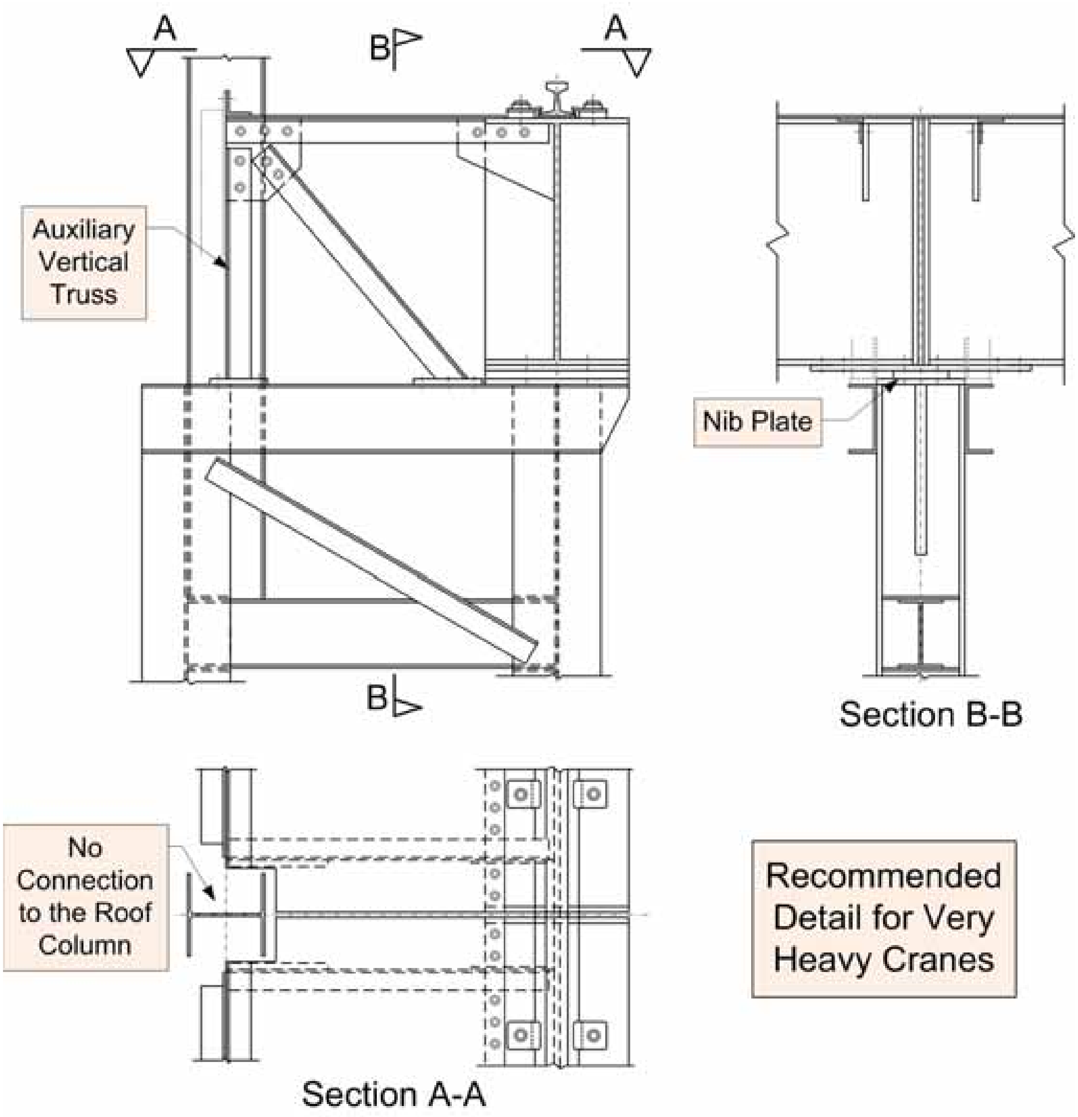


Figure 5.40: The detail most effective for extremely large cranes. [SASC Handbook 2005]

Note the following comments on the surge plate setup in *figure 5.40*:

i) The surge plate and auxiliary truss do not connect to the roof leg at all. The box section created using this detail rests as a unit on the crane and back legs of the split column.

ii) HSFG or Huck bolts must be used on the surge plate connection.

iii) In this detail the placement bolts go through the nib plate. This was recommended by the experts as the better solution. The decision of how to design the nib plate rests with the designer. The available space in the nib for placement of these bolts may influence the decision.

iv) When finger-tight bolts are used, the thread of the bolts should be welded or locknuts used to ensure the bolts stay in place and do not work loose. The implementation of routine maintenance is again emphasised and recommended.

5.4.4 Alternative movable Tieback Details

The details supplied in section *5.4.3* were those recommended by the experts. The commentary is also based on the elicited expert responses. Now alternative, improved tieback connections are discussed. These are based on literature and can be incorporated with the previous detail principles.

The tieback connections described for use with light or medium sized cranes have all included a rigid section that is pin connected at either end. This is normally acceptable, but fatigue problems will slowly surface as a result of the variety of movements that the connections must cater for. This is the reason for the connection in *figure 5.41* being developed. This sort of connection is thought to perform far better under fatigue conditions. Notably it was only mentioned by one expert. Rowswell [1987] did a fair amount of research on these connections together with Gantrex. Therefore more information on the connections can be found in Rowswell [1987]. The following comments are made based upon *figure 5.41*.

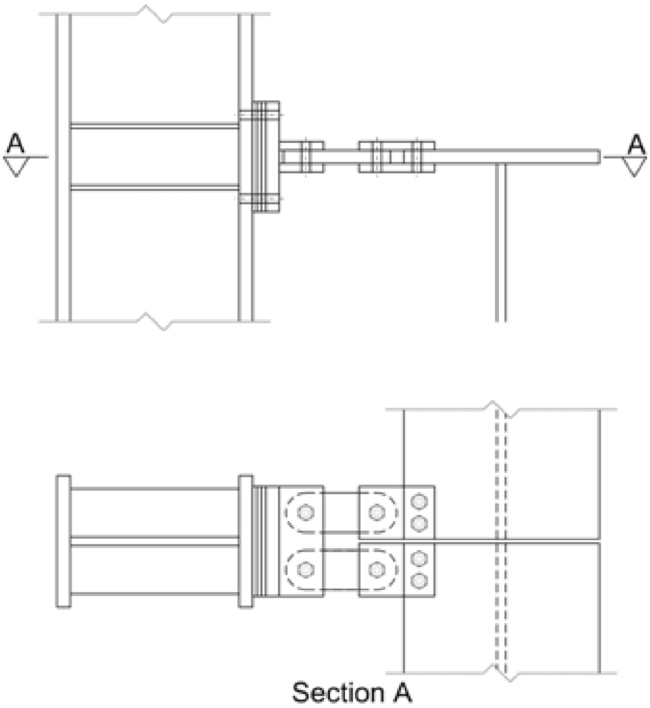
i) The straight link causes torsional effects on the column due to the eccentricity of its connection to the column.

ii) The inclined alternative tries to minimise the torsional forces imposed on the column.

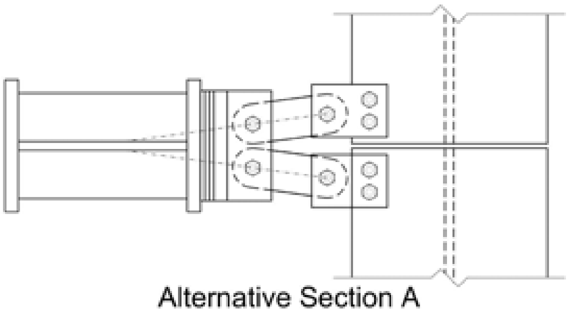
iii) The concept behind this connection is based on providing a link that moves easily in the longitudinal direction, provides for some rotation and vertical movement and is supportive in the lateral direction. The link, or similar, is the best solution found yet.

iv) The link can be used with a surge plate, if the surge plate makes use of an auxiliary girder connected to the roof column.

v) The thread of the bolts in the tieback link should be welded or locknuts used to ensure the bolts stay in place and do not work loose. This will allow for the movement and rotation needed, but prevent the bolts from working loose. HSFG's are recommended elsewhere on the connections to ensure an efficient connection that will not work loose.



Section A



Alternative Section A

Figure 5.41: Illustration of the tieback link. This sort of connection has been well described in Rowswell [1987].

Gantrex have developed a connection like this called the Gantrex Link. It is expensive but is described by Rowswell as being very efficient. It makes use of a bearing mechanism in the link which allows for the movements and rotations required. Further examples of the Gantrex Link are provided in *appendix E*.

5.4.5 Details to Avoid

The details in this section should be always be avoided when designing crane support structures.

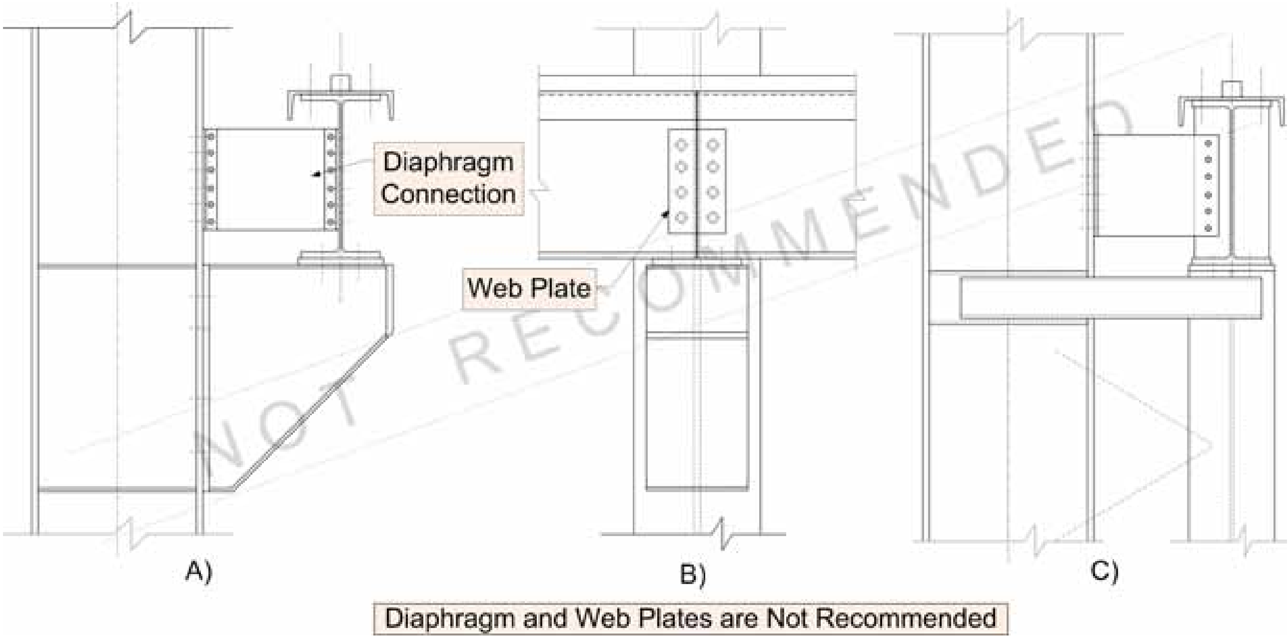


Figure 5.42: Some details that should be avoided when designing crane support structures.

- i) Any connections of the diaphragm kind should be avoided.
- ii) Web plates should never be used.
- iii) These connections are prone to fatigue failure under repetitive loading.
- iv) Cracks develop in several places due to extreme stresses in the diaphragms.
- v) The bolts can also be highly stressed and may fail.

5.4.6 End Stops

The final details to be studied are the end stop details. Two details were viewed with the background information. Both of which can be found in the SASC Handbook [2005]. An alternative end stop design found in literature is shown in *appendix E*.

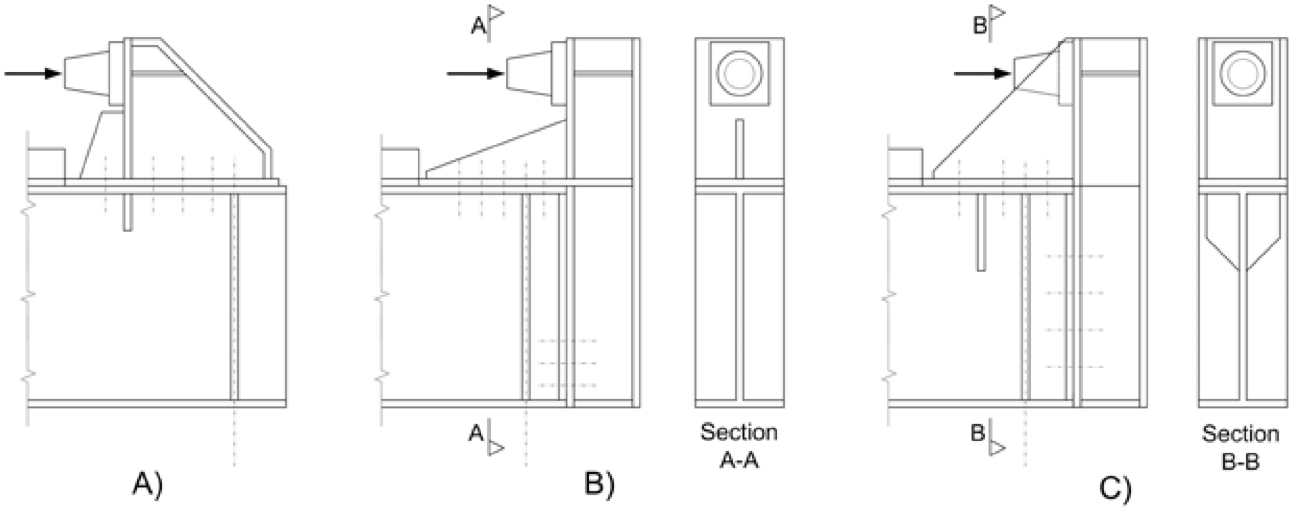


Figure 5.43: Three possible end stop designs as provided by the experts.

Example A) in *figure 5.43* makes use of the welded plate end stop which sits upon the crane runway girder. The other two designs make use of a universal section which helps transfer the forces back into the crane runway girder. In other words the buffer force generates a moment about the top flange connection; the bottom of the universal section then generates a counter moment due to the crane runway girders "support". An illustrative sketch is supplied in *figure 5.44*.

The designs making use of the "counter force" are better for the heavier crane gantries as they dissipate some of the energy safely in the crane runway girders. Example A) from *figure 5.45* includes the column cap design with the possibility of further expansion of the crane runway.

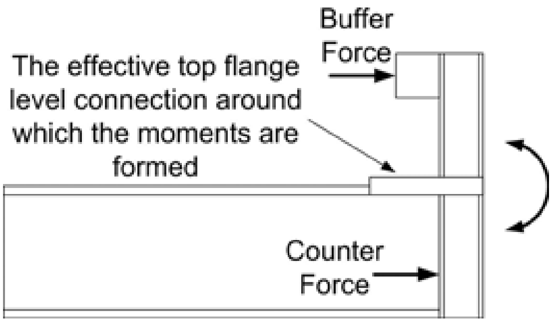


Figure 5.44: Schematic of the "counter force" used to dissipate the end stop impact forces safely.

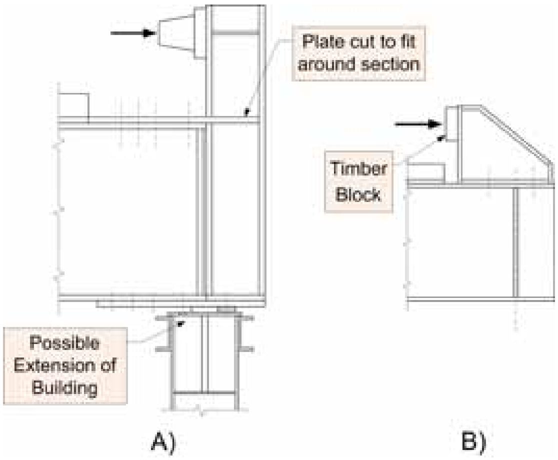


Figure 5.45: End stop design which facilitates later expansion (A) and a light crane gantry end stop (B).

5.4.7 Details Summary

Details are very important to crane gantry design as they can influence the structures fatigue resistance. Choosing the correct details therefore is of cardinal importance. The designs in literature are less practical and more expensive when compared to the designs in South African practice obtained from the experts. However, the experts' designs are assumed to work well. In fact the difference between literature and practice, though noticeable, was found to be small. Both sources intend to solve the same problems. It is reiterated that the only difference between literature and experts details are those pertaining to practicality, time and cost. The experts logically view these three subjects as more important.

All of the details included in the results and discussion and some additional sketches are provided in A4 format in *appendix E*.

5.5 Failure Investigation

As a result of the limited success of this investigation during the survey, the results obtained will simply be tabulated. The failure mechanisms will be listed with commentary from the experts. No indication of the number of failure events per mechanism or the number of experts that mentioned a mechanism is provided. This information is seen as unnecessary for the limited failure mechanism investigation which resulted from this survey.

General expert opinion states that almost all failure events could have been avoided if well selected design details were used and basic structural and crane maintenance were applied. Fatigue issues do not disappear as a result of a fatigue design. The structure is still subjected to the repetitive loads and the stresses will find any weak spots in the structure. For this reason maintenance becomes a prerequisite for support structures. A complete design for fatigue is nonetheless recommended.

Table 5-6: Failure investigation mechanisms with commentary.

Failure Investigation		
No.	**Failure Mechanism Description**	**Added Notes**
1	Articulating crane bogeys absence increases the wheel loads	This failure mechanism is related to the the relative stiffness of the crane to the support structure which has been discussed. Lifting loads close to one side of the gantry can cause relative deflections of the crane support structure to vary. This coupled with the higher torsional stiffness of the crane bridge can cause a wheel to loose contact with the runway. This leads to wheel forces exceeding the maximum design wheel loads occuring in the remaining wheels making contact. The bogeys of eight or more wheeled cranes should therefore be articulating.
2	Badly constructed or fabricated cranes or support structures	This can be the primary cause of other failure mechanisms. Furthermore if construction or fabrication is of a very poor quality, it can be directly responsible for the crane derailing or other catastrophic problems. Problems of this magnitude occur very rare.
3	Cap plates without nib plates	Nib plates are very important as they cause the column forces to be imposed symmetrically on the column. On heavy cranes, the lack of a nib plate can damage the runway girders and cause higher stresses in the columns due to eccentric application of the loads. Nib plates should be included on all heavy cranes.
4	Connical wear of roller guides	The mechanism is not fully understood. The wear is caused predominantly by misalignment and skewing. It is a snowballing occurance that worsens quickly over time. It is best to avoid using the roller guides at all.
5	Continuity plates and the bolts have failed	Continuity plate failures occur due to rotations and movements imposed on the plates by crane runway girders. Either the bolts work loose and fall to the ground or the plate itself develops cracks. Most commonly this problem can be avoided by choosing the correct bolts and implementing regular maintenance. So long as the bolts stay in place (tight or loose) they still work. Bolts in or adjacent to the nib should only be placement bolts.
6	Continuous girders	The problems experienced with continuous girders are quite wide-spread and have been discussed. Rather use simply supported girders.
7	Insufficient cope clearance	The stiffeners on crane runway girders must avoid influencing the top flange to web weld. Furthermore, the cope should not include any sharp corners as this promotes the crack initiation.
8	Diagonal lacing or tieback element incorrectly orientated	The positioning of these elements has been covered during the detail results section of the thesis. It can additionally be commented that if placed incorrectly the lacing or its bolts will rapidly reach failure.
9	End stops fail	In some cases the end stops are under-designed and cannot prevent the crane, under for example storm wind conditions, from running through the end stop. This has occured on several crane gantries in South Africa alone. Possible solutions are implementing storm brakes and more conservative end stop design. Ensuring the buffers are present will also assist the energy dissapation.
10	Expansion joints	Expansion joints in the rail and in the structure can lead to problems. If possible they should be avoided altogether. If the building requires them, careful implementation of the expansion joints will limit associated issues such as rail damage.
11	Outdoor crane runways and relative deflections	The columns of an outdoor crane deflect independently as they act as vertical cantilevers without the propping action of a roof system. For this reason it is possible that crane will "jam" due to inward column deflection. Further details on the influence of this mechanism has been discussed previously.
12	Packs working loose	The packs used to adjust the lateral and vertical alignment of the crane runway girders can work loose under repetitive loads. The packs must be placed correctly and preferrably with some means of securing them in place.
13	Rail clip failure	Rail clips are, similar to the girders, repetitvely loaded. This repetitive loading can cause rail clip failure and the clips may fall to the ground. Regular maintenance can ordinarily prevent these failures and subsequently prevent later rail damage which could result.

Table 5-7: Failure investigation mechanisms with commentary. (Continued)

Failure Investigation		
No.	**Failure Mechanism Description**	**Added Notes**
14	Rail performance problems	Crane rails on heavy duty gantries that are not continuous or that have been poorly welded to attain continuity can break. The weld used should be a thermit weld. The rails should always be regularly maintained.
15	Rail wear, rail neck failure and rail impedence	The rail can wear badly due to the wheel flange contact, skewing and misalignment. Wear commonly occurs at an inclined angle and can lead to the crane derailing. The rail neck has fractured due to the same horizontal forces. The rail neck failure could be avoided by using a proper crane rail. Items on the rail (e.g. clips and bolts) can cause crane and rail damage.
16	Rails welded to the top flange	The square bar rail is a bad rail type to use and the welded connections between the rail and runway girder often fail even when used on extremely light crane gantries.
17	Roof column torsion due to eccentric surge forces	The columns should be designed to withstand any torsional forces imposed upon them due to eccentric loads (e.g. from the surge forces in the tieback connection). Column damage has resulted when this is not done.
18	Stiffener connections	The welds connecting the stiffeners to the top flange and web have failed. Failure is caused by initiation and propogation of fatigue cracks in the welds. This can be avoided by using fatigue resistant connections as mentioned earlier in this chapter.
19	Stub stiffeners and top flange rotation causing cracks in the web	Crane runway girder top flange rotation has been discussed. The stub stiffeners were described as partially preventing the rotation of the top flange. Occurances where the rotation was simply transferred to the bottom of the stiffeners have been noted. This can lead to the web rotating at the stub stiffener toe and causing cracks to develop in the web. A solution is to reduce the rotation and lengthen the stub stiffeners slightly.
20	Surge plates with sharp geometric corners can initiate crack formation	Sharp geometric corners on surge plates have been found to increase crack initiation. Ensuring that the surge plates are well manufactured with few sharp geometric corners will reduce the chance of the problem surfacing.
21	Tieback connections and fatigue	The tieback connections are subject to large fatigue inducing stresses and many failures have been documented. If badly designed (with minimal movement) and subjected to enough stress cycles, the connections will fail. Solutions to these failures have been discussed. Good alignment and routine maintenance are most important.
22	Top flange to web weld failed as there were no stiffeners on the crane girders	The crane runway girders were designed without any stiffeners. This lead to larger increased rotation of the top flange which in turn caused large stresses leading to fatigue cracks. In time the entire weld can crack and develop complete separation. Alternatively, due to for example misalignment of the runways, the rail is placed eccentrically on the girders. This leads to the high stresses in the weld and fatigue cracking. A full penetration butt weld and better alignment can reduce this effect.
23	Vertical alignment of the rails	Vertical alignment of the girders and rails can lead to the raised girders bearing stiffeners failing under the increased loads. It is very important to ensure accurate vertical alignment in addition to lateral alignment.
24	Web plates crack	Web plates and diaphragms as tieback connections have developed cracks and gradually reach complete failure.
25	Welds on the crane runway girder webs	Welding to the web increases the chance of fatigue cracks forming. These welds are stress raisers. Cable carriers are commonly found welded to the web, and should be avoided.
26	Wheel flange wear and tolerances	Due to misalignment and skewing, the wheel flanges make contact with the rail. Wheel flange wear may result and can lead to the crane derailing. Additionally if too much tolerance is provided for the gap between wheel flange and rail, the crane can build up an angle of approach and can possibly cause derailment.

In most cases failures were found to occur as a result of the horizontal forces rather than the vertical forces. Perhaps a better level of reliability can be obtained if the crane gantries are designed using slightly increased horizontal forces. This is a recommendation made by several experts for class four cranes and possibly class three cranes. Furthermore the tieback connection must be designed in a way that facilitates as much of the girder movements as possible.

Secondary preventative measures to prevent failure can include the reduction or prevention of crane misuse and the improvement of maintenance inspections and routines. These steps will lengthen the life of the structure and prevent further structural deterioration and failure.

5.6 Concepts Introduced by the Experts

There were obviously some experts who had a theory, hypothesis or premise on the behaviour of the crane and the support structure. This is a theoretically difficult topic to conceptualise as there are such a large number of variables involved.

5.6.1 Relative Stiffness

Several experts have put some thought into the philosophy of design of crane support structures and cite the relative stiffness of the crane to the crane support structure as the most contentious issue in modern designs. The reference to "modern designs" is made due to the constant development of improved, efficient support structures. "Modern designs" consequently entails lighter, more flexible support structure designs - the less steel the cheaper the structure. This development is, at least partially, also a result of the availability of higher strength steel. According to the experts most crane manufacturers still design similar cranes to those designed several years ago. As a result the cranes (crane bridges) are stiff relative to the support structure.

Solving this problem will require much additional investigation, but for now the experts supplied the following recommendations:

i) Insist that cranes with eight or more wheels have articulating bogeys. This compensates, to an extent, for the crane being much stiffer than the support structure.

ii) Attempt to reduce the stiffness of the crane or increase the stiffness of the crane support structure. This option is far less feasible.

iii) Ensure that the allowable deflections used for the design are well within tolerances. This will serve to increase the structures stiffness.

Many of the problems experienced by crane support structures and cranes have been ascribed to this relative stiffness issue. For this reason further knowledge must be obtained on the subject. Advanced structural interpretation is required for the crane and support structure interaction to be fully understood. It is not clearly understood how this research could be feasibly conducted, unless by means of a numerical investigation. Due to time constraints and the detail involved with conducting such research, the subject is not further investigated in this thesis.

5.6.2 Contact Induced Skewing or Steering

A second subject elicited during the survey involved the steering of the crane. A crane will tend to move at an angle to the rail, even if only very slightly. No cranes are perfectly constructed, so slight movement can not entirely be avoided. Due to this lateral drift, the wheel flanges are expected to ensure the crane stays on the rail, by effectively steering the crane. At this point it can be acceptably assumed that the wheel flanges do make contact with the rail.

The problem is now differentiated according to which flange makes contact with the rail. The inside flange of any wheel, or the outside flange of any wheel. The reason for this differentiation is the following: In the event of an inside flange making contact (C in *figure 5.46*), the crane will want to “rotate” around the point of contact. At C) this is shown to enhance the skewing action and causes the crane to skew continuously as it moves down the gantry. In the event of an outside flange making contact (B in *figure 5.46*), the crane will again try to “rotate” around the point of contact and in so doing correct the skewing action, allowing the contact to be lost and the crane to continue in a “free” manner. These two examples are simply illustrated in the *figure 5.46* below. As logic would enforce, it is assumed that the crane is steered by the front wheels.

Note the inward deflection of the crane in example C) is as a result of the vertical crane loading - the movement of the crane girders and rails as seen in analysis. The result is that the rails are situated closer together and the inner wheel flanges are more likely to make contact. This effect has previously been called "jamming". Opinion from the survey therefore recommends that only outside wheel flanges be designed to the proposed tolerances. Perhaps the tolerance to the inside flanges can simply be increased to have the same overall effect. This would hopefully reduce the negative effects of "jamming" and skewing to some extent.

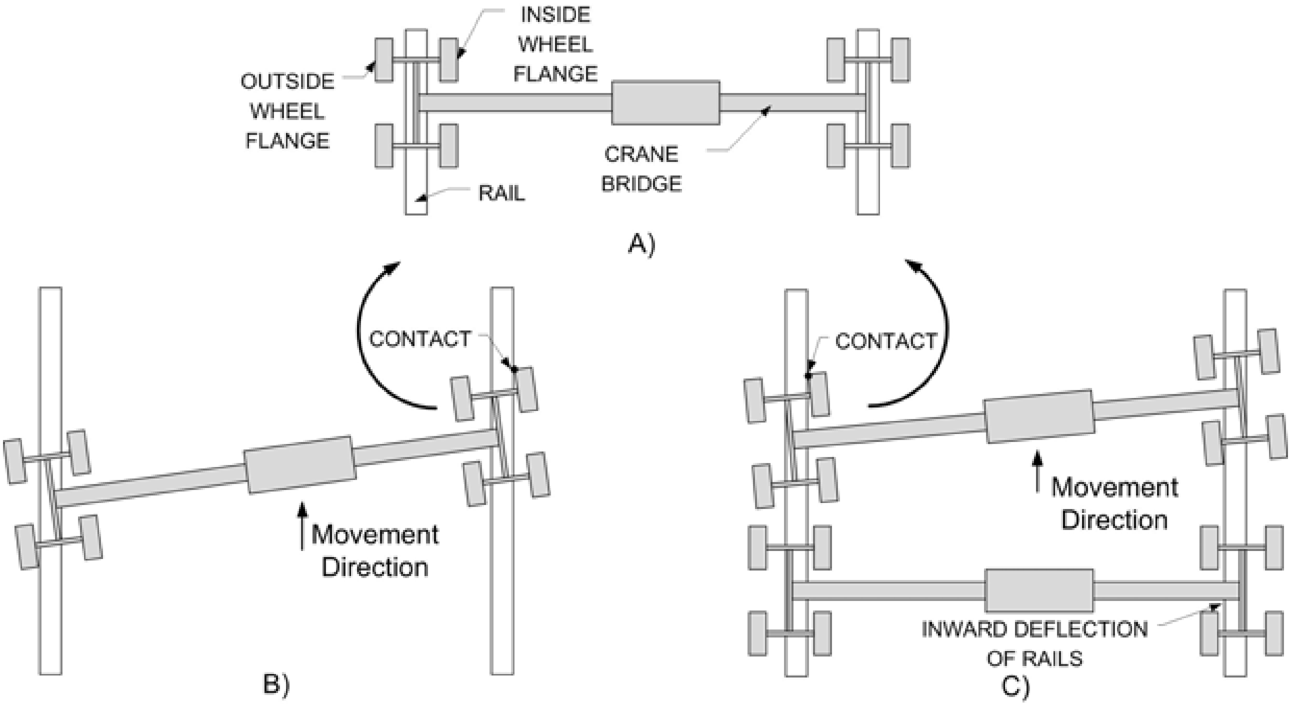


Figure 5.46: Illustration of the corrective and accumulative action of wheel flange contact.

The validity of this subject has not been proven, but theoretically it appears to be relevant. Further investigation would be necessary to define the possibility of the corrective or accumulative wheel flange contact.

CHAPTER 6:

CONCLUSIONS

This chapter highlights the most important information in the results and discussions. It does not provide a summary of all the work, but focuses on the topics associated with the objectives of the research provided in the introduction.

6.1 Expert Opinion Survey and Questionnaire

The first objective of the research was to obtain a method to elicit information from the experienced designers of crane support structures in the South African industry. The method chosen was the expert opinion survey. In order to do this, a questionnaire was developed and can be found in *appendix A*. The following conclusions regarding the survey and questionnaire can be formulated:

i) The expert survey was an effective method for obtaining expert opinion. It was found that in order to obtain rationally defendable results from such research, specific measures had to be implemented. These include proper scoring rules, expert rating, avoidance of biases and satisfactory selection of experts. Furthermore verification of results is very important to obtaining rationally defendable results.

ii) The use of literature as a means of compiling the questionnaire was an effective one considering the limitations of other routes. It must be concluded that the use of trial interviews was of cardinal importance in the process of questionnaire development.

iii) A consistent neutral approach to expert contact is the key. All experts must be treated in the same way prior to and during the interviews. It is important to note that time became the most critical factor in the execution of the survey. It can also be concluded that in order to improve the speed of the interview, the surveyor must gain experience.

6.2 Expert Opinion Elicitation

The elicitation process went very smoothly. Here are the facts relevant to the survey and the responses obtained.

i) 23 experts were consulted. 20 of which fall into the structural designer's category, two are crane manufacturers and one expert has some knowledge of both.
ii) There was over 50 hours of interview recordings to analyse.
iii) The longest interview took over four hours. This is not the best result of the process, but a valuable lesson learnt on the importance of time planning in conducting such an expert survey.
iv) 19 experts were from the Gauteng region and four from the Western Cape. This gives and indication of where the South African structural steel industry is the most active.

The interviews were effective in obtaining information from the experts during the more structured portion of the questionnaire. The details were answered weakly, yet sufficiently and the failure investigation was not nearly as effective as was intended.

The reason for the limited success of the details section is associated primarily with the time factor. The details, and the failure question, were investigated at the end of the interviews. This meant the expert's attention may have reverted back to their work or that the experts were eager to finish. The placement of these topics at the end of the questionnaire instead of at the beginning or towards the middle was a poor decision. Much of the information relevant to the sketches may have been supplied during the structured portion of the questionnaire when questions were asked on subjects related to the details. This would have made analysis more complex, but better results would possibly have resulted. It can consequently be concluded that, as with most circumstances, the more important subjects should be handled early on. A final reason for the limited success of the details involves the difficulty the experts had in recalling details used some time ago.

The failure investigation, and the details to a lesser extent, primarily failed as a result of confidentiality agreements between the experts and the clients. This fact together with the difficulty the experts had in recalling failure details from some time ago lead to vague results. In several cases the experts were not directly involved in the failure investigation and therefore have limited detailed knowledge of the failure events. Many failure mechanisms were nonetheless introduced.

6.3 Best Practice Research

Generally successful results were obtained on “best practice of crane support structures design”. The original intention was to obtain information by expert survey which could be used as background research to a possible crane support structures design guide. It is believed that the research has achieved this goal and will be beneficial to the cause. Many useful conclusions could be drawn from the expert opinion. In fact, the results are so plentiful, that to draw conclusions on all of them in this chapter would be practically impossible. Instead an attempt is made to choose only a few all-encompassing conclusions for special mention.

The results obtained from this research are valid and the uncertainty in expert opinion has to a large extent been removed from the results. This was managed through thorough results verification. In most cases, expert opinion was found to correspond strongly to the literature recommendations and interpretations. The easily comprehended results are excluded from the conclusions. The subjects that the opinion survey found to be contentious were the following:

i) The use of stub stiffeners.
ii) The interaction between the structure and the crane.
iii) The design and use of storm brakes on outdoor gantries.
iv) Fatigue design procedures – whether to actually design for fatigue.
v) Load and stress cycles.
vi) Tieback and column cap connection details.

These are all subjects that could warrant further investigation as the expert opinion is divided on the topics.

6.3.1 Fatigue

Fatigue is a subject that is not very well understood by many designers. The most important results on fatigue, in an attempt to clarify the uncertainty surrounding the concept, are:

i) A proper fatigue analysis should be completed using the SANS 10162-1:2005 steel design code. It is a step-by-step process which has also been described in this thesis.
ii) More importantly the correct details should be used. An attempt to describe the details that are appropriate for crane support structures was also made in this thesis.
iii) Ensure that all of the details are conservatively designed.

6.3.2 Information transfer

The premeditated issue of crane manufacturer information transfer did not surface. In most cases the experts regarded present information as acceptable. Only in the case of large special cranes do any complications occur.

6.3.3 Maintenance

Maintenance was a subject that elicited a large amount of dissatisfaction with present conditions. The experts all regard maintenance of the structure and the crane as highly important to the reliability of crane support structures and state that it is very rarely routinely performed.

A maintenance guide, preferably with legal authority, should consequently be supplied and implemented in South Africa to ensure the better upkeep of the support structures. A good example of a maintenance and inspection plan was defined in *chapter 5*. The gist of this is presented in *figure 6.1*.

Table 6-1: Proposed maintenance and inspection plan for implementation in South Africa.

Number	Type of Maintenance to be Performed	Part of Which Inspection
1	Visual inspection (crack initiation and general structure)	Regular check
2	Bolt (tight and present) check	Regular check
3	Rail clips check	Regular check
4	Painting	Regular check
5	Rail and wheel alignment to tolerances	Detailed check
6	Loaded structural behaviour check	Detailed check
7	Rail check	Detailed check
8	Vertical bracing check	Detailed check
9	Wheel flange tolerance check	Detailed check
10	Buffer inspection	Detailed check
11	Operation and safety control	Detailed check
12	None Destructive Testing	Occasional check

6.3.4 South African Support structures design

An additional result of the opinion survey is that it provides an indication of the present state of South African crane support structures design. It is possible to assess the “correctness of design” being used by South African designers. The expert ratings generally indicate that a good number of this group of experts are aware of the finer details of the design and that the knowledge base of the experts is completely acceptable.

Furthermore only two combined responses, according to the expert opinion survey, were not verifiable by literature comparison. This is a good indication of the South African crane support structure industries condition.

These two subjects were the use of notional loads and the second order analysis. South African codes stipulate that notional loads should be included in all load combinations and that second order effects should be included in the analysis.

The negative point of view must also be observed. A small number of expert ratings fell fairly far below the average. These were indicated in *figure 5.4* by the lower trend line. This coupled with the fact that the designers interviewed were considered by their peers to be experts, could be a sign that the number of structural designers with quality knowledge of crane support structures is limited.

6.3.5 Classification Distinctions for design

The survey results also show that many experts draw a distinct line between the design of class one and two crane structures and class three and four crane structures. Class three and four structures require far more skilled interpretation than the lower class structures. It is for the design of these structures that specialist literature, and if possible, a specialist designer should be consulted. It is thought and intended that the pending design guide resulting from this thesis will serve as a useful reference to more complex designs.

CHAPTER 7:

RECOMMENDATIONS

Based on the results and conclusions obtained in the research, the following recommendations can be made:

i) Expert surveys are a useful method of eliciting information from industry. If applied methodically, rationally defendable results can be obtained. As such the process itself can be recommended as an optional means of attaining information for future, technically related, research.

ii) Further investigation into the interaction between the crane support structure and the crane should be made. The effects of the wheel flange to rail contact can form a prominent part of the possible investigation.

iii) Difficulty in eliciting data on crane and crane support structure failures in South Africa was experienced. In order to obtain detailed information more intense investigation is required. It is recommended that the investigation be carried out under the supervision of a formal institute supported by the industry. The institute should be one that is trusted by the experts and the companies involved. Moreover, some authority may be required to ensure the success of this proposed investigation.

iv) As the thesis objectives proposed, the results obtained in the thesis should form part of the research needed to compose a “best practice” design guide for crane support structures. The results and discussions, in conjunction with the tabulated results in *appendix B,* can be used to ascertain useful data for careful employment by the author of such a “best practice” document. The results are recommended to this extent.

As a final recommendation it can be said that a careful approach should be exercised in crane support structures design. The loads imposed on these structures are more severe than most and a conservative approach to support structures design is often the best tactic. Details remain the most important facet of support structures design. It is therefore a “best practice” recommendation that only the best, most applicable, details are utilised – without compensating financially or due to time constraints. The savings in the long run will far outweigh those of the present.

CHAPTER 8:

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APPENDIX A:

Expert Survey Questionnaire

The questionnaire developed for the “Best Practice of Crane Support Structures Design – An Expert Survey” is included in its original format. The invitation to interview is included after the questionnaire. This is simply reproducibility purposes.

For the interviews conducted, each expert was provided with a questionnaire in a neat folder. This helped to establish the formality of the interview and indicate to the expert that the surveyor was well prepared. The surveyor also had a copy of the document with expected answers and some guidance on what the questions were intended to achieve. A digital voice recording device was used, making the space provided to the experts for answers and comments unnecessary. The intention of the answer blocks was focused on possible preparation by the experts, although this was not a requirement.

Best Practice of Overhead Travelling Crane Support Structure Design Questionnaire

Includes

Crane Support Structure Failure Investigation and a Crane Manufacturers' Information Questionnaire

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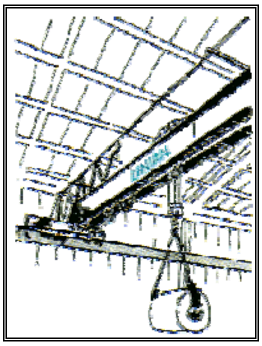

CIVIL ENGINEERING
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Prepared for: South African Structural Engineering Professionals
with Experience in Crane Support Structure Design

Prepared by: Geoffrey Thompson
Structural Engineering Division
University of Stellenbosch

Date: February 2007 – March 2007

Aim – The purpose of this survey is to gather as much information concerning overhead travelling crane support structure design as possible. Furthermore the purpose of this survey is to gain an understanding for the use and interpretation of the *SABS 0160-1989* loading code and the *SANS 10162-1:2005* steel design code. The final aim of the entire *expert survey* being conducted is to assist the research and development of the thesis topic *"Best Practice of Crane Support Structure Design*".

Limitations – The research topic is limited to indoor and outdoor overhead travelling cranes with both rail supports at the same height. This limitation is compatible with the scope of the new proposed *SANS 10160 (Section 10.1.1a)* loading code.

The primary focus of this questionnaire is the crane support structure. Its interaction with the crane and building is also regarded as relevant. The crane itself falls outside the scope of this research.

Included – Included in this questionnaire is the *crane manufacturers' information questionnaire* and a *crane support structure failure investigation*.

The intention of the *crane manufacturers' information questionnaire* is to assess whether information regarding cranes (transferred from crane manufacturer to crane support structure designer) is supplied / not supplied and needed / not needed.

The purpose of the *failure investigation (survey)* is to document as many overhead travelling crane support structure failures as possible.

All failures to overhead travelling cranes and their support structure need to be documented. The *failure investigation* is the only portion of the questionnaire where the crane itself may be included.

Failure should not be limited to the ultimate limit state, but should include the serviceability limit state. Other characteristics to be included are crack formation, serious wear to the structure and anything else the expert regards as relevant.

Please include as much information as possible. Not everyone taking part in this survey has equal experience in crane support structure design. Therefore, if you are unaware of certain topics or issues – simply state so and the next question will follow. Answers are according to *your* best knowledge as designer.

Pre Design Specifications

1. *Crane Manufacturer / Client information*

1.1 Information related to the crane is listed in *Table 1*. What information from the manufacturer is normally “Not Supplied – Needed”, “Not Supplied – Not Needed”, “Supplied – Needed” or “Supplied – Not Needed”, by the support structure designer? Assume *SABS 0160-1989* is the relevant loading code.

Table 1: Crane information according to the necessity of the support structure designer and supply by the crane manufacturer

Information	**Not Supplied Needed**	**Not Supplied Not Needed**	**Supplied Needed**	**Supplied Not Needed**
Nominal weights of crane and hoist load	**No Sup / Need**	**No Sup / No Need**	**Sup / Need**	**Sup / No Need**
Weight of crane bridge				
Weight of crab				
Weight of hoist load				
Crane geometry	**No Sup / Need**	**No Sup / No Need**	**Sup / Need**	**Sup / No Need**
Span of crane bridge				
Minimum distance (hoist to rail)				
Minimum distance between wheels of different cranes on the same runway				
Number of wheels				
Wheel spacing				
Rail	**No Sup / Need**	**No Sup / No Need**	**Sup / Need**	**Sup / No Need**
Rail type				
Rail to runway attachment (clips)				
Travel and hoist speeds	**No Sup / Need**	**No Sup / No Need**	**Sup / Need**	**Sup / No Need**
Long travel speed (crane bridge)				
Cross travel speed (crab)				
Steady hoisting speed				

Hoist type and characteristics	**No Sup / Need**	**No Sup / No Need**	**Sup / Need**	**Sup / No Need**
Type of load lifting mechanism				
Hoist load free to swing				
Design life in terms of total hoists				
Wheel and wheel drives	**No Sup / Need**	**No Sup / No Need**	**Sup / Need**	**Sup / No Need**
Drive mechanism (independent / coupled; synchronized)				
Behaviour of drives (smooth / sudden)				
Number of driven track wheels				
Guidance means	**No Sup / Need**	**No Sup / No Need**	**Sup / Need**	**Sup / No Need**
Guide rollers present (or not)				
Clearance between rail & wheel flange				
Buffers	**No Sup / Need**	**No Sup / No Need**	**Sup / Need**	**Sup / No Need**
Buffer type				
Height of the buffer above the rail				
Buffer characteristics (degree of plasticity; hydraulic information)				
Other	**No Sup / Need**	**No Sup / No Need**	**Sup / Need**	**Sup / No Need**
Storm break information				

1.2 Are the maximum and minimum wheel loads attained from the manufacturer

Table 2: Check boxes relevant to Question 1.2

Accepted as they are?	Checked with a calculation?	Not enough information to check, therefore accepted?	Other (explanation)

1.3 If the crane information (as listed in *Table 1*), required to complete a design, is only available after the conceptual design phase, what information do you use to complete the conceptual design and where can it be found?

1.4 Who is involved in generating the structural layout of the building and crane support structure?

1.5 Are crane support structures ever designed with alterations / expansions (crane upgrade) in mind?

2. *Maintenance*

2.1 List the different forms of crane / crane support structure abuse and misuse that occur in South Africa?

2.2 Is there a crane support structure maintenance guide available in South Africa (is application of the guide compulsory or not)?

2.3 What do you believe crane support structure maintenance should entail?

2.4 Complete *Table 3* for crane support structures and/or cranes in South Africa:

Table 3: The quality of the crane and support structure *maintenance* in South Africa, expressed as a percentage of cranes or as a percentage of crane support structures.

Percentage that are never maintained	Support %	Crane %
Percentage that are badly maintained	Support %	Crane %
Percentage that are correctly maintained	Support %	Crane %
TOTAL PERCENTAGE OF CRANES	Support **100** %	Crane **100** %

2.5 What percentage of crane support structures and/or cranes in South Africa are otherwise misused (excluding *maintenance*)?

2.6 Complete *Table 3* which describes the percentage of crane support structure components that are *misaligned* in South Africa? (according to the expert)

$$\text{Formula: } \frac{\text{Cranes that are misaligned}}{\text{Total number of all cranes}}$$

Table 4: Percentage of crane support structure features that are misaligned in SA

Misalignment of the crane **wheels**	%
Misalignment of the crane runway **girder**	%
Misalignment of the crane runway **rail**	%
Misalignment of any other **component**	%
Cranes that are **well** aligned	%
TOTAL PERCENTAGE OF COMPONENTS	**100** %

3. *References*

3.1 Do you make use of the *SANS 10162-1:2005* steel design code and the *SABS 0160-1989* loading code when designing crane support structures?

Table 5: Check boxes relevant to Question 3.1

Yes, I do make use of both of these codes.	I only make use of *SANS 10162-1:2005.*	I only make use of *SABS 0160-1989.*	I make use of neither – I instead use?

3.2 Which other literature references do you use and for what purpose?

Loads and Actions

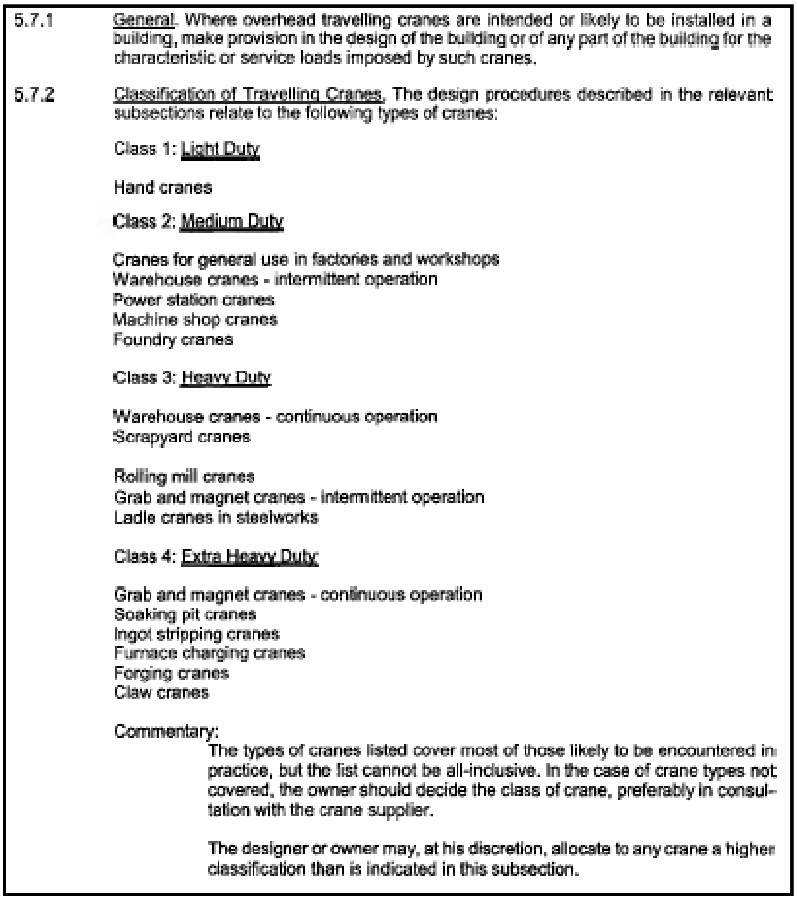
4. *Post Construction Test Loads*

4.1 Describe the crane test loads used to inspect the working safety of the crane and crane support structure?

5. *Classification of Structure*

5.1 How do you classify a crane? Who is involved in the classification process?

5.2 Do you think the present classification (*Figure 1 - SABS 0160-1989 5.7.2)* is sufficient or should a more detailed crane classification model be introduced?



5.7.1 General. Where overhead travelling cranes are intended or likely to be installed in a building, make provision in the design of the building or of any part of the building for the characteristic or service loads imposed by such cranes.

5.7.2 Classification of Travelling Cranes. The design procedures described in the relevant subsections relate to the following types of cranes:

Class 1: Light Duty

Hand cranes

Class 2: Medium Duty

Cranes for general use in factories and workshops
Warehouse cranes - intermittent operation
Power station cranes
Machine shop cranes
Foundry cranes

Class 3: Heavy Duty

Warehouse cranes - continuous operation
Scrapyard cranes

Rolling mill cranes
Grab and magnet cranes - intermittent operation
Ladle cranes in steelworks

Class 4: Extra Heavy Duty

Grab and magnet cranes - continuous operation
Soaking pit cranes
Ingot stripping cranes
Furnace charging cranes
Forging cranes
Claw cranes

Commentary:

The types of cranes listed cover most of those likely to be encountered in practice, but the list cannot be all-inclusive. In the case of crane types not covered, the owner should decide the class of crane, preferably in consultation with the crane supplier.

The designer or owner may, at his discretion, allocate to any crane a higher classification than is indicated in this subsection.

Figure 1: Crane classification as found in *SABS 0160-1989*

6. *Load Amplification Factors*

6.1 Are the dynamic load amplification factors to be applied to the static vertical wheel loads as specified per crane class (*SABS 0160-1989 5.7.3*) acceptable, conservative or non-conservative?

6.2 Are the load amplification factors to be applied to the horizontal wheel loads as specified per crane class (*SABS 0160-1989 5.7.4*) acceptable, conservative or non-conservative?

6.3 The load amplification factors (also dynamic load amplification factors) increase per crane class. Do you think this increase is relevant?

7. *Load Cases*

7.1 For misalignment, skewing and acceleration respectively, when dealing with multiple crane setups, how many cranes do you think should be used in combination to generate the respective loading situation?

7.2 For the purpose of a "second order analysis", how is the horizontal notional load calculated and where is it applied to the structure?

8. *Additional Design Situations*

8.1 What unusual load cases need to be investigated in South Africa? Give a brief description of the method used to design for these load situations?

9. *Load Combinations*

9.1 Are the load combinations as described in *SABS 0160-1989 Section 4* sufficient for design and analysis purposes?

9.2 List all ultimate limit state load combinations that you investigate for a regular portal frame industrial building with a crane? Also state if each combination is probably - “critical”, “check required” or “negligible”?

Table 6: Ultimate limit state load combinations with comment on the level of importance

Ultimate Limit State Load Combinations	Comment

9.3 List all serviceability limit state load combinations that you investigate for a regular portal frame industrial building with a crane? Also state if each combination is probably - “critical”, “check required” or “negligible”?

Table 7: Serviceability limit state load combinations with comment on the level of importance

Serviceability Limit State Load Combinations	Comment

9.4 Structural analysis involves many load combinations, how do you select (find) the maximum combinations to be used for the design of specific structural elements?

10. *Force Application*

10.1 At what height are *horizontal transverse crane forces* applied to the crane support system? (Answer for the *crane runway girder design* and *structural software analysis* separately)

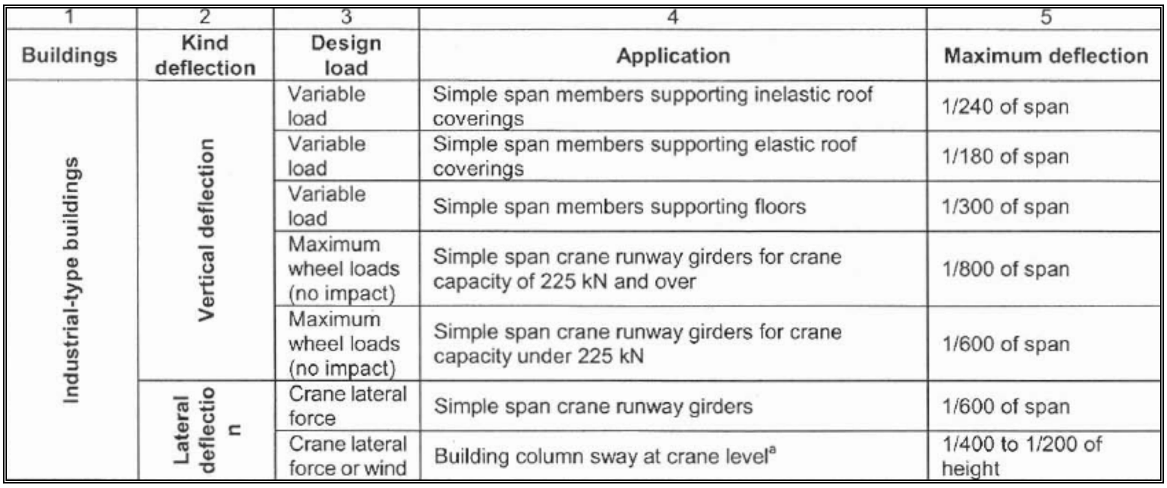
10.2 At what point and with what eccentricity is the vertical crane force applied? (Answer for the *crane runway girder design* and *structural software analysis* separately)

11. *Serviceability Limit State Design*

11.1 Are the deflection limits as included in *SANS 10162-1:2005 Annex D* conservative, acceptable or non-conservative? (see *Figure 2*)

Table 8: Check boxes relevant to Question 11.1

Conservative	Acceptable	Non-conservative	Other



1	2	3	4	5
Buildings	**Kind deflection**	**Design load**	**Application**	**Maximum deflection**
Industrial-type buildings	Vertical deflection	Variable load	Simple span members supporting inelastic roof coverings	1/240 of span
		Variable load	Simple span members supporting elastic roof coverings	1/180 of span
		Variable load	Simple span members supporting floors	1/300 of span
		Maximum wheel loads (no impact)	Simple span crane runway girders for crane capacity of 225 kN and over	1/800 of span
		Maximum wheel loads (no impact)	Simple span crane runway girders for crane capacity under 225 kN	1/600 of span
	Lateral deflection	Crane lateral force	Simple span crane runway girders	1/600 of span
		Crane lateral force or wind	Building column sway at crane level^a	1/400 to 1/200 of height

Figure 2: Maximum deflections at serviceability as found in *SANS 10162-1:2005 Annex D*

Structural Analysis

12. *Computer Software*

12.1 Which computer software package do you use for the *analysis* of the *crane runway girder* and the remainder of the *building structure* respectively?

12.2 What additional *analysis* and/or *design* software is available and why do you choose to use the software package mentioned above?

12.3 Do you use computer software for *design*? If so – which software package?

12.4 Do you make use of 2D or 3D *analysis*?

12.5 Considering the software package mentioned above; what type of analysis is used?

12.6 Are connections ever analysed in detail to produce a more accurate stress distribution for the purpose of connection design?

Design (Crane Girders; Building Structure; Crane Columns)

13. *Crane Girder*

13.1 Are simply supported or continuous crane runway girders preferred in SA?

13.2 What different crane runway girder sections are being used in South Africa?

13.3 How is alignment of the crane runway girder made possible? i.e. Describe the different vertical and horizontal adjustable connections that can be used?

13.4 How is the overall alignment of the crane supporting structure ensured during construction?

13.5 Are crane girders designed to have intermediate web stiffeners or not?

13.6 How do you determine the spacing of the intermediate (or stub) stiffeners on a crane girder?

13.7 How do you determine the depth and width of the intermediate (or stub) stiffeners? (see *Figure 3*)

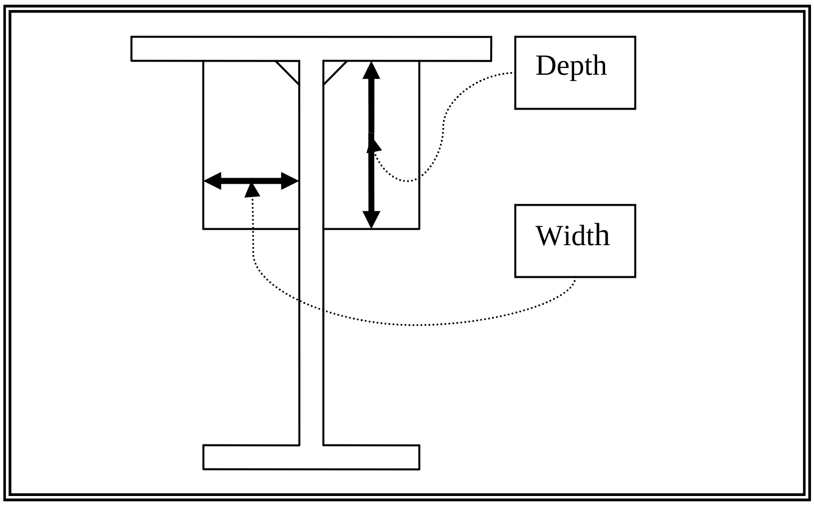


Figure 3: Illustration of the depth and width of intermediate (stub) stiffeners

13.8 How do you calculate the following parameters for a monosymmetric plate girder section (as used for some simply supported crane runway girders)? (see *Figure 4a*)

Table 9: Parameters that are required monosymmetric plate girder sections

C_w	
J	
β	

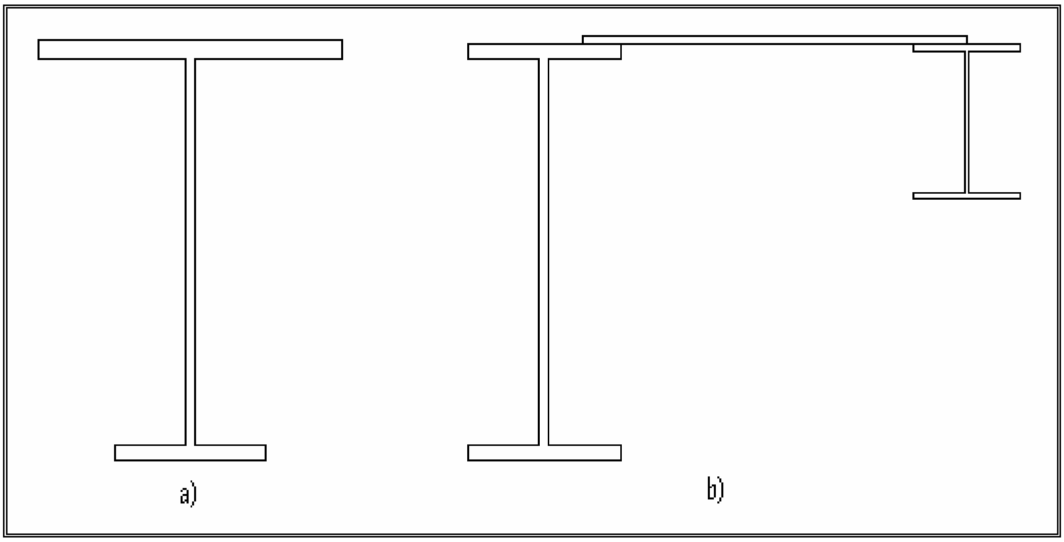


Figure 4a: Illustration of a typical monosymmetric section; often used as a crane runway girder
Figure 4b: Illustration of a surge plate setup for large crane runway girders. (Similar to surge girder)

13.9 Define the effective areas for the calculation of parameters I_y and I_x respectively - for an I-section plate girder with surge plate? (see *Figure 4b*)

13.10 Complete *Table 10* by filling in the type of weld that is normally used for the respective detail on a crane runway girder (for light and heavy cranes)?

Table 10: The type of weld used for the respective crane runway girder detail.

Girder Type	**Description of Detail**	**Light Cranes**	**Heavy Cranes**
Plate Girder	Top flange to web		
	Stiffener to web		
	Stiffener to flange		
	Endplate to girder		
Composite Section	Horizontal channel to top flange		
	Stiffener to web		
	Stiffener to flange		

	Endplate to girder		

14. *Rails*

14.1 What type of rail clip is most used in South Africa (and which do you prefer)?

14.2 How are rail splices made?

15. *Elastomeric Pads*

15.1 What is the purpose of the elastomeric pad between the crane runway girder and the rail?

15.2 Are elastomeric pads included in both heavy and light crane design?

15.3 Do elastomeric pads influence the design or load calculations in any way?

16. *Crane End-stops*

16.1 Explain which buffers, elastomeric or hydraulic, are preferred in SA?

17. *Structural and Crane Bracing*

17.1 Where in the structure do you place the building bracing and crane bracing respectively?

17.2 How are the *end stop impact forces* and/or the *longitudinal horizontal wheel forces* transferred to the bracing system?

17.3 What is done to transfer the *end stop impact forces* and/or the *longitudinal horizontal wheel forces* from the crane runway girders (end stops) to the bracing system - for structural layouts that do not allow the bracing system to be in the same plane as the crane girders?

17.4 How are crane runway expansion joints and crane rail expansion joints designed and where in the structure are they placed?

18. *Crane Column*

18.1 What types of crane columns are used in South Africa?

18.2 What critical parameter tends to limit the use of a corbel column?

18.3 Explain using *Table 11* what affect the crane load applied to the crane girder, has on the force distribution along the two columns? The fixity of the **back column to building column connection** varies around the **z-axis** (rotation around the axis perpendicular to the page) and in the **X-direction** (horizontal movement) – Comment on each scenario. (see *Figures 5 & 6*)

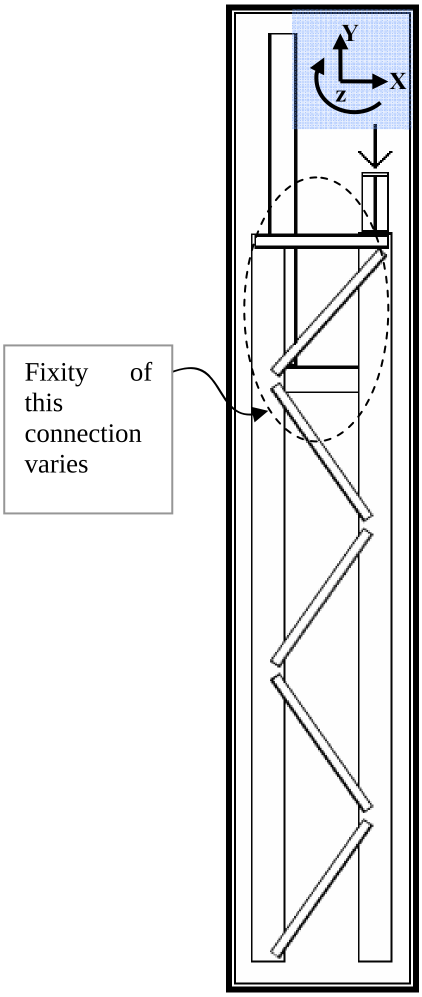


Figure 5: A laced column (side view)

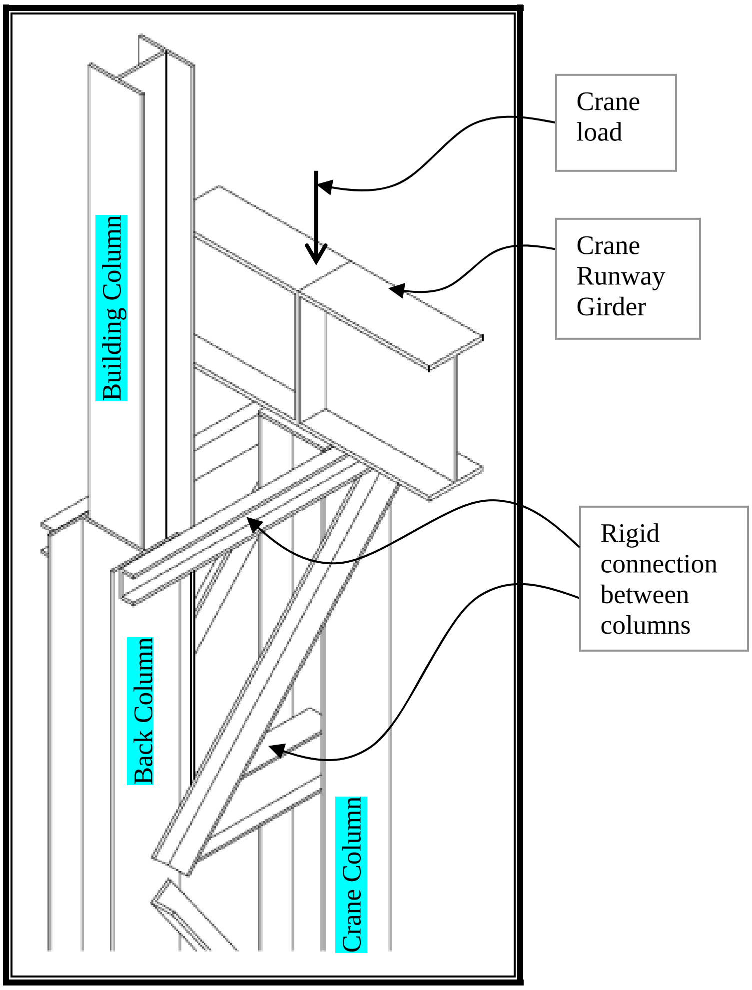


Figure 6: The top portion of the column setup (top left view). Assume a rigid connection between the back column and crane column

Table 11: The degree of fixity of the *back column-to-building column connection* used to analyse the force transfer from the top of the *back column* and *crane column* to the ground, respectively

Restraint	Forces back column	Forces crane column
Totally free		
Partial restraint in X direction only; (z free)		
Partial restraint around z-axis only; (X free)		
Total restraint in X-direction only; (z-free)		
Total restraint around z-axis only; (X-free)		
Total restraint (X direction and around z)		

19. *Outdoor Crane Gantries*

19.1 How and where do you place storm brakes on an outdoor crane?

19.2 Are there any other noteworthy differences in the design of an outdoor crane gantry compared with an indoor overhead travelling crane gantry?

20. *Unusual Structural Layout*

20.1 Certain crane support structures have varying crane runway girder lengths. What adjustments are made to the crane runway girder and column details? Furthermore how do you handle the design of these differences?

Fatigue

21. *Fatigue Classification*

21.1 Do you find the fatigue detail classification "*SANS 10162-1:2005 Table 10* & *Figure 2*" helpful and sufficient for classifying structural details for fatigue?

21.2 List all of the details that require fatigue analysis on a *crane runway girder*?

21.3 List all of the details that require fatigue analysis in the *rest of a crane support structure*?

22. *Load Cycles*

22.1 For the following example please calculate the number of stress cycles the top flange to web weld [1], the stiffener toe [2] and the corbel to column connection [3] will be subjected to? Please explain your calculation?

An overhead travelling crane with four wheels runs in a portal frame building with nine bays. The crane is empty and stationary at one end of the building. From here the crane picks up a maximum load, moves to the far end of the building and drops the whole load. Now the empty crane moves back to its starting position. This process is repeated 10 times. (see *Figures 7,8,9,10*)

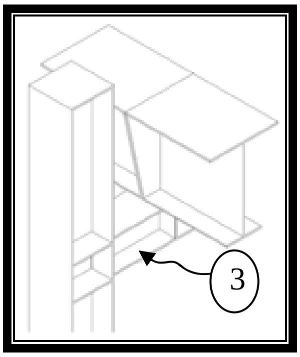


Figure 7: Corbel ISO view

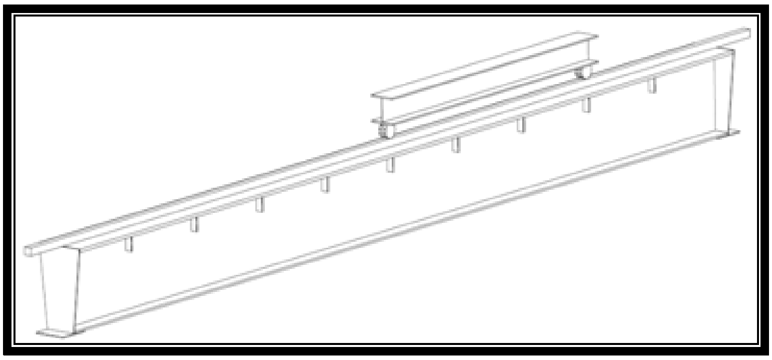


Figure 8: Runway ISO view

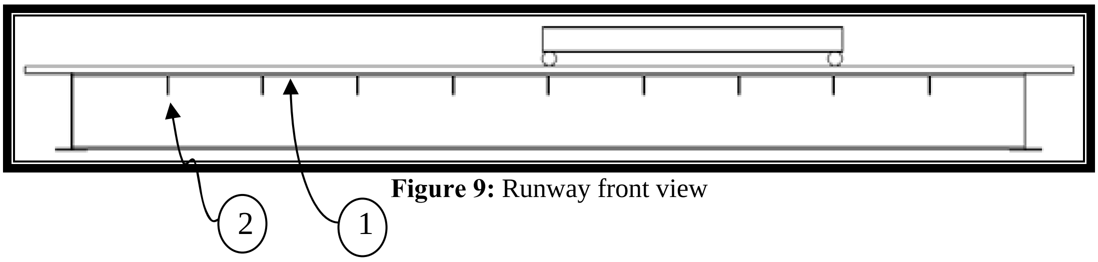


Figure 9: Runway front view

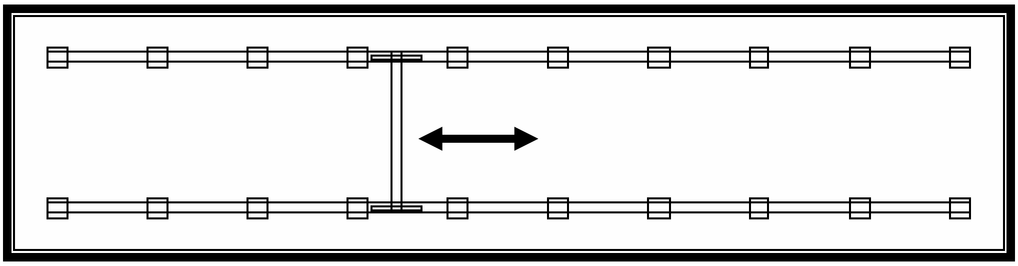


Figure 10: Illustration of building and crane runway layout

22.2 What is the difference between a load cycle and a stress range cycle?

22.3 How is the *load cycle* information attained?

22.4 How is the *load lifted* distribution calculated?

22.5 How is the *crane movement* around the crane gantry defined and calculated?

22.6 How much influence do *load cycles*, *load distribution* and *crane movement* have on fatigue calculations?

22.7 How do you make provision for multiple load distributions (for different percentages of total load) in fatigue design? (Do you exclude certain low stress ranges)?

Design Details Requiring Sketches for Illustration

An important portion of the research is formulated by the detail sketches that are required below. The intention, therefore, is to gain as much design information from the detailed sketches as possible. Consequently as much attention as possible should be afforded this section of the questionnaire.

Please note the following when making the sketches:

1. For each case mentioned below please draw all of the details that you would normally use.
2. Cover both light and heavy crane setups where ever necessary.
3. Clearly mark all welds.
4. Make sure that any differences that occur due to use of a different crane runway girder section are clearly explained in the sketch.
5. Make sure that any differences that occur due to use of a different crane column are clearly explained in the sketch.
6. Include as much detail as possible when drawing the sketches.
7. Give each sketch a short title to help with the explanation.
8. Details that you know have been used, but have faults, should also be included - but clearly marked.

The following details are required:

1. Crane runway end to runway end connections (e.g. continuity plates, shear keys, etc).
2. Crane column types (only those that require a descriptive sketch).
3. The crane column to crane runway connections (including the necessary allowance for vertical and horizontal movement / adjustment).
4. The connection between the crane column, building column and roof column.
5. The transverse horizontal connection between the crane runway girder and the roof column (allowing for adjustment).
6. Surge girder / surge plate and all of its connections to the structure (allowing for adjustment).
7. Endstops (all of the types that you use).
8. Details related to varying crane girder depths or uneven crane girder lengths.
9. Outdoor crane gantries (only details that differ from indoor crane gantries).

Failure Investigation

Reminder – The research topic is limited to overhead travelling cranes. Indoor and outdoor cranes are included. Although the topic is intended to focus more specifically on crane support structure failure, the crane itself may also be included in this survey.

Please include as much information as possible. Comment, if possible, on each of the topics listed below. Sketches and descriptions are welcome (add anything that you regard as relevant).

1. Failure mechanism description.
2. Any information relevant to the specific failure mechanism (probable reasons).
3. Nominal weights of crane and hoist load.
4. Crane and supporting structure geometry (crane runway girder sections).
5. State of the crane and crane support structure after the failure (can the damage be repaired).
6. Any information regarding maintenance prior to failure.
7. Other information concerning the investigation.

Dear Sir,

INVITATION TO INTERVIEW - BEST PRACTICE OF CRANE SUPPORT STRUCTURES DESIGN; MScEng RESEARCH

My name is Geoffrey Thompson and I am presently conducting my MScEng studies at the University of Stellenbosch under the guidance of Prof. P.E. Dunaiski.

The topic of my MScEng thesis is "*The Best Practice of Crane Support Structures Design*". The objective being to research crane support structure design by means of an expert survey. The survey responses will then be analysed and verified by means of further theoretical and literature research.

Concurrently an investigation into crane support structure failures and an investigation into what information is supplied and/or needed from the manufacturers will be completed. This will assist the MScEng thesis research.

Furthermore the MScEng thesis will facilitate the greater crane support structure research project being carried out at the University of Stellenbosch Structural Engineering Division.

The experts to be interviewed are structural engineers with experience in industrial building design, or more specifically, crane support structure design.

CONFIDENTIALITY AND ACKNOWLEDGEMENT

To ensure the intended outcome and value of this research is attained honest and accurate information is required. This is easily achieved during the *best practice* portion of the questionnaire.

For confidentiality reasons all connections, positive and negative, to specific structures and/or experts will be avoided. During the failure investigation, the expert is asked to give as much information (company name, designer, etc) as the expert feels is comfortably acceptable.

In the MScEng thesis and journal publication intended to be published in part completion of the MScEng programme, acknowledgement will be given to all the experts, and the expert's companies that were involved in the research.

INTERVIEWS – TIME AND PLACE

Experts have limited time available for involvement in a research project or interview of this kind. For this reason the questionnaire has been kept as brief as possible and is expected to take approximately 1.5 - 2 hours. The nature of the questions and amount of information to be handled make a shorter interview difficult to formulate.

A one-on-one interview, rather than a posted questionnaire is preferred, as questions and answers can be interpreted better during an interview-style conversation - leading to more useful outcomes. A relatively quiet room would be beneficial as the intention is to "voice record" the interview to assist with the post-interview analysis.

As I am studying and living in Stellenbosch, moving around the Gauteng area has its logistic problems. If you are willing to be interviewed, please give an indication of the time and place to conduct the interview to best suite your schedule. I have initially chosen the dates for one planned trip.

Monday March 5, 2007 – Saturday March 10, 2007

If you are not able to find time during this period – please select a date and time outside of the dates given that would suite you better. I will do my best to accommodate everyone but clashes are inevitable. For this reason I would appreciate that, if at all possible, you give me a range of times to choose from so that I can compile a schedule for my trip. I will send the proposed schedule to all involved for confirmation purposes.

I would appreciate it if you could please reply to me as soon as possible. For the purpose of the research and planning please include the following:

1. Name
2. Company name
3. Qualifications
4. Years of experience
5. Names of any experts you recommend are included in the study
6. Date and place for the interview (include full address please)

Thank you for your cooperation.

Sincerely,

Geoffrey Thompson

Prof. P.E.Dunaiski

APPENDIX B:

Formal Survey Results Tables

This appendix makes provision for the actual results achieved during the expert survey. No commentary on the results is provided in this section.

The tables include:

i) Questionnaire reference
ii) The related topic
iii) A rating according to the success or failure of the question
iv) A short version of the question
v) Coded answers that were found from the expert responses
vi) The percentile opinion – the most important results from the questionnaire.

Certain questions were approached differently in which case the results tables may vary slightly. Question 1.1 is already an example of this.

It is recommended that the results printed in this appendix be used in conjunction with the results and discussion in *chapter 6* of the thesis.

Table B-1: The information that is transferred from the manufacturer to the support structure designer.

QUESTION 1.1 - Information related to the crane is listed in the table. What information from the manufacturer is normally "Not Supplied - Needed", "Not Supplied - Not Needed", "Supplied - Needed" or "Supplied - Not Needed", by the support structure designer? Assume SABS 0160-1989 is the relevant loading code.

Information	Not Supplied Needed	Not Supplied Not Needed	Supplied Needed	Supplied Not Needed
Nominal weights of crane and hoist load				
Weight of crane bridge	0.0%	0.0%	**100.0%**	0.0%
Weigth of crab	0.0%	0.0%	**100.0%**	0.0%
Weight of hoist load	0.0%	0.0%	**100.0%**	0.0%
Crane Geometry				
Span of crane bridge	0.0%	0.0%	**100.0%**	0.0%
Minimum distance (hoist to rail)	4.2%	6.3%	**82.4%**	7.1%
Minimum distance between wheels of different cranes on the same runway	5.8%	0.0%	**94.2%**	0.0%
Number of wheels	0.0%	0.0%	**100.0%**	0.0%
Wheel spacing	0.0%	0.0%	**100.0%**	0.0%
Rail				
Rail type	23.4%	13.1%	**58.7%**	4.7%
Rail to runway attachment (clips)	30.5%	**66.5%**	3.0%	0.0%
Travel and hoist speeds				
Long travel speed (crane bridge)	0.0%	6.1%	**53.4%**	40.5%
Cross travel speed (crab)	0.0%	17.7%	**41.8%**	40.5%
Steady hoisting speed	0.0%	17.7%	34.7%	**47.6%**
Hoist type and characteristics				
Type of load lifting mechanism	0.0%	13.0%	**53.6%**	33.4%
Hoist load free to swing	0.0%	6.4%	**69.1%**	24.5%
Design life in terms of total hoists	30.7%	**31.9%**	21.4%	16.0%
Wheel and wheels drives				
Drive mechanism (independent / coupled / synchronized)	8.4%	**59.6%**	19.6%	12.4%
Behaviour of drives (smooth / sudden)	8.4%	**56.0%**	27.5%	8.1%
Number of driven track wheels	8.4%	**46.1%**	29.2%	16.3%
Guidance means				
Guide rollers present (or not)	0.0%	9.5%	**87.4%**	3.0%
Clearance between rail and wheel flange	17.6%	30.1%	**43.4%**	8.9%
Buffers				
Buffer type	26.7%	26.6%	**43.6%**	3.0%
Height of the buffer above the rail	9.7%	2.3%	**84.9%**	3.0%
Buffer characteristics (degree of plasticity; hydraulic information)	28.2%	**51.0%**	15.2%	5.7%
Other				
Storm brake information	**48.1%**	28.3%	20.6%	3.0%

References: ENV 1993-6:1999; Cadile [1976]; MBSM [2002]; Dymond [2005]

Question Number(s)	**1.2**	**Main Topic(s)**	Wheel Loads	**Question(s) Success**	A	**Questionnaire Reference**	Pre-Design
Question 1.2: Are the maximum and minimum wheel loads atained from the manufacturer [Accepted as they are / Checked with a calculation / Not enough information to check, therefore accepted / Other explanation]?							
Accepted as is		Checked with a quick calculation		Accepted as is or checked with a quick calculation			
38.5%		**18.8%**		**42.7%**			
Literature: Rowswell [1987]; Gorenc [2003]; MacCrimmon [2005]; MBSM [2002]; Fisher [1993]; SAISC Industrial Buildings Course [2007]; Dymond [2005]							

Question Number(s)	**1.3**	**Main Topic(s)**	Information Transfer	**Question(s) Success**	B	**Questionnaire Reference**	Pre-Design
Question 1.3: If the crane information (as listed in question 1.1) required to complete a design is only available after the conceptual design phase, what information do you use to complete the conceptual design phase and where can it be found?							
Information is available for the conceptual design of standard cranes in the crane manufacturer catalogues or from the manufacturers themselves		Both sufficient information is supplied from the crane manufacturer catalogues and the client, to use with previous jobs information and experience		The client supplies sufficient information, which can be used together with previous jobs information and experience			
60.3%		**29.3%**		**10.4%**			
Literature: Rowswell [1987]; Gorenc [2003]; MacCrimmon [2005]; Dymond [2005]							

Question Number(s)	**1.4**	**Main Topic(s)**	Structural Layout	**Question(s) Success**	B	**Questionnaire Reference**	Pre-Design
Question 1.4: Who is involved in generating the structural layout of the building and crane support structure?							
Primarily the designer with the client and the process engineer assisting to achieve the buildings objective		Primarily the client and process engineer supply this - adjustments can be made by the designer if accepted and necessary					
28.5%		**71.5%**					
Literature: Rowswell [1987]; Gorenc [2003]; MacCrimmon [2005]; SAISC Industrial Buildings Course [2007]							

Question Number(s)	**1.5**	**Main Topic(s)**	Crane Upgrade	**Question(s) Success**	B	**Questionnaire Reference**	Pre-Design
Question 1.5: Are crane support structures ever designed with alterations / expansions (crane upgrade) in mind?							
Expansions in bay length and additional bays is quite common; crane upgrade is much less common		Expansions in bay length and additional bays and crane upgrade is quite common		Expansions and crane upgrade are very seldom designed for			
46.7%		**44.4%**		**8.9%**			
Literature: Rowswell [1987]; Gorenc [2003]; MacCrimmon [2005]; AS 1418.18-2001; ENV 1993-6:1999							

Question Number(s)	2.1	Main Topic(s)	Crane Misuse / Abuse	Question(s) Success	B	Questionnaire Reference	Maintenance

Question 2.1: List the different forms of crane / crane support structure abuse and misuse that occur in South Africa?

Bad lack of maintenance	Crane repeatedly running into the end stops	overloading	oblique hoisting	banging of a hoist load to loosen sediment in a ladle	dragging of the hoist load	misalignment	misconstruction	modification of the support structure	Not sure	welding cable carriers to the crane runway girder web	surge connection failure	over-riding of the conrtol switches	stop-start braking wearing out the motor	thermal damage through radiant heat	hot metals spilling against the columns	loose bolts	wheel flange wear	lack of control over 3rd world work force	dust build up on elements
60.1%	**42.2%**	**33.4%**	**29.6%**	**27.9%**	**25.6%**	**22.9%**	**19.1%**	**18.0%**	**10.8%**	**10.7%**	**10.6%**	**9.7%**	**9.3%**	**6.1%**	**6.1%**	**6.1%**	**4.9%**	**4.4%**	**4.4%**

Literature: Rowswell [1987]; Gorenc [2003]; MacCrimmon [2005]; Fisher [1993]; Collins et al. [1991]; Senior et al. [1963]; SAISC Industrial Buildings Course [2007]; Dymond [2005]

Question Number(s)	2.2	Main Topic(s)	Maintenance Guide	Question(s) Success	B	Questionnaire Reference	Maintenance

Question 2.2: Is there a crane support structure maintenance guide available in South Africa (is application of the guide compulsory)?

No, not aware of one			
100.0%			

Literature: Rowswell [1987]; Gorenc [2003]; MacCrimmon [2005]; MBSM [2002]; Reemsnyder [1978]; Dymond [2005]

Question Number(s)	2.3	Main Topic(s)	Maintenance Guide	Question(s) Success	A	Questionnaire Reference	Maintenance

Question 2.3: What do you believe crane support structure maintenance should entail?

Visual inspection (crack initiation and general structure)	Rail and wheel alignment to tolerances	Bolt check (tight and present)	Rail clips check	Structural behaviour under loading check	Check the rail	Vertical bracing check	Flange clearances to tolerances	Painting	Not sure	Non destructive testing (class 1&2 10 yearly, class 2&4 5 yearly)	Buffer inspection	Ensure correct operation and safety
86.7%	**67.8%**	**53.7%**	**24.2%**	**12.9%**	**10.4%**	**6.3%**	**6.1%**	**6.0%**	**4.5%**	**4.3%**	**3.1%**	**2.7%**

Literature: Rowswell [1987]; Gorenc [2003]; MacCrimmon [2005]; AS 1418.18-2001; SASSSC [2000]; MBSM [2002]; Reemsnyder [1978]; Fisher [1993]; Collins et al. [1991]; Senior et al. [1963]

Question Number(s)	2.4	Main Topic(s)	Maintenance	Question(s) Success	B	Questionnaire Reference	Maintenance

Question 2.4: Fill in the table for crane support structures and / or cranes in South Africa: The table describes the quality of the crane and support structure maintenance in South Africa, expressed as a percentage of all crane support structures.

DESCRIPTION	Percentage that are never maintained	Percentage that are poorly maintained	Percentage that are correctly maintained
CRANE SUPPORT STRUCTURE	56.90%	32.30%	10.80%
CRANES	24.40%	42.00%	33.60%

Literature: Rowswell [1987]; Gorenc [2003]; MacCrimmon [2005]; AS 1418.18-2001; MBSM [2002]; Fisher [1993]; SAISC Industrial Buildings Course [2007]; Dymond [2005]

Question Number(s)	**2.5**	**Main Topic(s)**	Crane Misuse	**Question(s) Success**	B	**Questionnaire Reference**	Maintenance
Question 2.5: What percentage of crane support structures and / or cranes in South Africa are otherwise misused (excluding maintenance)?							
DESCRIPTION		Percentage that are misused		Percentage that are correctly used			
CRANE / CRANE SUPPORT STRUCTURE		42.4%		57.6%			
Literature: Rowswell [1987]; Gorenc [2003]; MacCrimmon [2005]; AS 1418.18-2001; Fisher [1993]; Collins et al. [1991]; Dymond [2005]							

Question Number(s)	**2.6**	**Main Topic(s)**	Misalignment	**Question(s) Success**	B	**Questionnaire Reference**	Maintenance
Question 2.6: Complet the table which describes the percentage of crane support structure components that are misaligned in South Africa? (percentage of cranes that are misaligned to the total number of all cranes)							
DESCRIPTION		Misalignment of the crane wheels	Misalignment of the crane runway girder	Misalignment of the crane runway rail	Misalignment of any other component (columns)	Cranes that are well aligned	
CRANE / CRANE SUPPORT STRUCTURE		25.9%	53.3%	54.0%	27.7%	26.5%	
Literature: Rowswell [1987]; Gorenc [2003]; MacCrimmon [2005]; AS 1418.18-2001; ENV 1993-6:1999; Lobov [1989]; Fisher [1993]; Thompson [1970]; Senior et al. [1963]; SAISC Industrial Buildings Course [2007]; Dymond [2005]							

Question Number(s)	**3.1**	**Main Topic(s)**	Design Codes	**Question(s) Success**	B	**Questionnaire Reference**	References
Question 3.1: Do you make use of the SANS 10162-1:2005 steel design code and the SABS 0160:1989 loading code when designing crane support structures?							
Yes, this is available		Yes, this is available but other international codes are consulted		Yes, this is available but old editions are used			
57.9%		15.4%		26.7%			
Literature: Rowswell [1987]; Gorenc [2003]							

Question Number(s)	**3.2**	**Main Topic(s)**		Additional Literature		**Question(s) Success**		A	**Questionnaire Reference**		References	
Question 3.2: Which other literature references do you use and for what purpose?												
International codes (DIN 1500; Eurocode; BS 7608)	SA Steel Construction Handbook	SAISC Course Notes (previous courses)	Rowswell [1987]	Crane manufacturer catalogues	Steel Designers Manual	Previous designs	Loading charts (out of date now with computer software)	Tips for Runway Girders	Company standards and guides	Class notes on fatigue [Prof. Dunaiski]	Other product supplier catalogues	Gorenc [2003]
37.8%	**23.8%**	**18.7%**	**18.0%**	**9.1%**	**7.4%**	**6.5%**	**6.3%**	**6.0%**	**5.3%**	**4.4%**	**2.7%**	**2.4%**
Literature:												

Question 4.1 has been discussed in the thesis.

Question Number(s)	**5.1**	**Main Topic(s)**	Classification	**Question(s) Success**	B	**Questionnaire Reference**	Classification of Structure
Question 5.1: How do you classify a crane? Who is involved in the classification process?							
Client and/or crane manufacturer responsible for classification according to crane related classification and information about type of facility. Structure is then classified according to SABS 0160			Client responsible for classification according to SABS 0160		Structural designer responsible for classification according to SABS 0160		Not sure
63.4%			**19.6%**		**13.9%**		**3.1%**
Literature: Rowswell [1987]; Gorenc [2003]; MacCrimmon [2005]; AS 1418.18-2001; ENV 1993-6:1999; Cadile [1976]; Goldman [1990]; Fisher [1993]; SAISC Industrial Buildings Course [2007]; Dymond [2005]							

Question Number(s)	**5.2**	**Main Topic(s)**	Classification	**Question(s) Success**	B	**Questionnaire Reference**	Classification of Structure
Question 5.2: Do you think the present classification (SABS 0160-1989 5.7.2) is sufficient or should a more detailed crane classification model be introduced?							
Classification using SABS 0160 is sufficient and acceptable in almost all cases		Classification using SABS 0160 is not sufficient and a more detailed classification model should be introduced (using utilization class and duty cycles)					
82.3%		**17.7%**					
Literature: Rowswell [1987]; Gorenc [2003]; MacCrimmon [2005]; Cadile [1976]; Fisher [1993]; SAISC Industrial Buildings Course [2007]; Dymond [2005]							

Question Number(s)	**6.1**	**Main Topic(s)**	Dynamic Factors	**Question(s) Success**	B	**Questionnaire Reference**	Load Amplification Factors
Question 6.1: Are the dynamic load amplification factors to be applied to the static vertical wheel loads as specified per crane class (SABS 0160-1989 5.7.3) acceptable, conservative or non-conservative?							
Acceptable as they have worked for previous designs		Unconservative as the dynamic loads generated may actually be larger		Conservative but accepted as such because they have worked for previous designs			
75.7%		**16.1%**		**8.2%**			
Literature: Rowswell [1987]; Gorenc [2003]; MacCrimmon [2005]; AS 1418.18-2001; ENV 1993-6:1999; Lobov [1989]; MBSM [2002]; Fisher [1993]; Thompson [1970]; SAISC Industrial Buildings Course [2007]; Dymond [2005]							

Question Number(s)	**6.2**	**Main Topic(s)**	Horizontal Load Factors	**Question(s) Success**	B	**Questionnaire Reference**	Load Amplification Factors
Question 6.2: Are the load amplification factors to be applied to the horizontal wheel loads as specified per crane class (SABS 0160:1989 5.7.4) acceptable, conservative or non-conservative?							
Acceptable as they have worked for previous designs		Unconservative as the dynamic loads generated may actually be larger		Conservative but accepted as such because they have worked for previous designs		Not sure	
80.2%		**7.1%**		**8.2%**		**4.5%**	
Literature: Rowswell [1987]; Gorenc [2003]; MacCrimmon [2005]; AS 1418.18-2001; ENV 1993-6:1999; Lobov [1989]; MBSM [2002]; Fisher [1993]; Viljoen [2004]; Thompson [1970]; SAISC Industrial Buildings Course [2007]; Dymond [2005]							

Question Number(s)	**6.3**	**Main Topic(s)**	Load Amplification Factors	**Question(s) Success**	B	**Questionnaire Reference**	Load Amplification Factors
Question 6.3: The load amplification factors (also dynamic load amplifiation factors) increase per crane class. Do you think this increase is relevant?							
Yes the higher factors are applicable out of a reliability and probability perspective (more likely to undergo large loads)		No, it does not make sense to increase these forces (increase should be the same regardless of the crane class)					
91.2%		**8.8%**					
Literature: Rowswell [1987]; Gorenc [2003]; MacCrimmon [2005]; AISE [2003]; AS 1418.18-2001; ENV 1993-6:1999; Lobov [1989]; MBSM [2002]; Fisher [1993]; Viljoen [2004]; Thompson [1970]; SAISC Industrial Buildings Course [2007]; Dymond [2005]							

Question Number(s)	**7.1**	**Main Topic(s)**	Multiple Crane Loads	**Question(s) Success**	B	**Questionnaire Reference**	Load Cases
Question 7.1: For misalignment, skewing and acceleration respectively, when dealing with multiple crane setups, how many cranes do you think should be used in combination to generate the respective loading situation?							
The number of cranes is acceptable according to the code unless further, specific, information is known		All cranes for certical, but the horizontal cranes could be decreased		All cranes for vertical, but the horizontal cases could be increased especially for dual crane simultaneous lifting			
71.3%		**10.8%**		**17.8%**			
Literature: Gorenc [2003]; AISE [2003]; MacCrimmon [2005]; Rowswell [1987]; AS 1418.18-2001; ENV 1993-6:1999; MBSM [2002]; SAISC Industrial Buildings Course [2007]; Dymond [2005]							

Question Number(s)	**7.2**	**Main Topic(s)**	Notional Loads	**Question(s) Success**	B	**Questionnaire Reference**	Load Cases
Question 7.2: For the purpose of a "second order analysis", how is the horizontal notional load calculated and where is it applied to the structure?							
Notional loads are not needed / applied for the design of crane buildings		The codes description of notional loads for crane buildings is followed		Not sure			
78.2%		**18.7%**		**3.1%**			
Literature: Gorenc [2003]; SANS 10162-1:2005; MacCrimmon [2005]; AS 1418.18-2001; ENV 1993-6:1999; SAISC Industrial Buildings Course [2007]; Dymond [2005]							

Question Number(s)	**8.1**	**Main Topic(s)**	Strange Load Cases	**Question(s) Success**	B	**Questionnaire Reference**	Additional Design Situations
Question 8.1: What unusual load cases need to be investigated in South Africa?							
None	End stop impact	Temperature variations	Wheel flange contact and its influences	Uneven drive induced surge and misalignment	Specific structures may have specifc load cases	Settlement and soil movement	
49.8%	**23.5%**	**13.5%**	**12.1%**	**4.9%**	**4.4%**	**2.7%**	
Literature: Gorenc [2003]; AISE [2003]; MacCrimmon [2005]; AS 1418.18-2001; ENV 1993-6:1999; Dymond [2005]							

<table>
<tr><td>Question Number(s)</td><td>9.1</td><td>Main Topic(s)</td><td>Code Load Combinations</td><td>Question(s) Success</td><td>B</td><td>Questionnaire Reference</td><td>Load Combinations</td></tr>
<tr><td colspan="8">Question 9.1: Are the load combinations as described in SABS 0160:1989 section 4 sufficient for design and analysis purposes?</td></tr>
<tr><td colspan="2">Yes, the combinations are sufficient</td><td colspan="2">Yes, the combinations are sufficient, but engineering judgement is required for interpretation and some additional load cases could be included</td><td colspan="2">Not sure</td><td colspan="2"></td></tr>
<tr><td colspan="2">59.0%</td><td colspan="2">38.3%</td><td colspan="2">2,7%</td><td colspan="2"></td></tr>
<tr><td colspan="8">Literature: Rowswell [1987]; Gorenc [2003]; MacCrimmon [2005]; AISE [2003]; SABS 0160:1989; SASCH [2005]; AS 1418.18-2001; prEN 1990:2001; ENV 1993-6:1999; MBSM [2002]; SAISC Industrial Buildings Course [2007]; Dymond [2005]</td></tr>
</table>

<table>
<tr><td>Question Number(s)</td><td>9.2</td><td>Main Topic(s)</td><td>Ultimate Load Combinations</td><td>Question(s) Success</td><td>C</td><td>Questionnaire Reference</td><td>Load Combinations</td></tr>
<tr><td colspan="8">Question 9.2: List all ultimate limit state load combinations that you investigate for a regular portal frame industrial building with a crane? Also state if each combination is probably "critical", "check required" or "negligible"?</td></tr>
<tr><td colspan="8">Note: Due to the nature of the response and the limited number of answers actually attained, weighted combination was not applied here. Instead the answers listed here are the areas were answers differed from one another. The SABS 0160:1989 loading code is used by all experts. It is simply the interpretation thereof that varies. These interpretive differences are listed in this table.</td></tr>
<tr><td colspan="2">The following forces are all listed as dominant for a combination: Crane vertical; Crane horizontal; Wind.</td><td colspan="2">The crane loads are considered to be live load. Some uncertainty was noted as the crane loads could be dead load?</td><td colspan="2">The degree of correlation between the loads is very uncertain. Especially the correlation between the vertical and horizontal crane loads.</td><td colspan="2">Linked with this correlation is also the wind factors when wind is regarded as non-dominant. Should this value be zero, or have a partial value?</td></tr>
<tr><td colspan="8">Literature: Rowswell [1987]; Gorenc [2003]; MacCrimmon [2005]; AISE [2003]; SABS 0160:1989; SASCH [2005]; AS 1418.18-2001; prEN 1990:2001; ENV 1993-6:1999; MBSM [2002]; SAISC Industrial Buildings Course [2007]; Dymond [2005]</td></tr>
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<table>
<tr><td>Question Number(s)</td><td>9.3</td><td>Main Topic(s)</td><td>Serviceability Combinations</td><td>Question(s) Success</td><td>C</td><td>Questionnaire Reference</td><td>Load Combinations</td></tr>
<tr><td colspan="8">Question 9.2: List all serviceability limit state load combinations that you investigate for a regular portal frame industrial building with a crane? Also state if each combination is probably "critical", "check required" or "negligible"?</td></tr>
<tr><td colspan="8">Note: Due to the nature of the response and the limited number of answers actually attained, weighted combination was not applied here. Instead the answers listed here are the areas were answers differed from one another. The SABS 0160:1989 loading code is used by all experts. It is simply the interpretation thereof that varies. These interpretive differences are listed in this table.</td></tr>
<tr><td colspan="2">The code is seen as completely adequate and the analysed structure is tested for the deflection limits. Unfortunately only a guide is given on the deflection limits.</td><td colspan="2">The cases where wind is dominant and the case where the crane is dominant normally governs for sway.</td><td colspan="2">The girders must also be checked individually under loading to assess deflection limits.</td><td colspan="2"></td></tr>
<tr><td colspan="8">Literature: Rowswell [1987]; Gorenc [2003]; MacCrimmon [2005]; AISE [2003]; SABS 0160:1989; AS 1418.18-2001; prEN 1990:2001; ENV 1993-6:1999; MBSM [2002]; Goldman [1990]; Fisher [1993]; SAISC Industrial Buildings Course [2007]; Dymond [2005]</td></tr>
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<table>
<tr><td>Question Number(s)</td><td>9.4</td><td>Main Topic(s)</td><td>Critical Load Combinations</td><td>Question(s) Success</td><td>B</td><td>Questionnaire Reference</td><td>Load Combinations</td></tr>
<tr><td colspan="8">Question 9.4: Structural analysis involves many load combinations, how do you select (find) the maximum combinations to be used for the design of specific elements?</td></tr>
<tr><td colspan="2">Experience, intuition and engineering judgement - used to find the critical crane positions and load combinations</td><td colspan="2">A combination of analysis software, engineering judgement and experience</td><td colspan="2">Software packages and / or envelopes</td><td colspan="2"></td></tr>
<tr><td colspan="2">53.8%</td><td colspan="2">34.0%</td><td colspan="2">12.2%</td><td colspan="2"></td></tr>
<tr><td colspan="8">Literature: Rowswell [1987]; Gorenc [2003]; MacCrimmon [2005]; AISE [2003]; SASCH [2005]</td></tr>
</table>

<table>
<tr><td>Question Number(s)</td><td>10.1</td><td>Main Topic(s)</td><td>Eccentricities</td><td>Question(s) Success</td><td>B</td><td>Questionnaire Reference</td><td>Force Application</td></tr>
<tr><td colspan="8">Question 10.1: At what height are horizontal transverse crane forces applied to the crane support system? (Answer for the crane runway dirder design and structural software analysis separately)</td></tr>
<tr><td colspan="2">Crane Runway Girder Design</td><td colspan="2">Top of the rail</td><td colspan="2">Top flange level</td><td colspan="2"></td></tr>
<tr><td colspan="2">Percentage</td><td colspan="2">80.6%</td><td colspan="2">19.4%</td><td colspan="2"></td></tr>
<tr><td colspan="2">Structural Analysis</td><td colspan="2">Top flange level (surge connection level)</td><td colspan="2">Top of the rail</td><td colspan="2">Centroid of the crane girder</td></tr>
<tr><td colspan="2">Percentage</td><td colspan="2">69.7%</td><td colspan="2">27.5%</td><td colspan="2">2.7%</td></tr>
<tr><td colspan="8">Literature: Rowswell [1987]; Gorenc [2003]; AISE [2003]; MacCrimmon [2005]; SASCH [2005]; AS 1418.18-2001; ENV 1993-6:1999; Reemsnyder [1978]; Fisher [1993]; Viljoen [2004]; Thompson [1970]; Maas [1972]; Collins et al. [1991]; Senior et al. [1963]; SAISC Industrial Buildings Course [2007]</td></tr>
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<table>
<tr><td>Question Number(s)</td><td>10.2</td><td>Main Topic(s)</td><td>Eccentricities</td><td>Question(s) Success</td><td>B</td><td>Questionnaire Reference</td><td>Force Application</td></tr>
<tr><td colspan="8">Question 10.1: At what point and with what eccentricity is the vertical crane force applied? (Answer for the crane runway dirder design and structural software analysis separately)</td></tr>
<tr><td colspan="2">Crane Runway Girder Design</td><td colspan="2">Centreline of the web (no eccentricity)</td><td colspan="2">Centreline of the web (¼ rail head width either side)</td><td colspan="2">Centreline of the web (crane girder web thickness either side)</td></tr>
<tr><td colspan="2">Percentage</td><td colspan="2">68.8%</td><td colspan="2">17.4%</td><td colspan="2">13.8%</td></tr>
<tr><td colspan="2">Structural Analysis</td><td colspan="2">Top flange level (surge connection level)</td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td colspan="2">Percentage</td><td colspan="2">100.0%</td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td colspan="8">Literature: Rowswell [1987]; Gorenc [2003]; AISE [2003]; MacCrimmon [2005]; SASCH [2005]; AS 1418.18-2001; ENV 1993-6:1999; Reemsnyder [1978]; Fisher [1993]; Viljoen [2004]; Thompson [1970]; Maas [1972]; Collins et al. [1991]; Senior et al. [1963]; SAISC Industrial Buildings Course [2007]</td></tr>
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<table>
<tr><td>Question Number(s)</td><td>11.1</td><td>Main Topic(s)</td><td>Deflections</td><td>Question(s) Success</td><td>B</td><td>Questionnaire Reference</td><td>Serviceability</td></tr>
<tr><td colspan="8">Question 11.1: Are the deflection limits as included in SANS 10162-1:2005 Annex D conservative, acceptable or non-conservative?</td></tr>
<tr><td colspan="2">Acceptable, they work and are therefore used</td><td colspan="2">Conservative, they are often critical in design</td><td colspan="2">Unconservative or unclear, an improved / adjusted deflection guide is needed</td><td colspan="2"></td></tr>
<tr><td colspan="2">85.4%</td><td colspan="2">9.7%</td><td colspan="2">4.9%</td><td colspan="2"></td></tr>
<tr><td colspan="8">Literature: Rowswell [1987]; Gorenc [2003]; AISE [2003]; MacCrimmon [2005]; SANS 10162-1:2005; AS 1418.18-2001; ENV 1993-6:1999; SAISC Industrial Buildings Course [2007]</td></tr>
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<table>
<tr><td>Question Number(s)</td><td>12.1</td><td>Main Topic(s)</td><td>Analysis Software</td><td>Question(s) Success</td><td>B</td><td>Questionnaire Reference</td><td>Computer Software</td></tr>
<tr><td colspan="8">Question 12.1: Which computer software package do you use for the anlaysis of the crane runway girder and the remainder of the building structure respectively?</td></tr>
<tr><td colspan="2">Crane Runway Girder Analysis</td><td colspan="2">Hand calculations (Excel spreadsheets)</td><td colspan="2">Prokon</td><td colspan="2">Other finite element software</td></tr>
<tr><td colspan="2">Percentage</td><td colspan="2">62.4%</td><td colspan="2">32.8%</td><td colspan="2">4.9%</td></tr>
<tr><td colspan="2">Structural Analysis</td><td colspan="2">Prokon</td><td colspan="2">Other finite element software</td><td colspan="2"></td></tr>
<tr><td colspan="2">Percentage</td><td colspan="2">76.6%</td><td colspan="2">23.4%</td><td colspan="2"></td></tr>
<tr><td colspan="8">Literature:</td></tr>
</table>

Question Number(s)	**12.2**	**Main Topic(s)**	Design Software	**Question(s) Success**	C	**Questionnaire Reference**	Computer Software
Question 12.2: What additional analysis and / or design software is available?							
Not sure	Prokon	ROBOT	Framework version 9.4	STRAP	STRAND 7	STAAD PRO	CAD series
44.8%	**21.0%**	**7.3%**	**6.5%**	**6.3%**	**6.1%**	**5.3%**	**2.7%**
Literature:							

Question Number(s)	**12.3**	**Main Topic(s)**	Design Software	**Question(s) Success**	B	**Questionnaire Reference**	Computer Software
Question 12.3: Do you use computer software for design?							
No, hand calculation are preferred		Yes, but a combination of hand calculations and the software is preferred (cross check)		Yes			
21.9%		**65.3%**		**12.8%**			
Literature:							

Question Number(s)	**12.4**	**Main Topic(s)**	2D or 3D Analysis	**Question(s) Success**	A	**Questionnaire Reference**	Computer Software
Question 12.4: Do you make use of 2D or 3D analysis?							
Mainly 2D		Mainly 3D		2D if the structure is uniform, 3D if the time allows or it is necessary			
44.4%		**29.4%**		**26.2%**			
Literature: Gorenc [2003]; MacCrimmon [2005]; AISE [2003]							

Question Number(s)	**12.5**	**Main Topic(s)**	Type of Analysis	**Question(s) Success**	A	**Questionnaire Reference**	Computer Software
Question 12.5: Considering te software package mentioned above; what type of analysis is used?							
Linear		2^{nd} order		Non-linear			
71.6%		**22.4%**		**6.0%**			
Literature: Gorenc [2003]; MacCrimmon [2005]; AISE [2003]; SANS 10162-1:2005; AS 1418.18-2001; ENV 1993-6:1999; Fisher [1993]; SAISC Industrial Buildings Course [2007]							

Question Number(s)	**12.6**	**Main Topic(s)**	Connection Analysis	**Question(s) Success**	B	**Questionnaire Reference**	Computer Software
Question 12.6: Are connections ever analysed in detail to produce a more accurate stress distribution for the purpose of connection design?							
Yes, hand calculations are used for detailed design of connections		Yes, hand calculations are used together with the computer software					
77.7%		**22.3%**					
Literature: Gorenc [2003]; Fisher [1993]							

Question Number(s)	**13.1**	**Main Topic(s)**	Crane Girder Type	**Question(s) Success**	B	**Questionnaire Reference**	Crane Girder
Question 13.1: Are simply supported or continuous crane runway girders preferred in South Africa?							
Simply supported		Simply supported are preferred, but continuous can be used for specific cases		Simply supported are used, continuous girders create many problems			
21.7%		**47.8%**		**30.5%**			
Literature: Rowswell [1987]; Gorenc [2003]; MacCrimmon [2005]; AISE [2003]; SASCH [2005]; AS 1418.18-2001; ENV 1993-6:1999; MBSM [2002]; Goldman [1990]; Fisher [1993]; Thompson [1970]; SAISC Industrial Buildings Course [2007]; Dymond [2005]							

Question Number(s)	**13.2**	**Main Topic(s)**	Crane Girder Type	**Question(s) Success**	B	**Questionnaire Reference**	Crane Girder
Question 13.2: What different crane runway girder sections are being used in South Africa?							
A variety are available - mainly Universal sections (horizontal channel), plate girders, surge plate girders		Not sure					
96.9%		**3.1%**					
Literature: Rowswell [1987]; Gorenc [2003]; MacCrimmon [2005]; AISE [2003]; SASCH [2005]; AS 1418.18-2001; ENV 1993-6:1999; MBSM [2002]; Goldman [1990]; Maas [1972]; SAISC Industrial Buildings Course [2007]							

Question Number(s)	**13.3**	**Main Topic(s)**	Girder Alignment	**Question(s) Success**	B	**Questionnaire Reference**	Crane Girders
Question 13.3: How is alignmnet of the crane runway girder made possible? i.e. Describe the different vertical and horizontal adjustable connections that can be used?							
Vertical	Packing (under crane girder or at column base)	Not sure	Adjustable lock bolts	None is provided	Slotted holes		
Percentage	**88.9%**	**5.9%**	**9.7%**	**5.3%**	**6.3%**		
Horizontal	Packing	slotted holes	None is provided	Not sure			
Percentage	**70.9%**	**85.7%**	**6.0%**	**5.9%**			
Literature: Rowswell [1987]; Gorenc [2003]; MacCrimmon [2005]; AISE [2003]; SASCH [2005]; AS 1418.18-2001; ENV 1993-6:1999; MBSM [2002]; Goldman [1990]; SAISC Industrial Buildings Course [2007]							

Question Number(s)	**13.4**	**Main Topic(s)**	Alignment at Construction	**Question(s) Success**	C	**Questionnaire Reference**	Crane Girder
Question 13.4: How is the overall alignment of the crane supporting structure ensured during construction?							
Accurate construction to tolerances		Not sure					
96.9%		**3.1%**					
Literature: Rowswell [1987]; AISE [2003]; MacCrimmon [2005]; AS 1418.18-2001; ENV 1993-6:1999; SASSSC [2000]; Fisher [1993]; Thompson [1970]							

Question Number(s)	**13.5**	**Main Topic(s)**	Stiffeners	**Question(s) Success**	A	**Questionnaire Reference**	Crane Girders
Question 13.5: Are crane girders designed to have intermediate web stiffeners or not?							
Yes, stiffeners are included if needed according to normal stiffener design (stub stiffeners can be included)	Yes, stiffeners are included to reduce the top flange rotation and according to normal stiffener design (stub stiffeners can be included)	Yes, stiffeners are included if needed according to normal stiffener design	No, an attempt should be made to not use stiffeners (stub stiffeners can be included)	No, an attempt should be made to not use stiffeners			
35.8%	**32.2%**	**23.3%**	**4.4%**	**4.3%**			
Literature: Rowswell [1987]; Gorenc [2003]; MacCrimmon [2005]; AISE [2003]; SASCH [2005]; SANS 10162-1:2005; AS 1418.18-2001; ENV 1993-6:1999; MBSM [2002]; Reemsnyder [1978]; Maas [1972]; Collins et al. [1991]; Senior et al. [1963]; SAISC Industrial Buildings Course [2007]							

Question Number(s)	**13.6**	**Main Topic(s)**	Stiffeners	**Question(s) Success**	B	**Questionnaire Reference**	Crane Girder
Question 13.6: How do you determine the spacing of the intermediate (or stub) stiffeners on a crane girder?							
According to the code design and the South African Steel Construction Handbook		According to the code design		According to the code design and experience (rule of thumb)			
26.2%		**40.0%**		**33.8%**			
Literature: Rowswell [1987]; Gorenc [2003]; MacCrimmon [2005]; AISE [2003]; SASCH [2005]; SANS 10162-1:2005; AS 1418.18-2001; ENV 1993-6:1999; MBSM [2002]; Reemsnyder [1978]; Maas [1972]; Collins et al. [1991]; SAISC Industrial Buildings Course [2007]							

Question Number(s)	**13.7**	**Main Topic(s)**	Stiffeners	**Question(s) Success**	B	**Questionnaire Reference**	Crane Girder
Question 13.7: How do you determine the depth and width of the intermediate (or stub) stiffeners?							
According to the code design and the South African Steel Construction Handbook (intermediate stiffeners are stopped short)		According to the code design (intermediate stiffeners taken to bottom flange)		According to the code design and experience (rule of thumb), (intermediate stiffeners are stopped short)		According to the code design (intermediate stiffeners are stopped short)	
51.1%		**2.7%**		**15.7%**		**30.5%**	
Literature: Rowswell [1987]; Gorenc [2003]; MacCrimmon [2005]; AISE [2003]; SASCH [2005]; SANS 10162-1:2005; AS 1418.18-2001; ENV 1993-6:1999; MBSM [2002]; Reemsnyder [1978]; Maas [1972]; Collins et al. [1991]; SAISC Industrial Buildings Course [2007]							

Question Number(s)	**13.8**	**Main Topic(s)**	Mono-symmetric Section	**Question(s) Success**	C	**Questionnaire Reference**	Crane Girders
Question 13.8: How do yo calculate the following parameters for a monosymmetric plate girder section?							
Using Prokon's properties section (Prosec)	Girder designed assuming a conservative approach (assuming a symmetric section)	Not sure where, but can be found in literature (Parrot)	Not sure	Prof. Dunaiski notes			
49.7%	**21.5%**	**18.7%**	**5.6%**	**4.5%**			
Literature: Rowswell [1987]; Gorenc [2003]; MacCrimmon [2005]; Goldman [1990]; SAISC Industrial Buildings Course [2007]							

Question Number(s)	**13.9**	**Main Topic(s)**	Section Properties	**Question(s) Success**	B	**Questionnaire Reference**	Crane Girders

Question 13.9: Define the effective areas for the calculation of parameters I_y and I_x respectively - for an I-section plate girder with surge plate?

I_x	Crane girder only	According to the SASC Handbook	Using Prokon's properties section (Prosec)	Not sure			
Percentage	**60.7%**	**26.2%**	**7.6%**	**5.6%**			
I_y	Top flange of the crane girder (can add web portion), the surge plate and the whole auxiliary girder	Top flange of the crane girder (can add web portion), the surge plate and the top flange of the auxiliary girder (can add web portion)	According to the SASC Handbook	Using Prokon's properties section (Prosec)	Top half of the crane girder, the surge plate and the auxiliary girder	Top flange of the crane girder and the surge plate	Not sure
Percentage	**31.2%**	**22.4%**	**19.8%**	**7.6%**	**7.3%**	**6.1%**	**5.6%**

Literature: Rowswell [1987]; Gorenc [2003]; MacCrimmon [2005]; AISE [2003]; SASCH [2005]; AS 1418.18-2001; ENV 1993-6:1999; SAISC Industrial Buildings Course [2007]

Question Number(s)	**13.10**	**Main Topic(s)**	Rail Clips	**Question (s) Success**	B	**Question-naire Reference**	Rails

Question 13.10: Complete the table by filling in the type of weild that is normally used for the respective detail on a crane runway girder (for light and heavy cranes)?

Girder Type	**Detail Description**	**Class 1 & 2**					
		FPB	**Fillet**	**Fillet (St)**	**NA**	**Bearing**	**HSFG**
Plate Girder	Top flange to web	67.5%	25.6%	0.0%	6.9%	0.0%	0.0%
	Stiffener to web	0.0%	75.7%	19.8%	4.4%	0.0%	0.0%
	Stiffener to top flange	23.9%	57.9%	0.0%	4.4%	13.8%	0.0%
	Endplate to girder (bearing stiffener)	31.5%	64.1%	0.0%	4.4%	0.0%	0.0%
I-beam with Channel	Horizontal channel to top flange	12.5%	66.9%	16.2%	0.0%	0.0%	4.4%
	Stiffener to web	0.0%	80.2%	19.8%	0.0%	0.0%	0.0%
	Stiffener to top flange	23.9%	62.3%	0.0%	0.0%	13.8%	0.0%
	Endplate to girder	25.0%	75.0%	0.0%	0.0%	0.0%	0.0%
Girder Type	**Detail Description**	**Class 3 & 4**					
		FPB	**Fillet**	**Fillet (St)**	**NA**	**Bearing**	**HSFG**
Plate Girder	Top flange to web	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Stiffener to web	6.8%	88.8%	4.4%	0.0%	0.0%	0.0%
	Stiffener to top flange	38.9%	47.3%	0.0%	0.0%	13.8%	0.0%
	Endplate to girder (bearing stiffener)	46.5%	53.5%	0.0%	0.0%	0.0%	0.0%
I-beam with Channel	Horizontal channel to top flange	0.0%	38.0%	4.4%	46.4%	0.0%	11.2%
	Stiffener to web	6.8%	42.5%	4.4%	46.4%	0.0%	0.0%
	Stiffener to top flange	19.7%	29.5%	0.0%	46.4%	4.4%	0.0%
	Endplate to girder	26.0%	27.6%	0.0%	46.4%	0.0%	0.0%

Literature: Rowswell [1987]; Gorenc [2003]; MacCrimmon [2005]; AISE [2003]; SASCH [2005]; AS 1418.18-2001; ENV 1993-6:1999; MBSM [2002]; Reemsnyder [1978]; Viljoen [2004]; Thompson [1970]; Maas [1972]; Collins et al. [1991]; Senior et al. [1963]; SAISC Industrial Buildings Course [2007]

Question Number(s)	**14.1**	**Main Topic(s)**	Rail Clips	**Question(s) Success**	B	**Questionnaire Reference**	Rails

Question 14.1: What type of rail clip is most used in South Africa (and which do you prefer)?

Gantrex or Gantrail (maybe Lindaptors)	Gantrex, Gantrail or basic bolted block	Not sure	Basic bolted block	Straight weld between the girder and rail			
65.9%	**25.8%**	**3.1%**	**2.7%**	**2.4%**			

Literature: Rowswell [1987]; Gorenc [2003]; MacCrimmon [2005]; AISE [2003]; SASCH [2005]; AS 1418.18-2001; ENV 1993-6:1999; Lobov [1989]; MBSM [2002]; Goldman [1990]; Fisher [1993]; Thompson [1970]; Maas [1972]; Collins et al. [1991]; SAISC Industrial Buildings Course [2007]

Question Number(s)	**14.2**	**Main Topic(s)**	Rail Splices	**Question(s) Success**	B	**Questionnaire Reference**	Rails
Question 14.2: How are rail splices made?							
Low Duty Cranes	Bearing	Fishplates	Bearing at angle	Thermite welding (continuous rail)	Not sure		
Percentage	**64.7%**	**17.8%**	**9.8%**	**4.5%**	**3.1%**		
High Duty Cranes	Thermite welding (continuous rail)	Bearing	Not sure	Bearing at angle			
Percentage	**90.1%**	**4.3%**	**3.1%**	**2.4%**			
Literature: Rowswell [1987]; Gorenc [2003]; MacCrimmon [2005]; AISE [2003]; SASCH [2005]; AS 1418.18-2001; ENV 1993-6:1999; Lobov [1989]; MBSM [2002]; Goldman [1990]; Fisher [1993]; Thompson [1970]; Maas [1972]; Collins et al. [1991]; SAISC Industrial Buildings Course [2007]							

Question Number(s)	**15.1**	**Main Topic(s)**	Elastomeric Pad	**Question(s) Success**	B	**Questionnaire Reference**	Elastomeric Pad	
Question 15.1: What is the purpose of the elastomeric pad between the crane runway girder and the rail?								
Reduce impact loading	Reduces top flange wear	Load spreading	Smooths the crane use	Noise reduction	Allows for a better floating rail	Reduces rotation of the top flange	Prolongs the life or rail clips	Not sure
59.1%	**47.0%**	**36.9%**	**27.7%**	**21.8%**	**16.5%**	**11.9%**	**5.3%**	**2.4%**
Literature: Rowswell [1987]; Gorenc [2003]; AISE [2003]; SASCH [2005]; AS 1418.18-2001; Maas [1972]; Collins et al. [1991]; SAISC Industrial Buildings Course [2007]								

Question Number(s)	**15.2**	**Main Topic(s)**	Elastomeric Pads	**Question(s) Success**	A	**Questionnaire Reference**	Elastomeric Pads
Question 15.2: Are elastomeric pads included in both heavy and light crane design?							
Light duty: No Heavy duty: No		Light duty: No Heavy duty: Yes		Light duty: Yes Heavy duty: Yes		Not sure	
30.3%		**59.2%**		**4.9%**		**5.6%**	
Literature: Rowswell [1987]; Gorenc [2003]; AISE [2003]; SASCH [2005]; AS 1418.18-2001; Maas [1972]							

Question Number(s)	**15.3**	**Main Topic(s)**	Elastomeric Pads	**Question(s) Success**	B	**Questionnaire Reference**	Elastomeric Pads
Question 15.3: Do elastomeric pads influence the design or load calculations in any way?							
No, not at all		Improves fatigue calculation for top flange to web weld		Not sure			
87.9%		**6.5%**		**5.6%**			
Literature: Rowswell [1987]; Gorenc [2003]; AISE [2003]; SASCH [2005]; AS 1418.18-2001; Maas [1972]							

Question Number(s)	**16.1**	**Main Topic(s)**	End Stops	**Question(s) Success**	B	**Questionnaire Reference**	End Stops
Question 16.2: Explain which buffers, elastomeric or hydraulic, are preferred in South Africa?							
Light Duty Cranes		Timber		Elastomeric		Any	
Percentage		**6.7%**		**47.0%**		**46.3%**	
Heavy Duty Cranes		Any		Elastomeric or Hydraulic		Elastomeric	
Percentage		**48.7%**		**41.3%**		**10.0%**	
Literature: Rowswell [1987]; Gorenc [2003]; MacCrimmon [2005]; AISE [2003]; SASCH [2005]; SABS 0160:1989; AS 1418.18-2001; ENV 1993-6:1999; MBSM [2002]; Goldman [1990]; Fisher [1993]; SAISC Industrial Buildings Course [2007]; Dymond [2005]							

Question Number(s)	**17.1**	**Main Topic(s)**	Bracing Placement	**Question(s) Success**	B	**Questionnaire Reference**	Structural and Crane Bracing
Question 17.1: Where in the structure do you place the building bracing and crane bracing respectively?							
As central as possible		Primarily process driven		In the endbay(s) connected to the gable systems			
85.0%		**2.7%**		**12.3%**			
Literature: Rowswell [1987]; Gorenc [2003]; MacCrimmon [2005]; AISE [2003]; ENV 1993-6:1999; MBSM [2002]; Fisher [1993]; SAISC Industrial Buildings Course [2007]							

Question Number(s)	**17.2**	**Main Topic(s)**	Longitudinal Force Transfer	**Question(s) Success**	B	**Questionnaire Reference**	Structural and Crane Bracing
Question 17.2: How are the end stop impact forces and / or the longitudinal horizontal wheel forces transferred to the bracing system?							
Down the girders using continuity plates	Down the girders using continuity plates or the column caps and bolts	Down the girders using the column caps and bolts	Down the rail	Not sure	Down the girders using web plates		
55.9%	**27.0%**	**8.7%**	**3.1%**	**2.7%**	**2.4%**		
Literature: Rowswell [1987]; Gorenc [2003]; MacCrimmon [2005]; AISE [2003]; SASCH [2005]; AS 1418.18-2001; ENV 1993-6:1999; MBSM [2002]; SAISC Industrial Buildings Course [2007]							

Question Number(s)	**17.3**	**Main Topic(s)**	Expansion Joints	**Question(s) Success**	B	**Questionnaire Reference**	Structural and Crane Bracing
Question 17.3: What is done to transfer the end stop impact forces and / or the longitudinal horizontal wheel loads from the crane runway girders (end stops) to the bracing system - for structural layouts that do not allow the bracing system to be in the same plane as the crane girders?							
Forces seen to distribute between adjacent columns		One or more horizontal trusses (similar to surge plates or horizontal bracing) will transfer the forces to the plane of the column and bracing		Not sure		Knee braces to get the forces to the plane of the column	
15.8%		**69.8%**		**3.1%**		**11.4%**	
Literature: Rowswell [1987]; Gorenc [2003]; MacCrimmon [2005]; AISE [2003]; SABS 0160:1989; ENV 1993-6:1999; MBSM [2002]; Collins et al. [1991]; SAISC Industrial Buildings Course [2007]							

Question Number(s)	**17.4**	**Main Topic(s)**	Expansion Joints	**Question(s) Success**	B	**Questionnaire Reference**	Structural and Crane Bracing
Question 17.4: How are crane runway expansion joints and crane rail expansion joints designed and where in the structure are they placed?							
Rail	Continuous	Scarf splice	Angle splice	Bearing	Avoid altogether		
Percentage	**57.2%**	**40.0%**	**21.3%**	**17.7%**	**14.2%**		
Runway Girders	Double column	Simply supported girders allows enough expansion	Avoid if possible	Slotted holes in all columns			
Percentage	**64.4%**	**18.9%**	**16.7%**	**10.2%**			
Literature: Rowswell [1987]; Gorenc [2003]; MacCrimmon [2005]; AISE [2003]; SABS 0160:1989; ENV 1993-6:1999; MBSM [2002]; Collins et al. [1991]; SAISC Industrial Buildings Course [2007]							

Question Number(s)	**18.1**	**Main Topic(s)**	Column Types	**Question(s) Success**	B	**Questionnaire Reference**	Crane Columns
Question 18.1: What types of crane columns are used in South Africa?							
Universal sections with a bracket (sometimes concrete columns)		Latticed columns		Battened columns		Plate-step columns	
100.0%		**100.0%**		**50.3%**		**39.3%**	
Literature: Rowswell [1987]; Gorenc [2003]; MacCrimmon [2005]; AISE [2003]; SASCH [2005]; MBSM [2002]; Goldman [1990]; Fisher [1993]; SAISC Industrial Buildings Course [2007]							

Question Number(s)	**18.2**	**Main Topic(s)**	Bracket Limits	**Question(s) Success**	B	**Questionnaire Reference**	Crane Columns
Question 18.2: What critical parameter tends to limit the use of a corbel (bracket) column?							
The size of the bracket (distance between rail and building column)		The height to the bracket (8:1 or 7:1)		The size (tons) of the crane			
13.9%		**6.1%**		**80.0%**			
Literature: AISE [2003]; MBSM [2002]; Goldman [1990]; Fisher [1993]; SAISC Industrial Buildings Course [2007]							

Question 18.3 has been discussed in the thesis.

Question Number(s)	**19.1**	**Main Topic(s)**	Storm Brakes	**Question(s) Success**	A	**Questionnaire Reference**	Outdoor Crane Gantries
Question 19.1: How and where do you place storm brakes on an outdoor crane?							
Not sure	Manufacturer's perogative	A fixed pin between crane and crane girder in the parked position (electronically controlled)	The power to the drives is automatically cut when the power is cut	The storm brakes clamp onto the rail (manual switch)			
34.1%	**27.5%**	**20.8%**	**11.4%**	**6.1%**			
Literature:							

Question Number(s)	**19.2**	**Main Topic(s)**	Outdoor Cranes	**Question(s) Success**	B	**Questionnaire Reference**	Outdoor Crane Gantries
Question 19.2: Are there any other noteworthy differences in the design of an outdoor crane gantry compared with an indoor overhead travelling crane gantry?							
Wind forces	Columns are cantilevers and deflections and moments are larger	Not sure	Thermal forces	Water runoff (corrosion)			
40.0%	**30.5%**	**13.6%**	**10.9%**	**4.9%**			
Literature: Rowswell [1987]; Gorenc [2003]; MacCrimmon [2005]; AISE [2003]; Fisher [1993]							

Question Number(s)	**20.1**	**Main Topic(s)**	Unequal Depth Beams	**Question(s) Success**	B	**Questionnaire Reference**	Unusual Layout
Question 20.1: Certain crane support structures have varying crane runway girder lengths. What adjustments are made to the crane runway girder and column details? Furthermore how do you handle the design of these differences?							
The extended crane girder will be "fishbellied" or "haunched" and the design made accordingly		Not sure		The maximum designed girder will be used for the structures crane girders			
94.4%		**3.1%**		**2.4%**			
Literature: Rowswell [1987]; MacCrimmon [2005]; Fisher [1993]							

Question Number(s)	**21.1**	**Main Topic(s)**	Fatigue Classification	**Question(s) Success**	B	**Questionnaire Reference**	Fatigue Classification
Question 21.1: Do you find the fatigue detail classification "SANS 10162-1:2005 table 10 & figure 2" helpful and sufficient for classifying structural details for fatigue?							
Yes, it is sufficient		Not entirely, I prefer additional literature		Yes, it is sufficient but rather just ensure the corret details are used			
41.3%		**53.4%**		**5.3%**			
Literature: Rowswell [1987]; Gorenc [2003]; MacCrimmon [2005]; AISE [2003]; SASCH [2005]; SANS 10162-1:2005; AS 1418.18-2001; ENV 1993-6:1999; Cadile [1976]; MBSM [2002]; Goldman [1990]; Fisher [1993]; Maas [1972]; SAISC Industrial Buildings Course [2007]; Dymond [2005]							

Question Number(s)	**21.2**	**Main Topic(s)**	Fatigue Details	**Question(s) Success**	B	**Questionnaire Reference**	Fatigue Classification
Question 21.2: List all of the details that require fatigue analysis on a crane runway girder?							
Any welds (girder)	Tie-back connectionn	column cap connection	Bolted connections (girder)	Geometric irregularities (girder)	Use the correct details	Steel yielding	Column lacing
75.4%	**69.4%**	**69.4%**	**63.3%**	**63.3%**	**24.6%**	**6.0%**	**5.3%**
Literature: Rowswell [1987]; Gorenc [2003]; MacCrimmon [2005]; AISE [2003]; SASCH [2005]; SANS 10162-1:2005; ENV 1993-6:1999; Reemsnyder [1978]; Thompson [1970]; Maas [1972]; Collins et al. [1991]; Senior et al. [1963]; SAISC Industrial Buildings Course [2007]							

Question Number(s)	**21.3**	**Main Topic(s)**	Fatigue Details	**Question(s) Success**	B	**Questionnaire Reference**	Fatigue Classification
Question 21.3: List all of the details that require fatigue analysis in the rest of a crane support structure?							
None		None, except the bracing		None, except the column base		None, use the correct details	
70.3%		**18.6%**		**6.8%**		**4.3%**	
Literature: Rowswell [1987]; Gorenc [2003]; MacCrimmon [2005]; AISE [2003]; SASCH [2005]; SANS 10162-1:2005; ENV 1993-6:1999; Reemsnyder [1978]; Thompson [1970]; Senior et al. [1963]; SAISC Industrial Buildings Course [2007]							

Question 22.1 has been discussed in the thesis.

Question Number(s)	**22.2**	**Main Topic(s)**	Stress Cycles	**Question(s) Success**	B	**Questionnaire Reference**	Load Cycles
Question 22.2: What is the difference between a load cycle and a stress range cycle?							
1 load = 1 stress cycle		1 load = variable stress cycles (min-max-min)		Not sure			
8.7%		**86.9%**		**4.3%**			
Literature: Rowswell [1987]; Gorenc [2003]; MacCrimmon [2005]; AISE [2003]; SASCH [2005]; SANS 10162-1:2005; AS 1418.18-2001; ENV 1993-6:1999; Cadile [1976]; Reemsnyder [1978]; Fisher [1993]; Senior et al. [1963]; EN 1993-1-9:2005; SAISC Industrial Buildings Course [2007]							

Question Number(s)	**22.3**	**Main Topic(s)**	Load Spectrum	**Question(s) Success**	B	**Questionnaire Reference**	Load Cycles
Question 22.3: How is the load cycle information attained?							
Client should supply a load spectrum		Not sure (details are more important)					
82.1%		**17.9%**					
Literature: Rowswell [1987]; Gorenc [2003]; MacCrimmon [2005]; SANS 10162-1:2005; AS 1418.18-2001; ENV 1993-6:1999; Cadile [1976]; Reemsnyder [1978]; Senior et al. [1963]; EN 1993-1-9:2005; SAISC Industrial Buildings Course [2007]							

Question Number(s)	**22.4**	**Main Topic(s)**	Load Spectrum	**Question(s) Success**	B	**Questionnaire Reference**	Load Cycles
Question 22.4: How is the load lifted distribution calculated?							
This information is not available		Not sure (details are more important)		Supplied as a loading spectrum from the client			
34.2%		**11.4%**		**54.4%**			
Literature: Rowswell [1987]; Gorenc [2003]; MacCrimmon [2005]; SANS 10162-1:2005; AS 1418.18-2001; ENV 1993-6:1999; Cadile [1976]; Senior et al. [1963]; EN 1993-1-9:2005; SAISC Industrial Buildings Course [2007]							

Question Number(s)	**22.5**	**Main Topic(s)**	Load Spectrum	**Question(s) Success**	C	**Questionnaire Reference**	Load Cycles
Question 22.5: How is the crane movement around the crane gantry defined and calculated?							
This information is not available or does not affect the design		Not sure (details are more important)		Supplied as a loading spectrum from the client			
64.7%		**11.4%**		**23.9%**			
Literature: Rowswell [1987]; Gorenc [2003]; MacCrimmon [2005]; SANS 10162-1:2005; Cadile [1976]							

Question Number(s)	**22.6**	**Main Topic(s)**	Load Spectrum	**Question(s) Success**	C	**Questionnaire Reference**	Load Cycles
Question 22.6: How much influence do load cycles, load distribution and crane movement have on fatigue analysis?							
Load cycles and distribution form the start of the fatigue analysis		Not sure (details are more important)					
88.6%		**11.4%**					
Literature: Rowswell [1987]; Gorenc [2003]; MacCrimmon [2005]; SANS 10162-1:2005; AS 1418.18-2001; ENV 1993-6:1999; Cadile [1976]; SAISC Industrial Buildings Course [2007]							

Question Number(s)	**22.7**	**Main Topic(s)**	Multiple Load Fatigue	**Question(s) Success**	B	**Questionnaire Reference**	Load Cycles
Question 22.7: How do you make provision for multiple load distributions (for different percentages of total load) in fatigue design (do you exclude certain low stress ranges)?							
Not needed as the information is not available		Not sure (details are more important)		Cummulative distribution analysis (Palmgren Miner)		Fatigue analysis is always done with maximum loads	
27.9%		**11.4%**		**42.7%**		**18.0%**	
Literature: Rowswell [1987]; Gorenc [2003]; MacCrimmon [2005]; SANS 10162-1:2005; AS 1418.18-2001; ENV 1993-6:1999; Cadile [1976]; EN 1993-1-9:2005; SAISC Industrial Buildings Course [2007]							

APPENDIX C:

Seed question on the latticed column

Basic analysis of a structural model would certainly provide some insight into the experts' degree of structural interpretation. The proposed model would need to be simple and require insight from the designers. The shortening of a latticed column under the crane load was selected.

The structural behaviour of a latticed column is one that has been interpreted in more than one way. The first is assuming that the vertical crane load is carried by the crane column alone. The back leg assumes no or very little stress from the crane loads. This can be compared to a linear interpretation of the behaviour. The alternative to this is that the forces distribute between the crane column and the back leg as they "move" down to the foundations. In this case it is understood that the crane column shortens under the crane load. This shortening would subsequently pull the back column down too and in the process the whole latticed column would deflect slightly inward.

C.1 Latticed column frame model

Too verify these effects and investigate under what circumstances the effects actually transpire a Prokon Frame model was compiled. Visual details of the model implemented are provided in *figure C.1*.

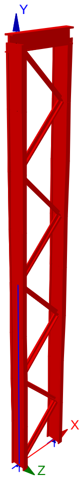


Figure C.1: The 3D view of the basic frame model used to analyse the latticed column.

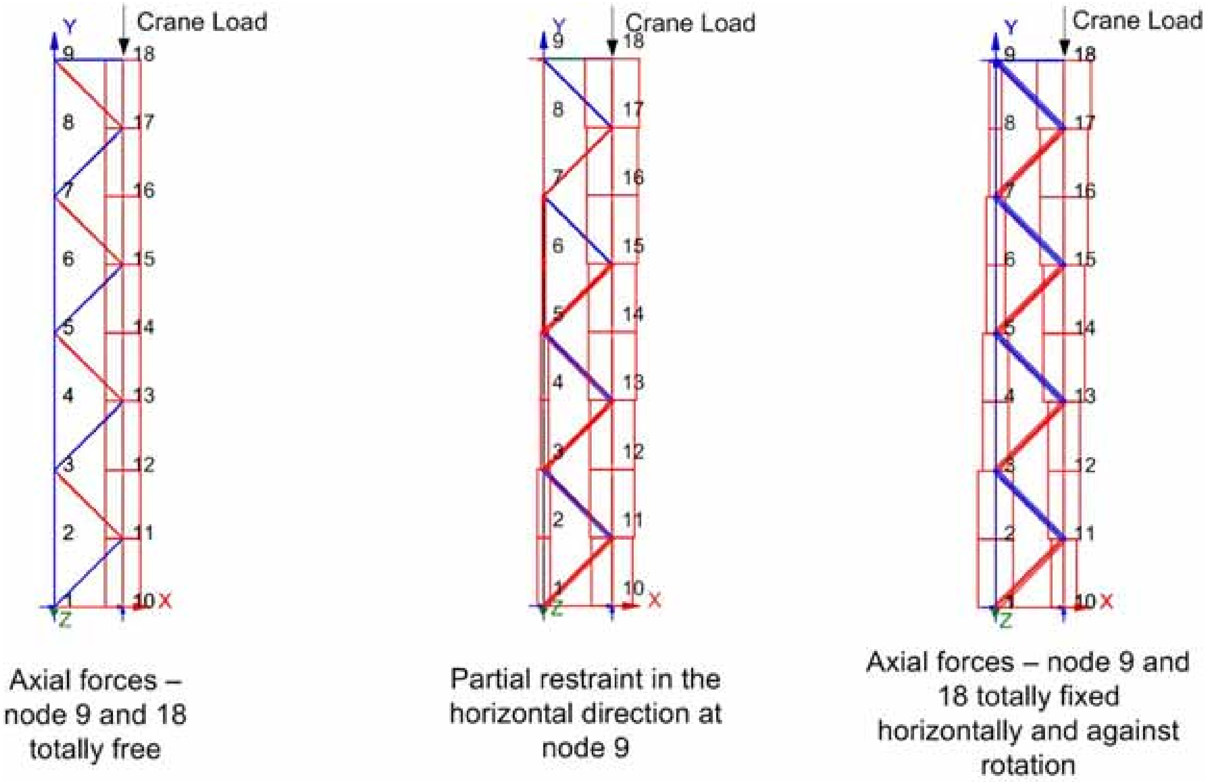
The analysis was completed using a very basic frame that effectively acts as a vertical truss. The columns are pinned at their bases, but the lacing elements are connected using a fixed connection. The vertical crane load is applied to the one column only, therefore eccentric to the entire latticed column.

C.2 Analysis and results

One of the uncertainties surrounding this setup in a normal crane building is the degree of support provided by the light roof system and the crane bridge itself. This is a topic discussed in *chapter 6* of the thesis. As a result of this uncertainty, a support is provided at the top of the back column. This is the column that is not subjected to the vertical load directly. The back column support, at the top of the column, is adjusted and the resulting behaviour of the structure analysed. In this case the axial forces were chosen as the critical parameter to the investigation.

The support varies from completely free to completely fixed. Partial restraint is also investigated using a spring support. Note that lateral and rotational support is provided, not in the vertical plane.

The following results were obtained.



Axial forces – node 9 and 18 totally free

Partial restraint in the horizontal direction at node 9

Axial forces – node 9 and 18 totally fixed horizontally and against rotation

Figure C.2: The change in axial force distribution according to the different fixity of node 9 and 18.

Table C-1: The results obtained using the frame model described. The results are used for a seed question.

Restraint	Forces back column	Forces crane column
Totally free	minimal	maximal
Partial restraint in X direction only; (z free)	increasing	decreasing
Partial restraint around z axis only; (X free)	increasing	decreasing
Total restraint in X direction only; (z free)	increasing to equal	decreasing to equal
Total restraint around z axis only; (X free)	increasing to equal	decreasing to equal
Total restraint (X direction and around z)	almost equal	almost equal

The results obtained in this table are described according to a generalised interpretation of what occurs structurally under different fixity setups. This is the reason for the vague comments. It is for instance found that the restraint of the X-direction compared with the z-axis does differ slightly. The gist of the results is still well described in the table. The results are furthermore based on the changes found at the base of the column.

APPENDIX D:

Seed question on fatigue stress cycles

As part of the preparation of the questionnaire and expert survey, seed questions were needed to form part of the proper scoring rules. This in turn would allow the experts to be rated. One of the questions sited as a possible seed question was the number of stress cycles three details on crane support structures undergo for every passing of a crane. The question (*question 22.1 in appendix A*) was further refined to:

For the following example please calculate the number of stress cycles the top flange to web weld [1], the stiffener toe [2] and the corbel to column connection [3] will be subjected to? Please explain your calculation?

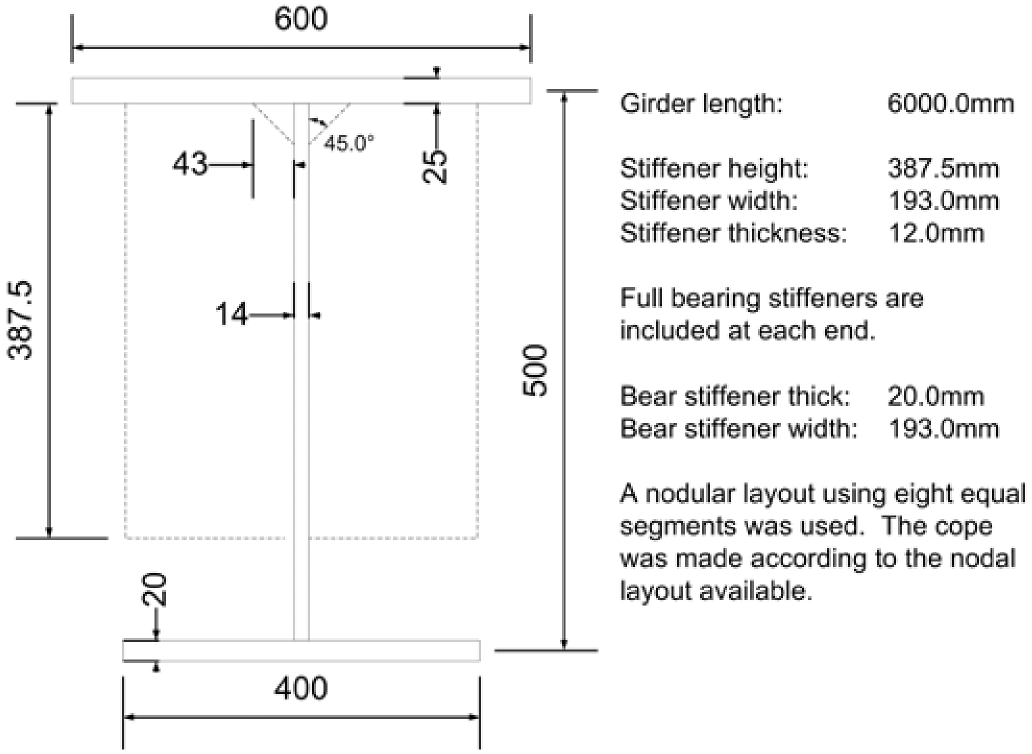
What was required to be able to score the question was the number of stress cycles each of these details experiences when a crane passes the detail. It was stated for this investigation that the crane has four wheels, two on each end carriage. The estimated answers were possibly:

i) One stress cycle for each load cycle (passing of the crane)
ii) Two stress cycles for each load cycle (passing of the crane)

Firstly the numerical setup will be briefly described and then the results presented. Following this is a short hand calculation verifying the results.

D.1 Prokon model

A simply supported mono-symmetric crane runway girder was modelled using finite elements in Prokon. The girders dimensions are provided in *figure D.1*. This is a simplification of the crane runway girders being used on a building in Saldanha. The model does result in an exceptionally large flanged girder, but again this will have little influence on the investigations results.



Girder length: 6000.0mm

Stiffener height: 387.5mm
Stiffener width: 193.0mm
Stiffener thickness: 12.0mm

Full bearing stiffeners are included at each end.

Bear stiffener thick: 20.0mm
Bear stiffener width: 193.0mm

A nodular layout using eight equal segments was used. The cope was made according to the nodal layout available.

Figure D.1: Section of the beam analysed during the fatigue seed question calculation.

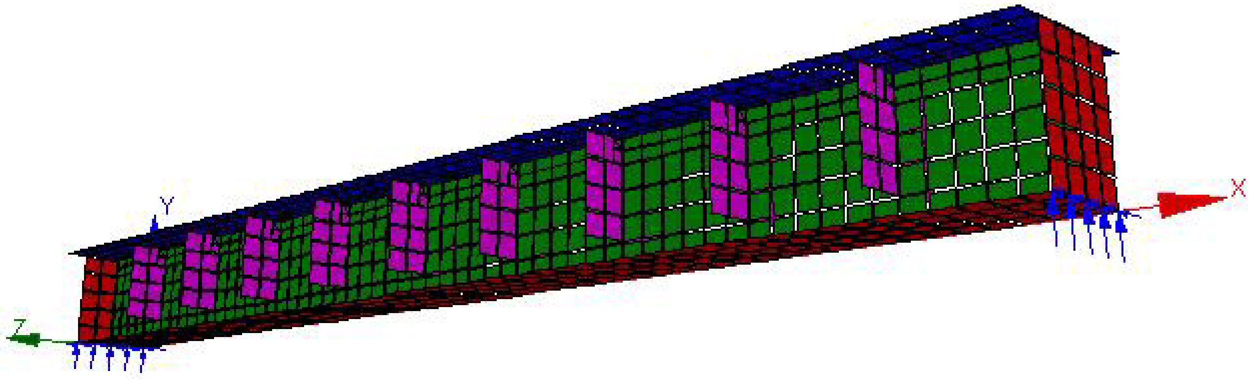


Figure D.2: The Prokon beam model setup. Shell elements were used.

D.2 Loading and validation

Once the setup was complete, the model needed to be loaded and analysed. Note that the selection of the rail, bearing area and wheel loads were not critical to this investigation and as such were not selected according to a design method, but rather according to logic. Accordingly a bearing area had to be derived. For the purpose of simplicity a 40 kg/m rail was selected only for dimension calculations. A pad of 5mm was also placed beneath the rail. The angle at which the wheel loads were thought to distribute in both the rail and the pad is 30°. Figure D.3 describes the consequent rail bearing area calculated.

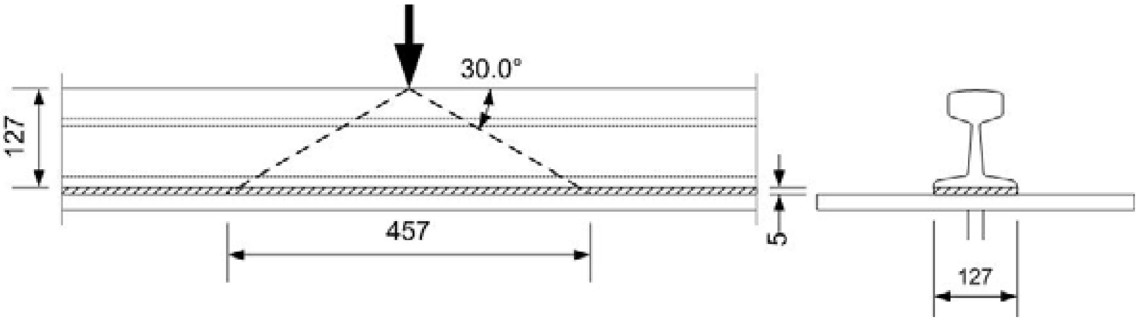


Figure D.3: The calculated bearing area of one wheel.

To further simplify the computation it was thought to be acceptable to reduce the area to the nearest geometric area available to the model setup. This area was 100mm wide and 400mm long. The wheel load applied is 201kN. This then simplifies to 5025kN/m. Note also that the crane end carriage wheel span is 4000mm.

The load as just calculated per wheel would then be simulated in 400mm steps along the beam. The second wheel is also included as required. This continues until the first wheel and then finally the second wheel has left the girder. This simulates the passing of the crane in small incremental steps.

The loads were applied with an eccentricity of 50mm from the centreline of the girder. This was the smallest eccentricity the models geometry would allow. Rail clips are thought to provide as much as 30mm adjustment in certain cases and rotation can also affect eccentricity. Therefore 50mm is a very conservative, yet acceptable choice for this study.

Finally before the model can be analysed it was necessary to first validate the setup. This was done using a 500kN vertical point load at the very centre of the span (no eccentricities). The Prokon deflection output was 9.2mm. Using hand calculations a value of 7.7mm was attained. The difference, though quite large, is thought not to influence the results in a large way. Prokon uses a smaller value which results in a deflection of 9.1mm by hand calculations.

Formula D.1:

$$\Delta = \frac{PL^3}{48EI} = \frac{500000 \times 6^3}{48 \times 200 \times 10^9 \times 1.4603 \times 10^{-3}} = 7.7mm$$

The beam stresses were also checked as these are more critical to the investigation. Prokon attains stresses in the mid-span bottom flange equal to 162.2MN/m^2. Using basic hand calculations a stress of 158.7MN/m^2 was attained. This is a good result and validates the models use.

Formula D.2: $$\sigma = \frac{My}{I} = \frac{750 \times 10^3 \times 0.309}{1.4603 \times 10^{-3}} = 158.7 MN/m^2$$

It is concluded that the stresses of the model are far more critical than the deflections. Furthermore, no matter the actual stresses, the model is sufficient so long as the relative stress range and stress cycles can be illustrated accurately. The model was therefore acceptable for the purposes of this investigation.

D.3 Analysis and results

The graphs are indicative of 25 crane positions varying from the one wheel entering the crane, to both wheels being present and then lastly with the remaining wheel being the only wheel left. The y-axis of each graph may have magnitude values, but it is more important to view the relative variations in magnitude.

A variety of stress concepts are introduced in each graph of which the S_{max} and S_{min} are seen as the most important and are attained from the middle of the shells thickness. If these stresses were to be attained from the top or bottom surfaces of the shell, they may well have been larger. Von Mises stresses at the top and bottom of the shell elements are included. They are simply understood to give a fair indication of the total combined stress magnitudes at a specific point.

First the top flange to web connection is investigated for two scenarios. The first is at a stiffener near mid-span and the second is between two stiffeners. The following resulted:

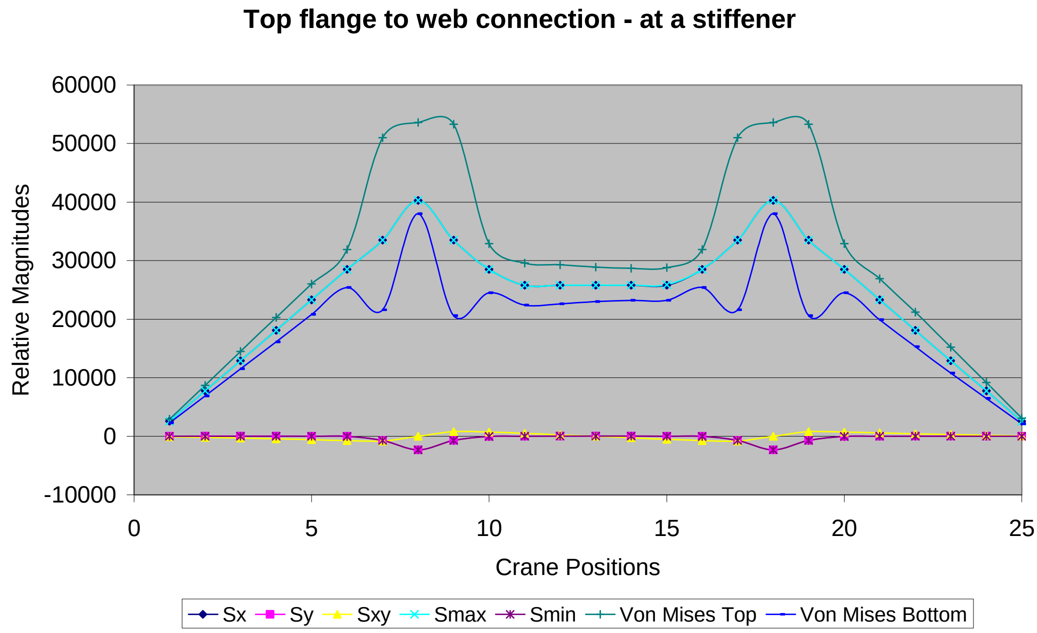


Figure D.4: The stress ranges experienced at the top flange to web connection at a stiffener for a crane passing.

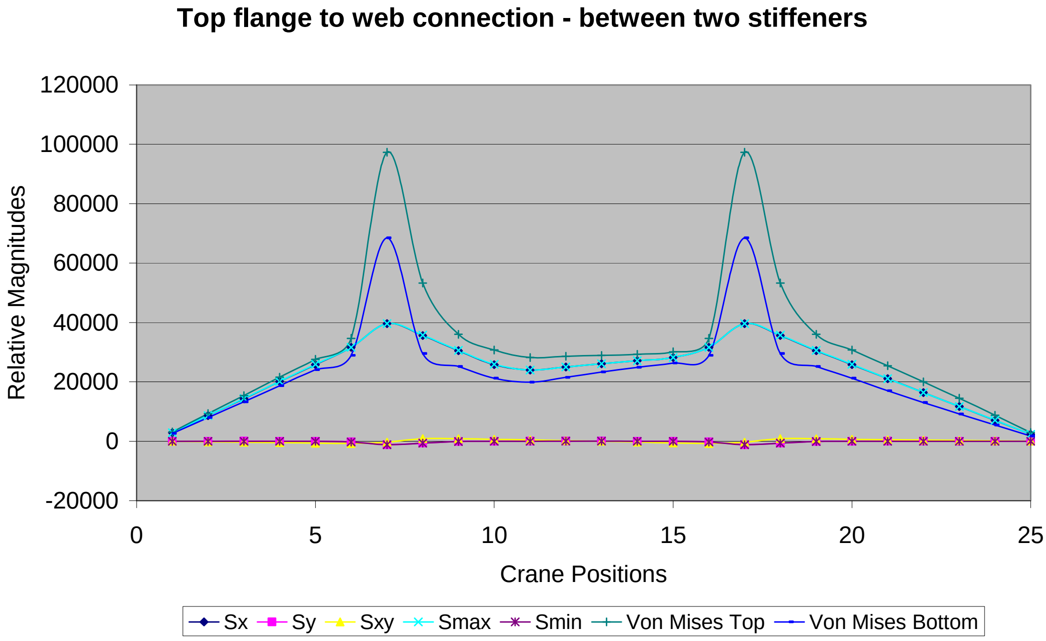


Figure D.5: The stress ranges experienced at the top flange to web connection between two stiffeners for a crane passing.

It can clearly be seen that two stress range cycles are experienced at the top flange to web connection for each passing of a crane. That means that one cycle occurs per wheel. Theoretically two different stress ranges should be analysed - one for the maximum stress to minimum stress (only occurring once) and another for the two wheels passing individually. This would involve a lot of extra calculation. For this reason it is good to err on the conservative side and accept two stress range cycles at maximum.

Next the stiffener toe is investigated. In this case the need for two stress range cycles per crane passing is even more apparent. This means again that one stress cycle is experienced per crane wheel.

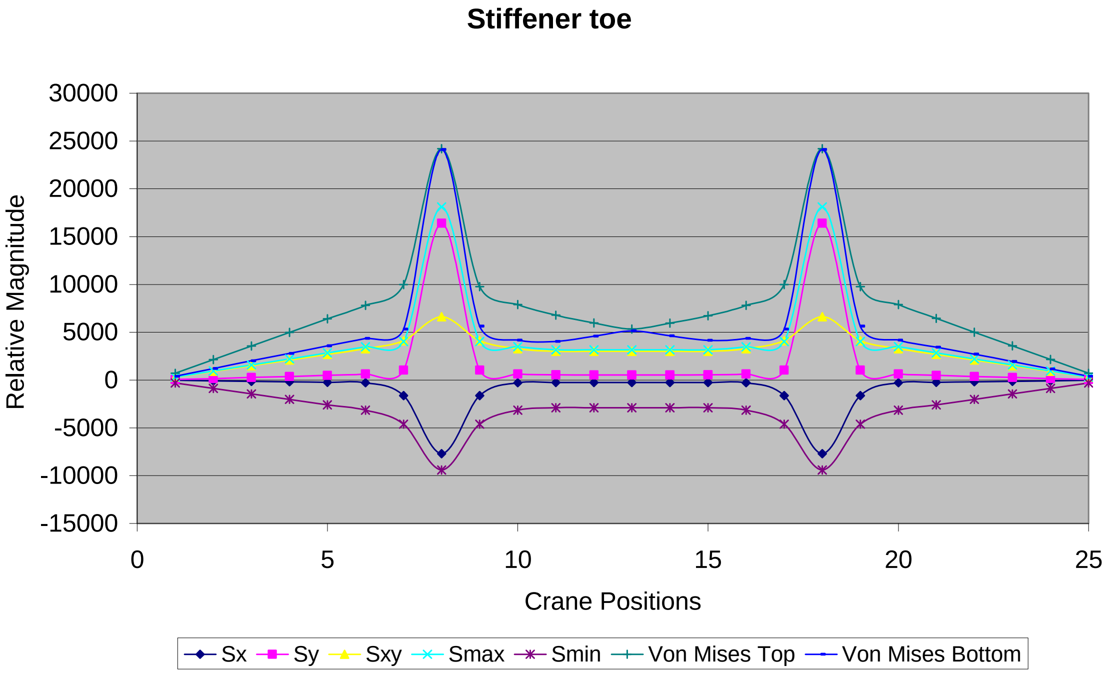


Figure D.6: The stress ranges experienced at the stiffener toe for a crane passing.

Lastly the bracket must be investigated. As the bracket itself is not modelled an alternative method of measuring the stress range cycles must be found. The force experienced at the supports is the same force that should, theoretically, be imposed on the bracket. For this reason the relative forces at the supports were used to give an indication of the stress cycles.

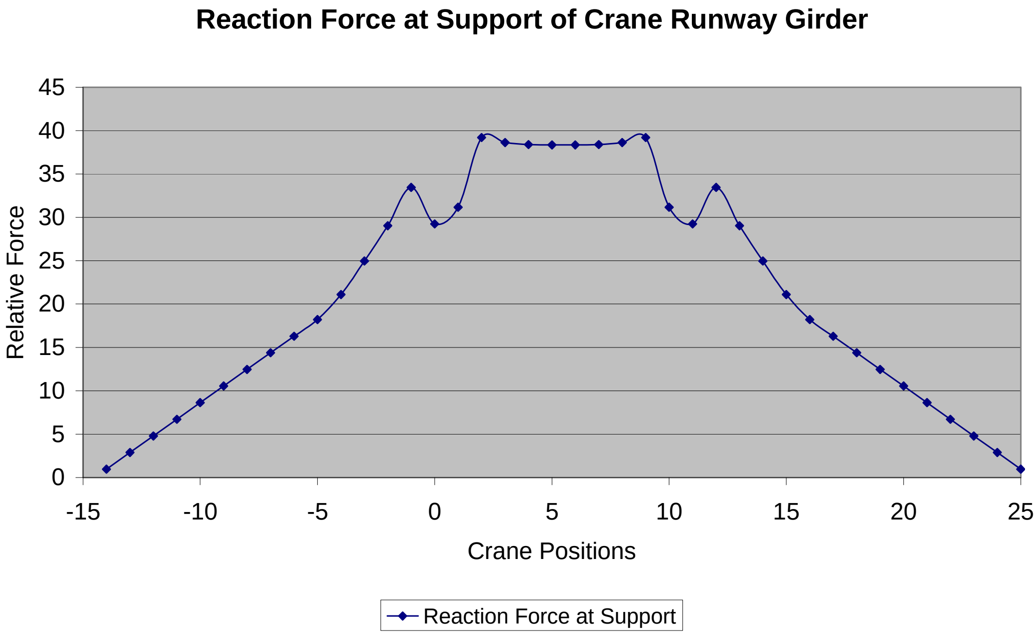


Figure D.7: The stress ranges experienced by the bracket to column connection for a crane passing.

In this case the crane causes only one stress cycle per passing. Note that the crane moves from a position of -15. This is because of the influence the adjacent girder has on the column simultaneously.

D.4 Conclusions

The following stress cycles resulted and were subsequently used in the questionnaire as a seed question.

i) Top flange to web weld – two cycles per load cycle.
ii) Stiffener toe – two cycles per load cycle.
iii) Bracket to column connection – one cycle per load cycle.

These compare well to the cycles expected at the commencement of the investigation.

APPENDIX E:

Full size detail sketches

The detail sketches provided in the text are provided in this appendix in a full page format. Some additional sketches are also included which could supply some additional clarity to the use of certain setups.

E.1 List of Figures

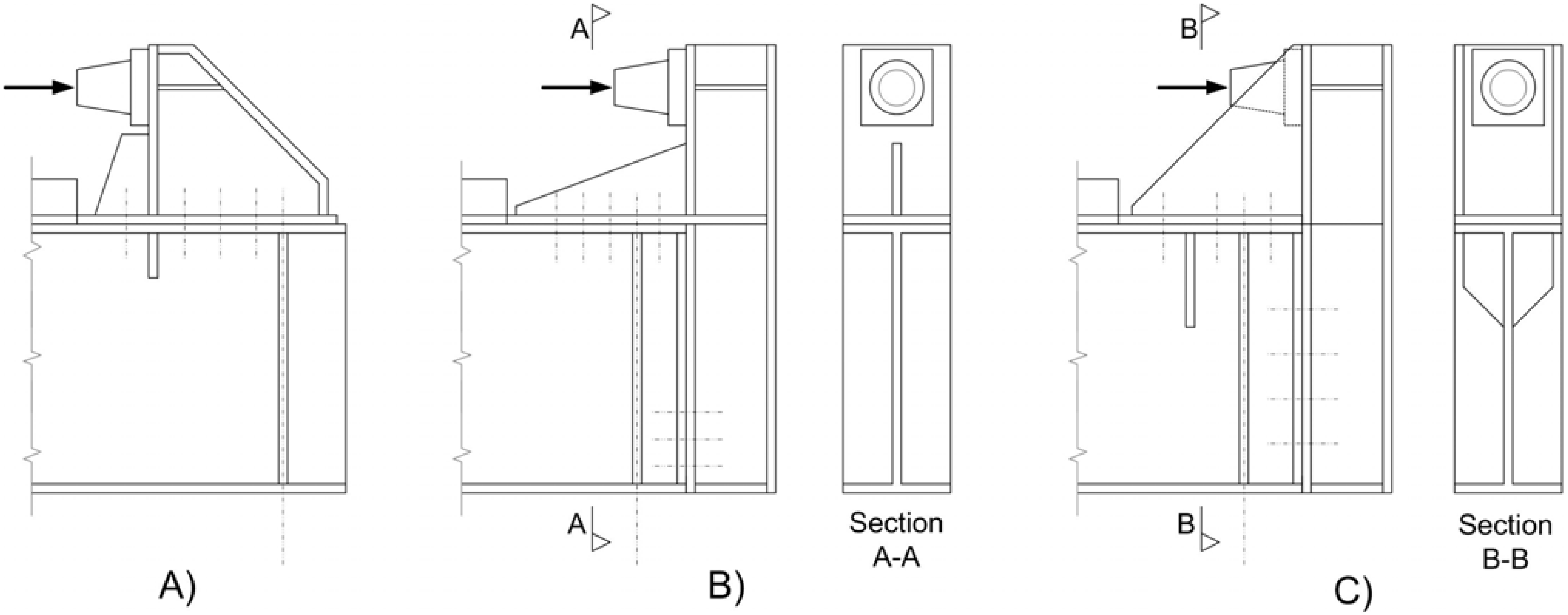


Figure E.1: End stop designs commonly used in South Africa. The SASCH [2005] promotes designing the end stops in a similar manner.

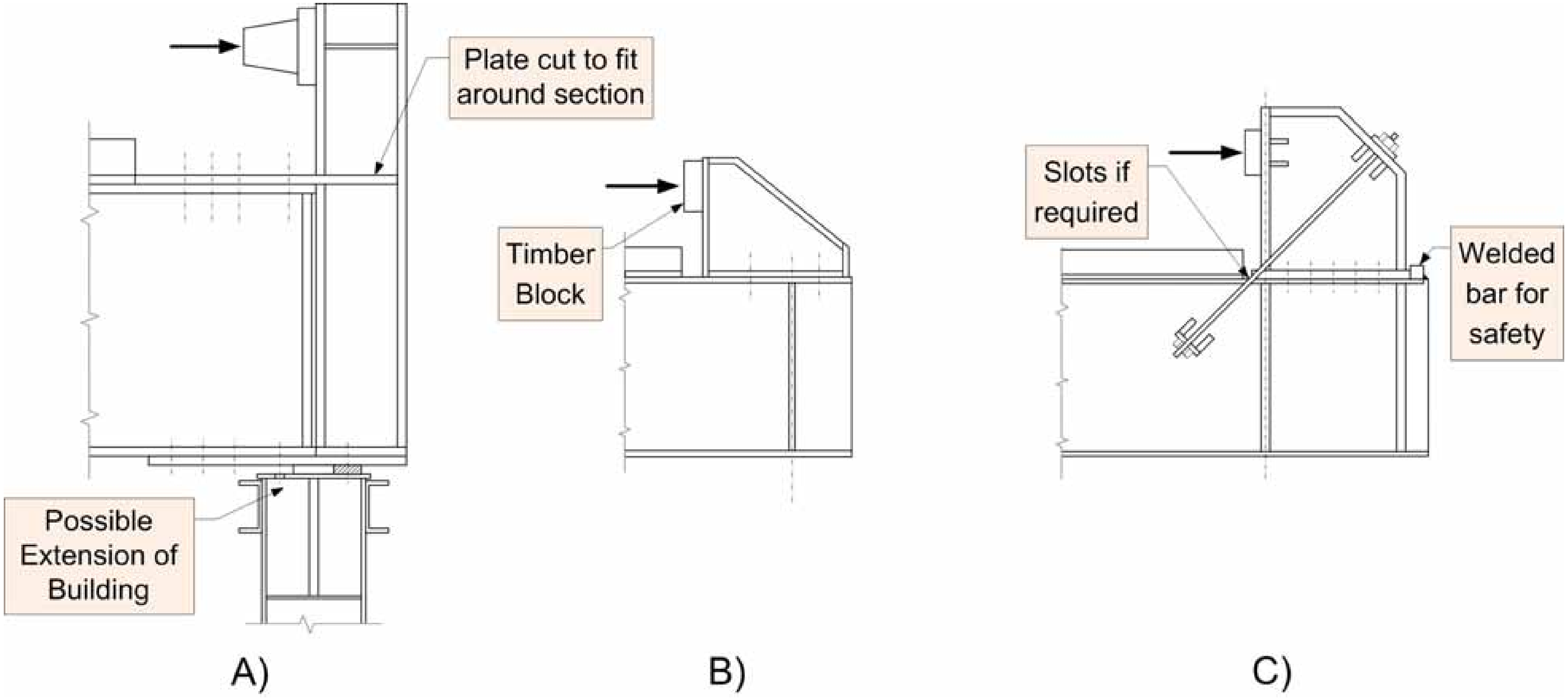
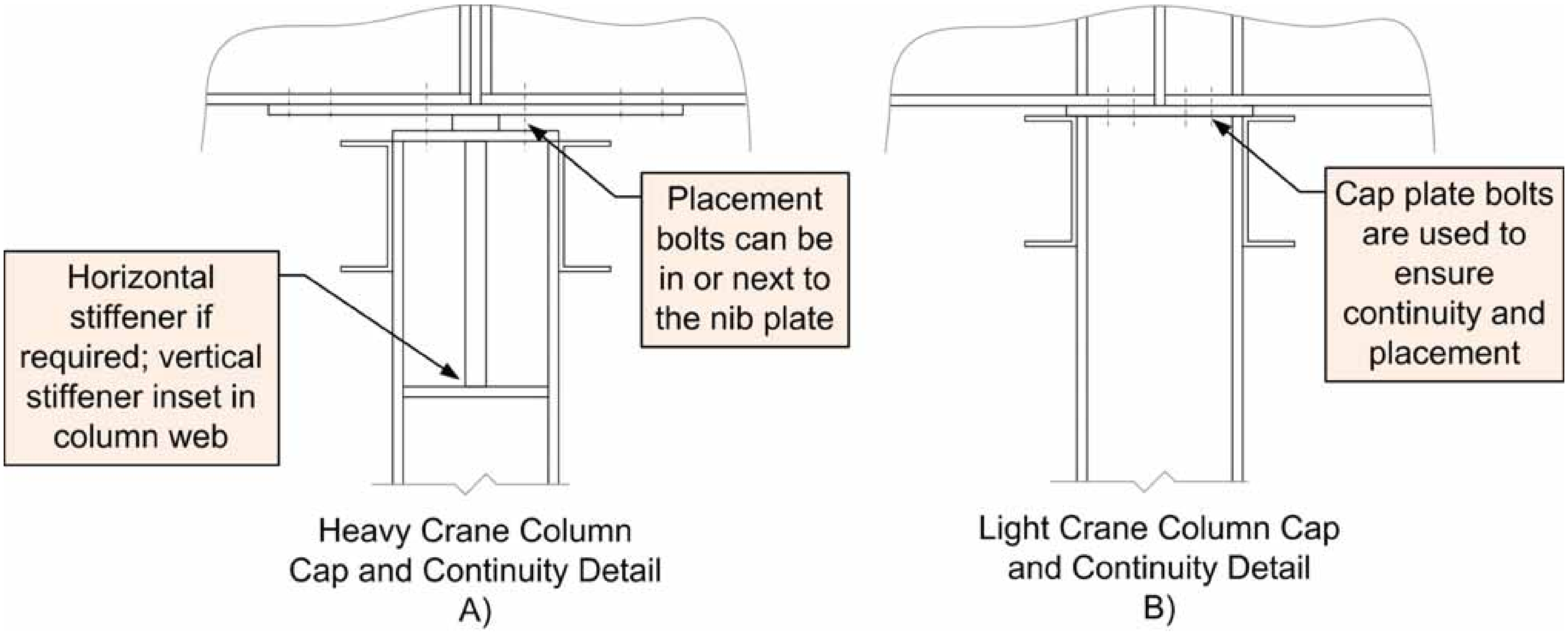


Figure E.2: Alternative end stop designs.



Heavy Crane Column Cap and Continuity Detail
A)

Light Crane Column Cap and Continuity Detail
B)

Figure E.3: Column cap details that are recommended with the continuity method described.

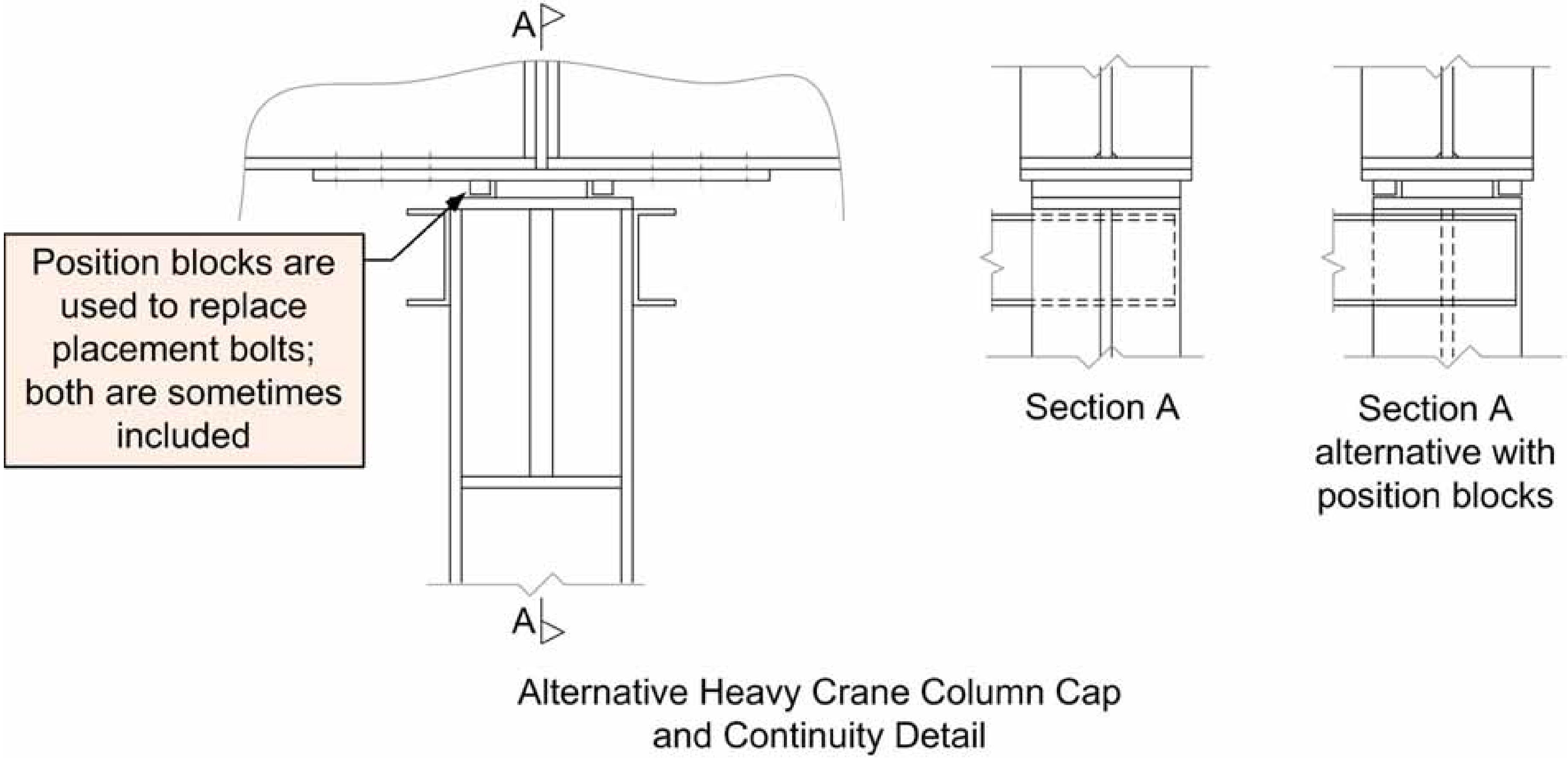
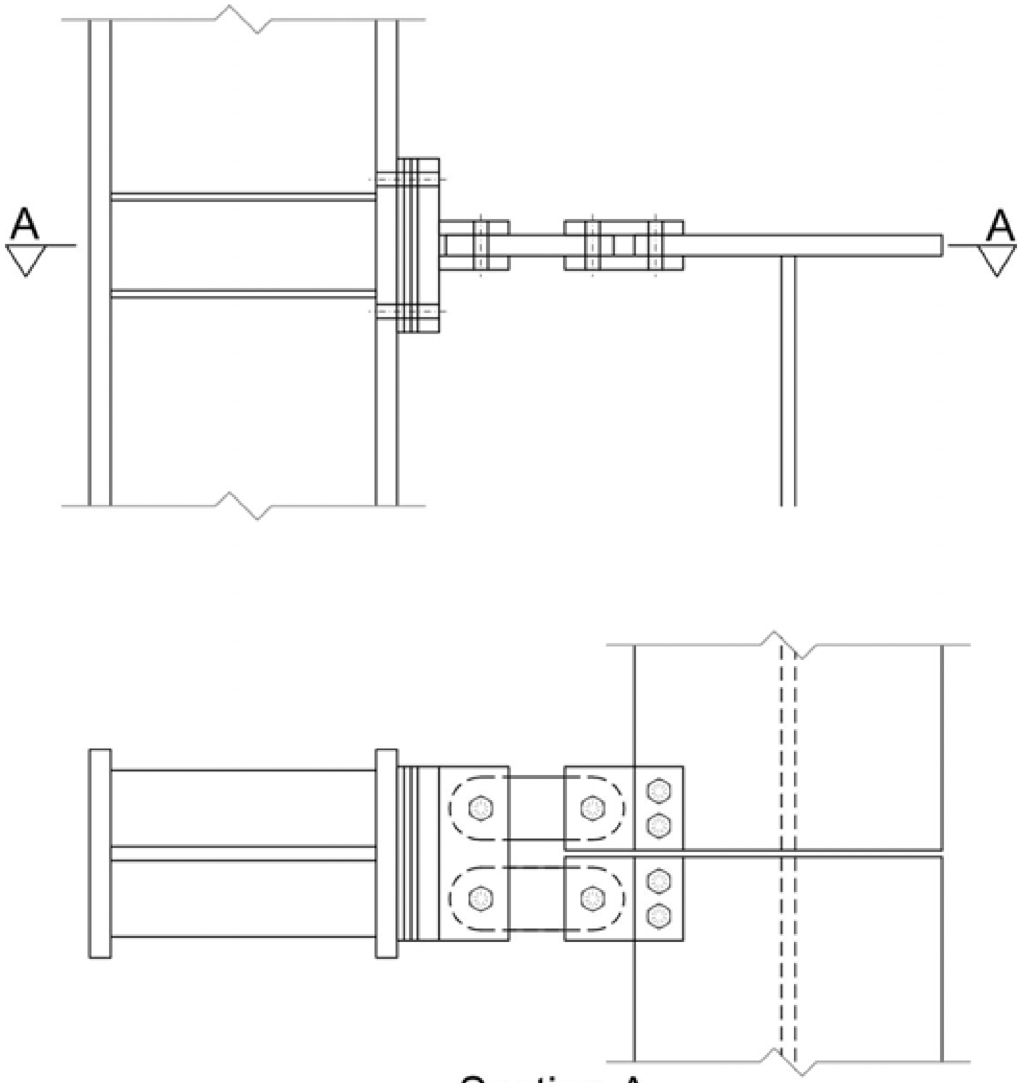
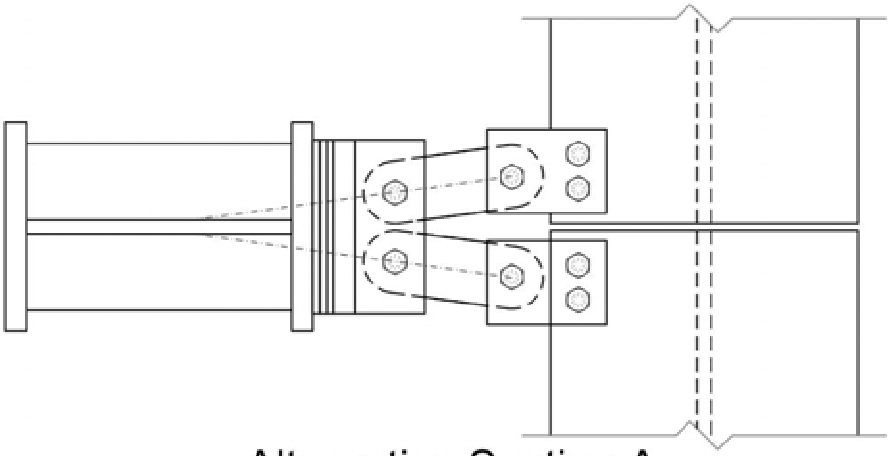


Figure E.4: Alternative setups for continuity of the column cap using positioning blocks.



Section A



Alternative Section A

Figure E.5: The tieback link, which is preferred as it makes better provision for the movements required of the tie-back connection.

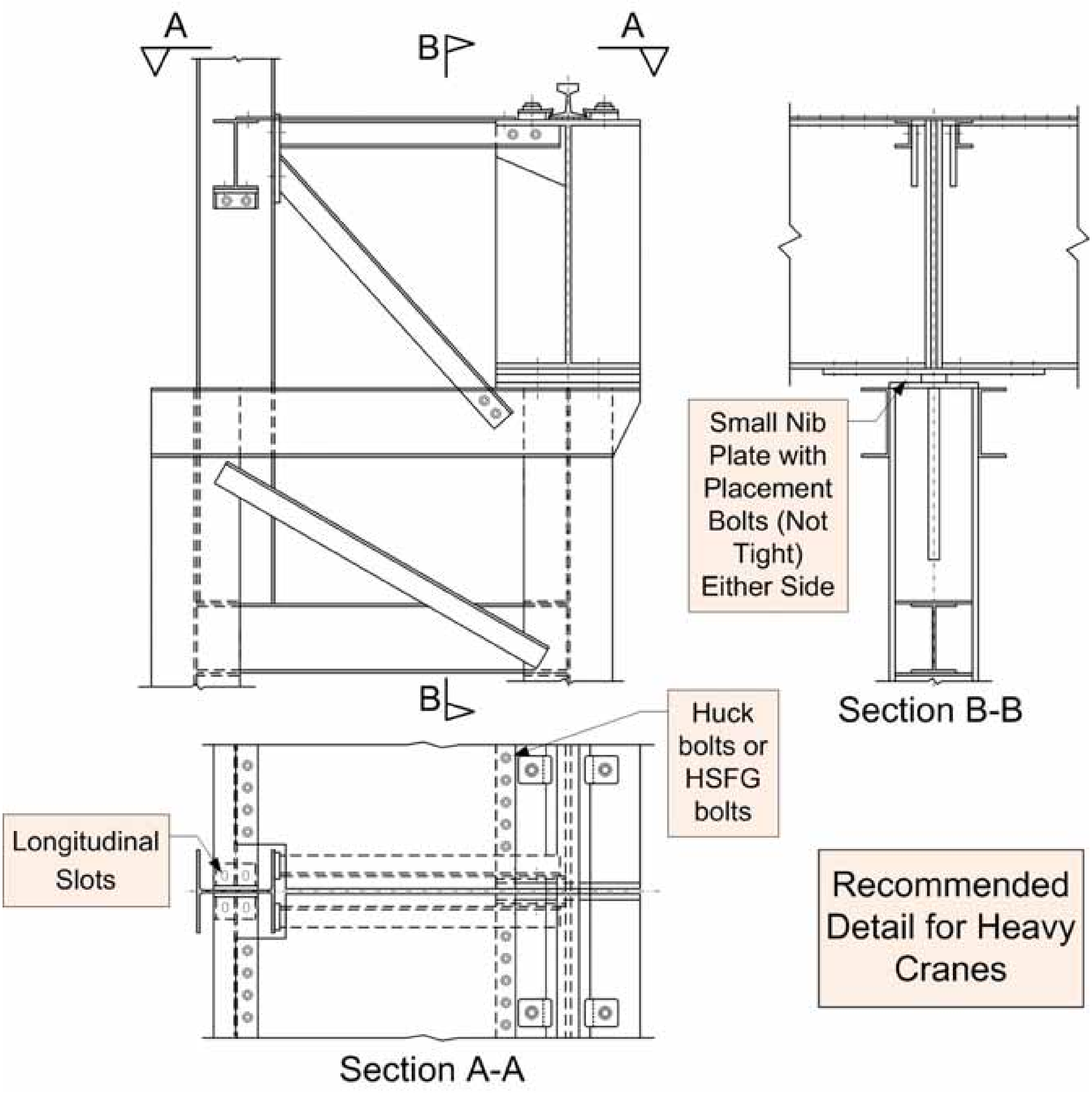
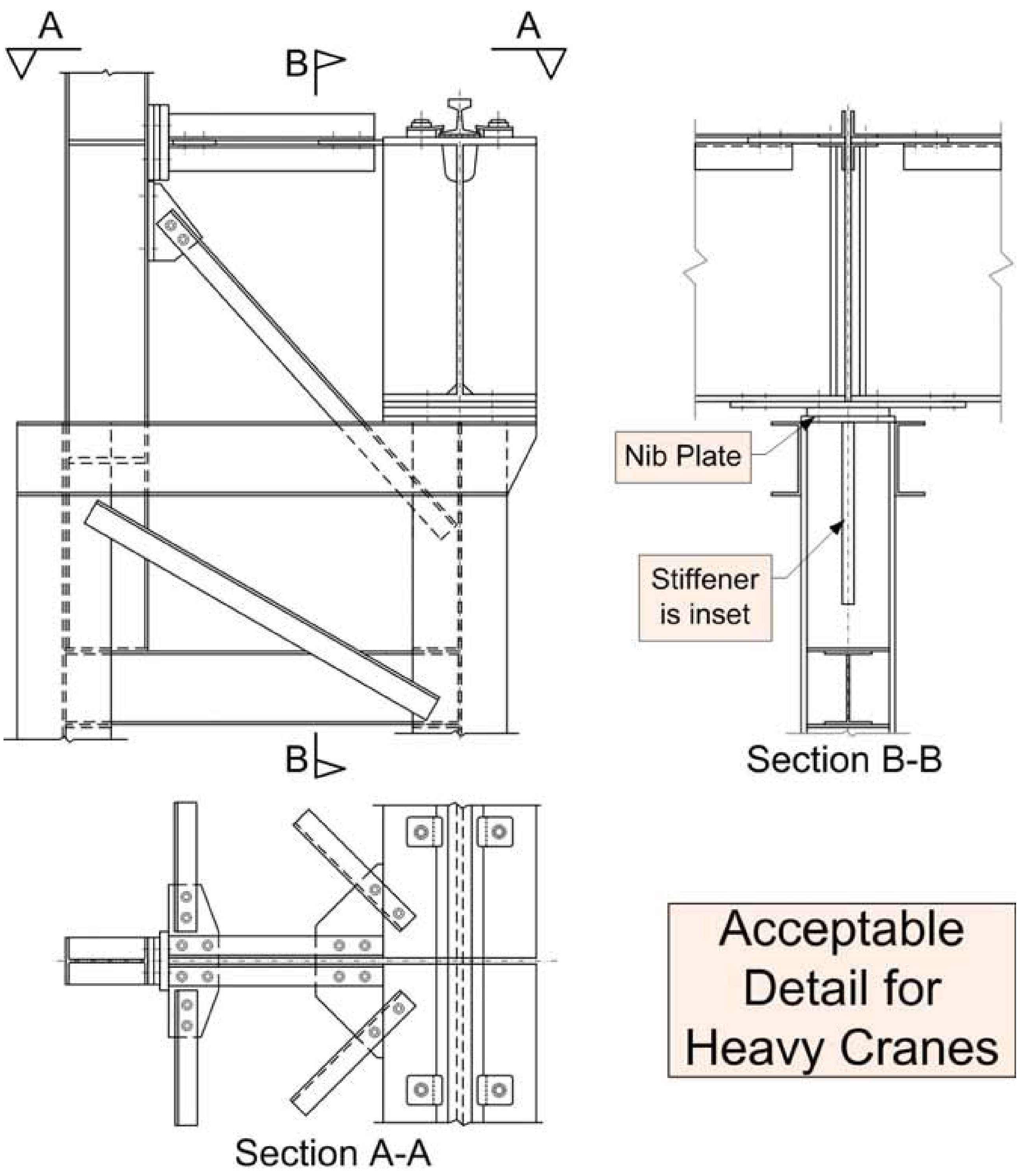


Figure E.6: Tieback connection for use on heavy crane setups.



Acceptable Detail for Heavy Cranes

Figure E.7: Tieback connection using a surge girder. Acceptable detail, but not recommended.

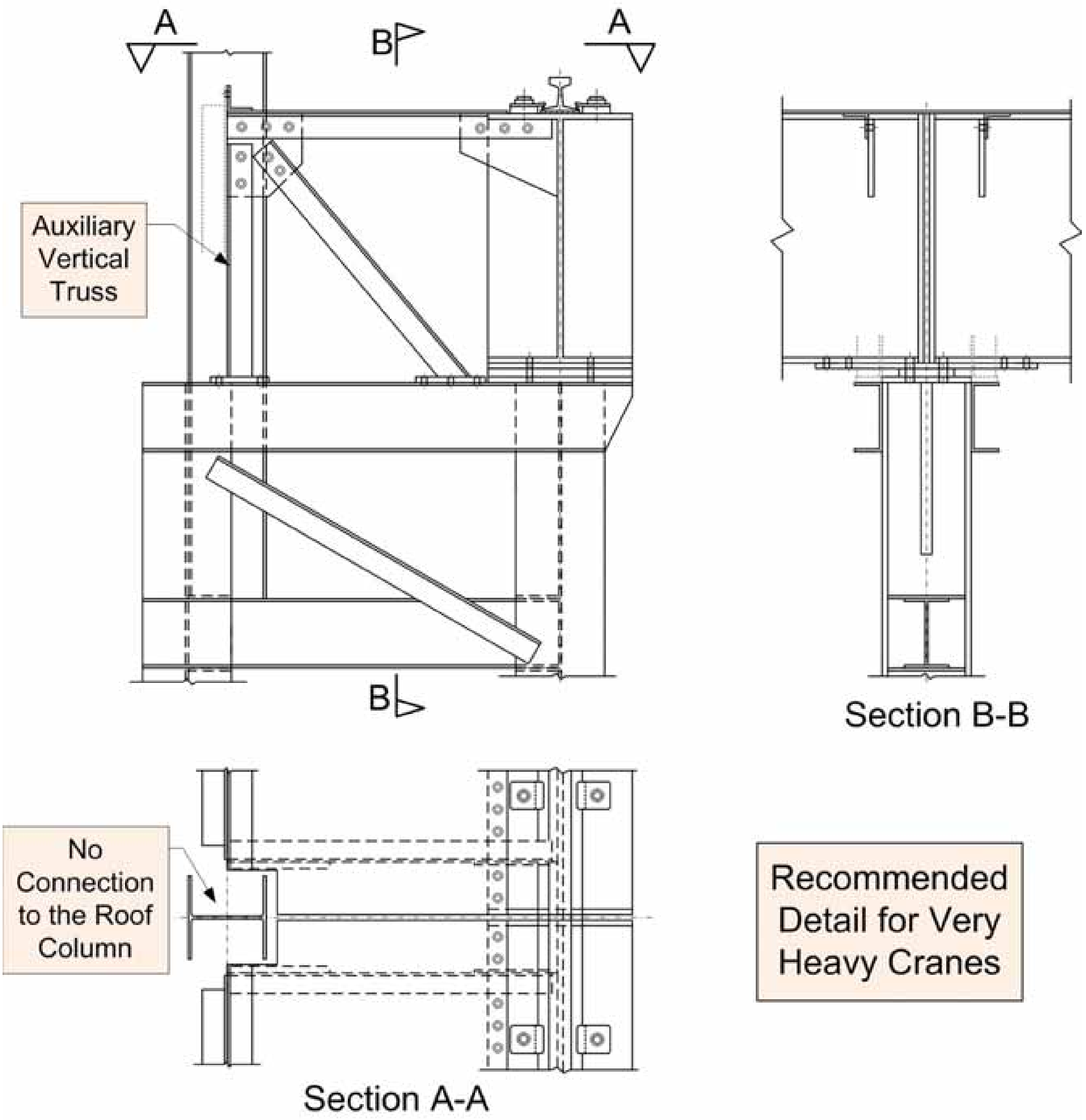


Figure E.8: Tieback connection recommended for the largest cranes.

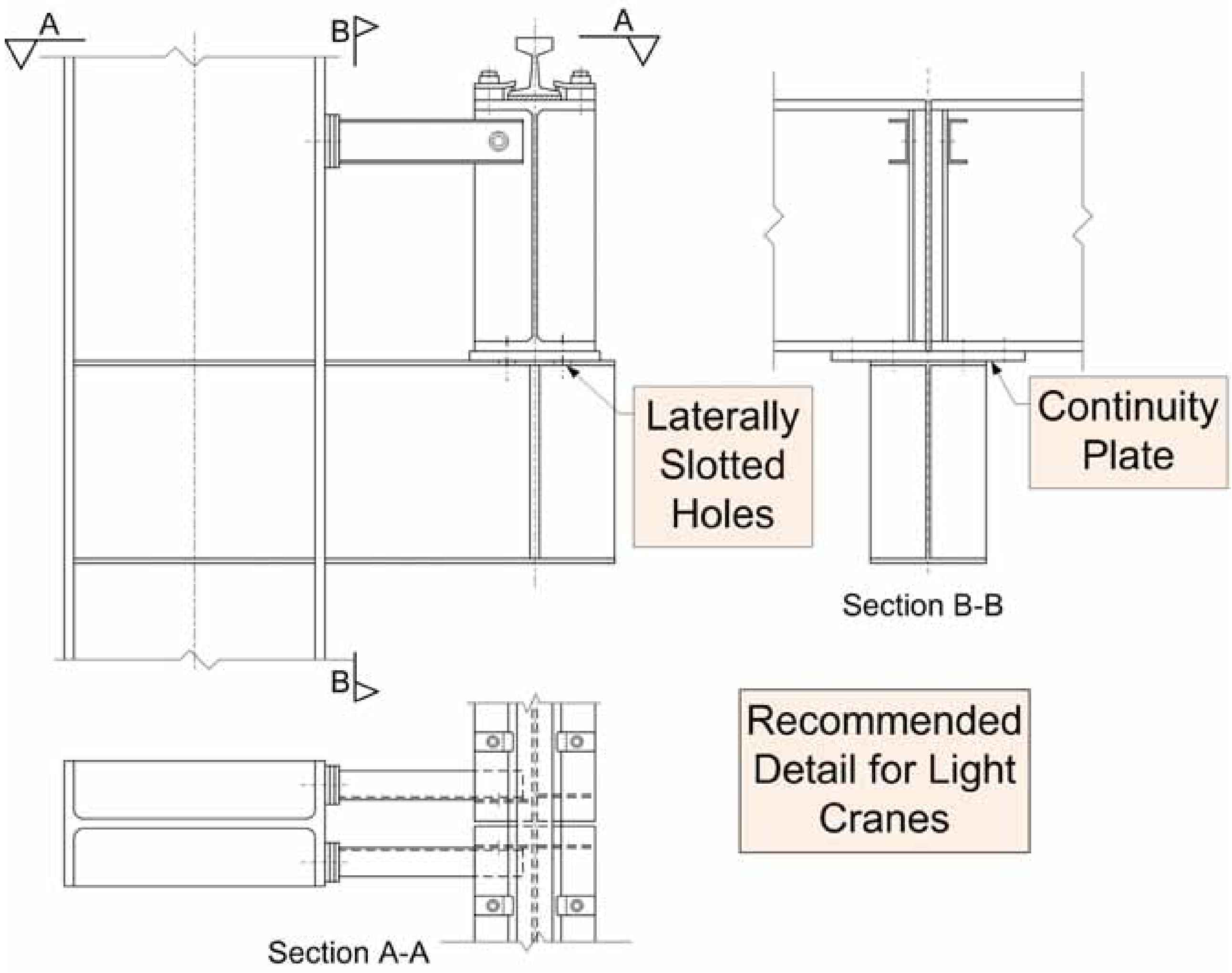


Figure E.9: Recommended detail for light cranes that sit on a bracket.

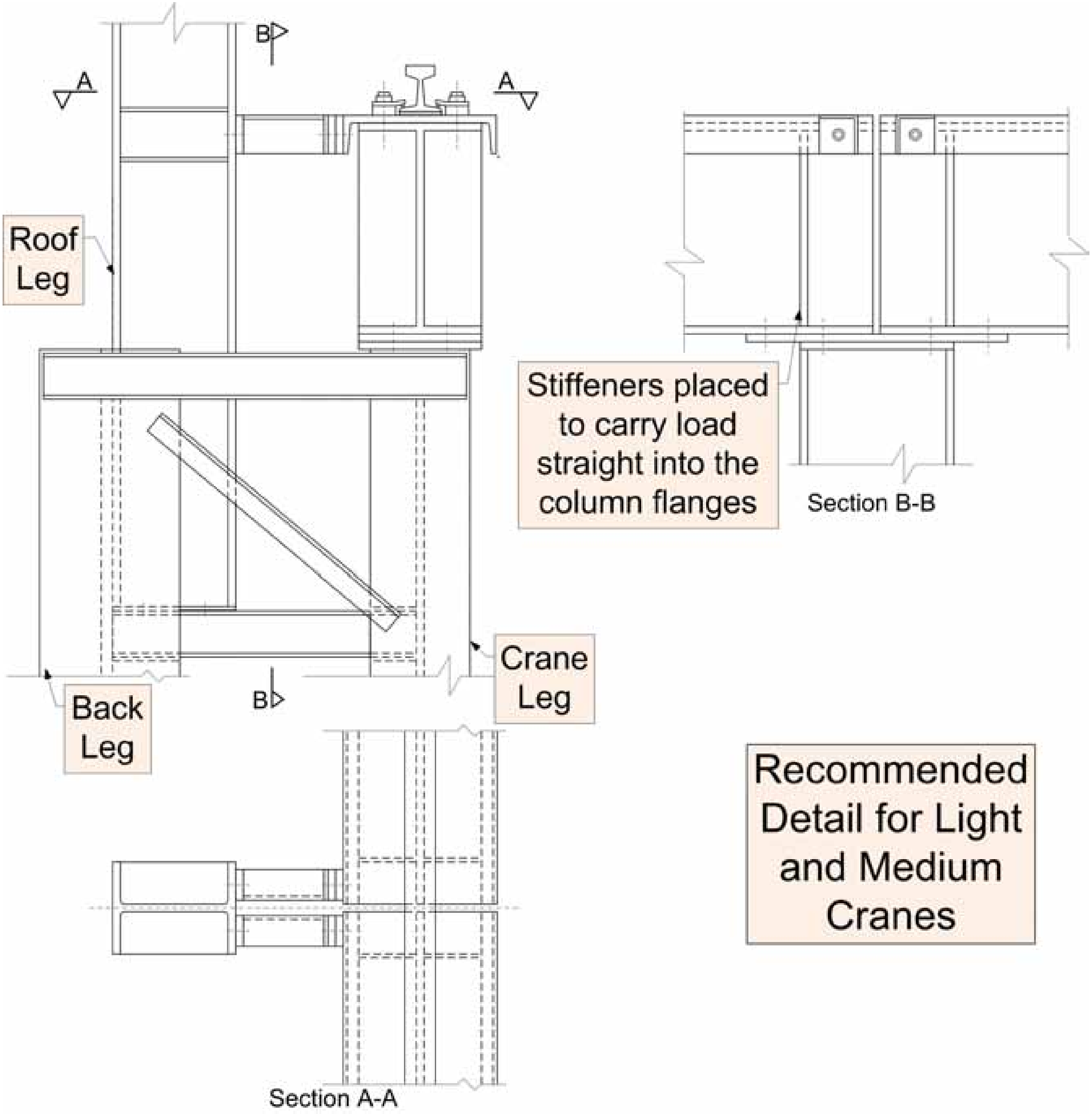


Figure E.10: Alternative recommended detail for light cranes. The column design varies.

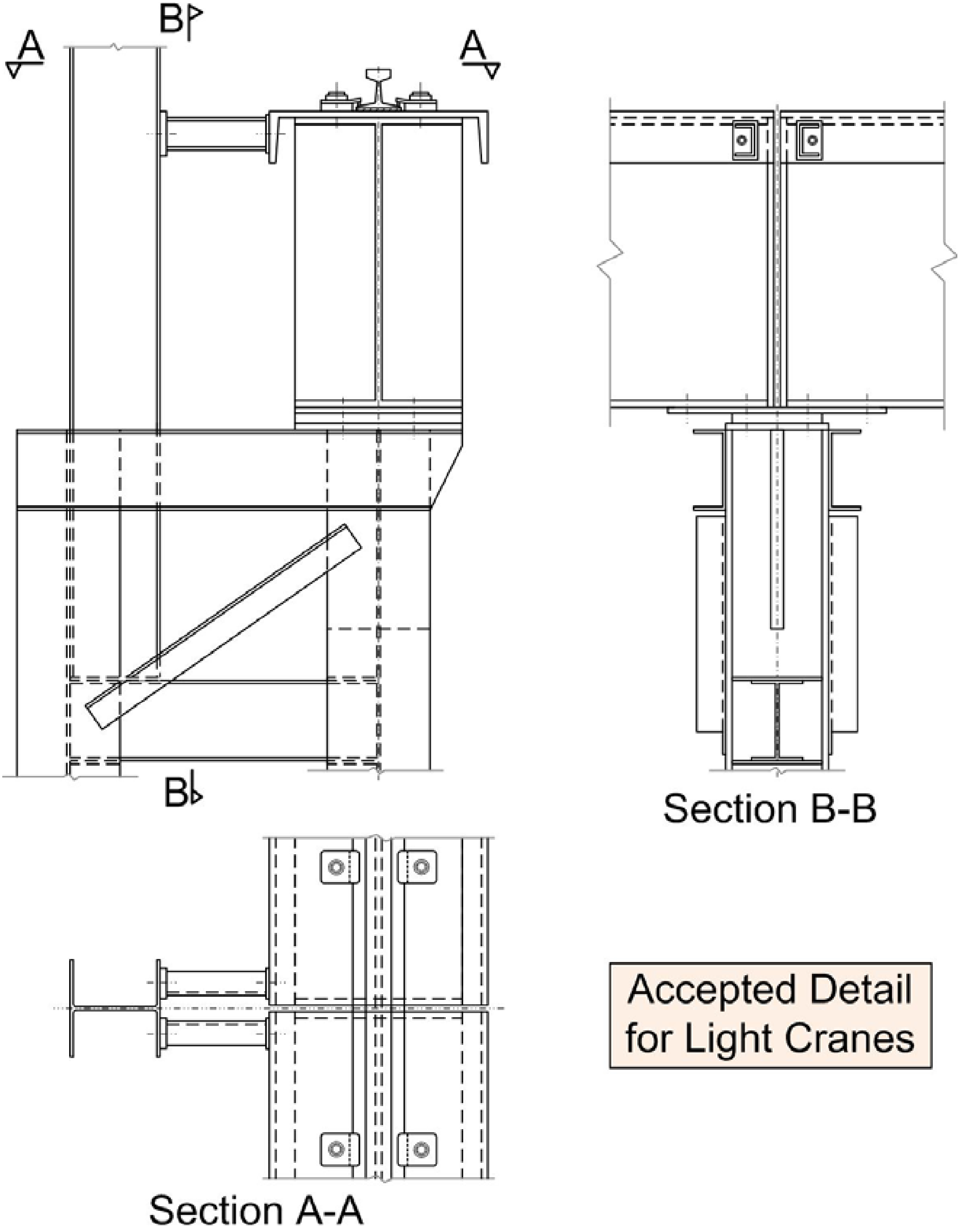


Figure E.11: Accepted detail for light cranes situated on a latticed column. It is not recommended as the best option.

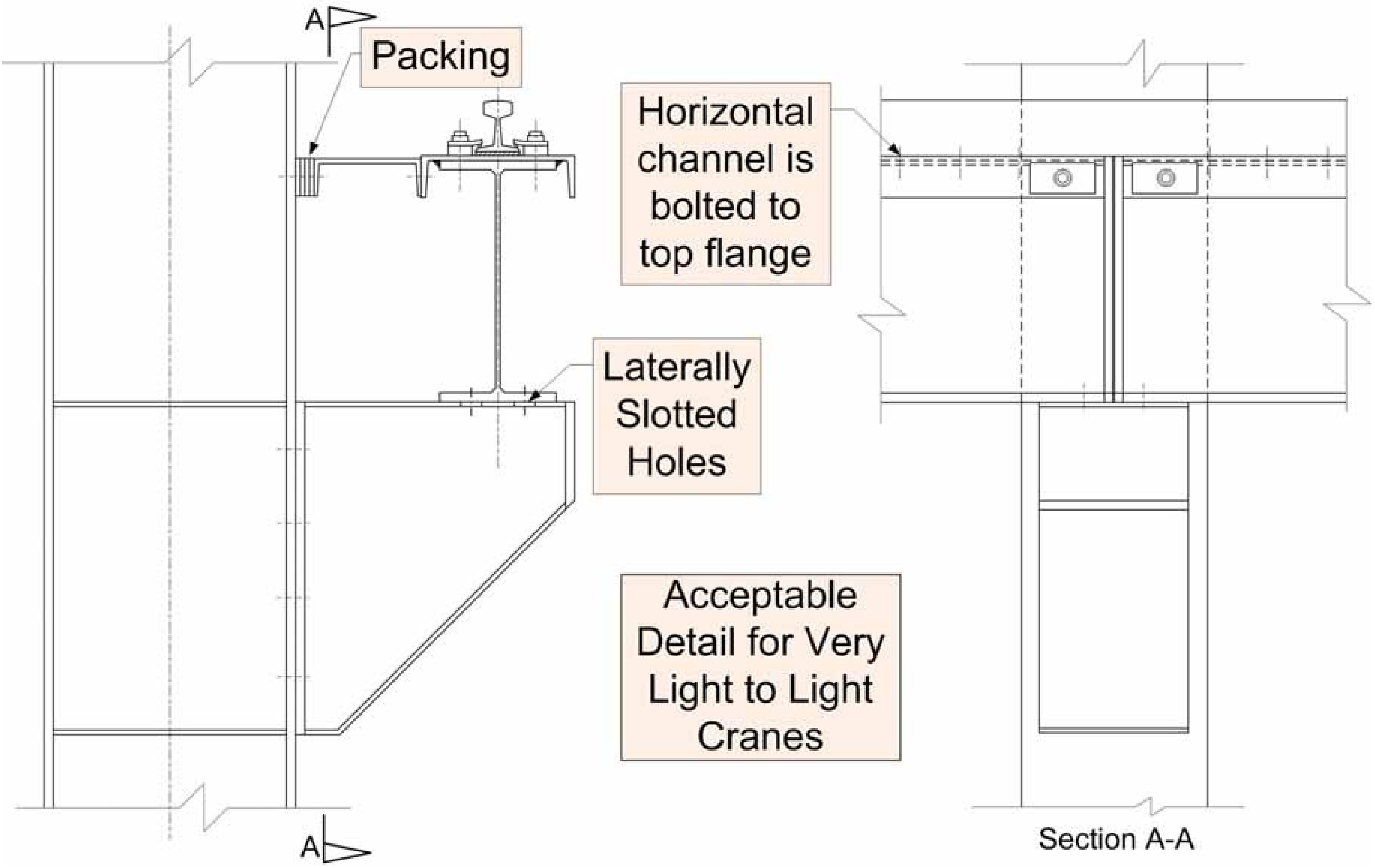


Figure E.12: Alternative setup of the bracket for a light crane gantry.

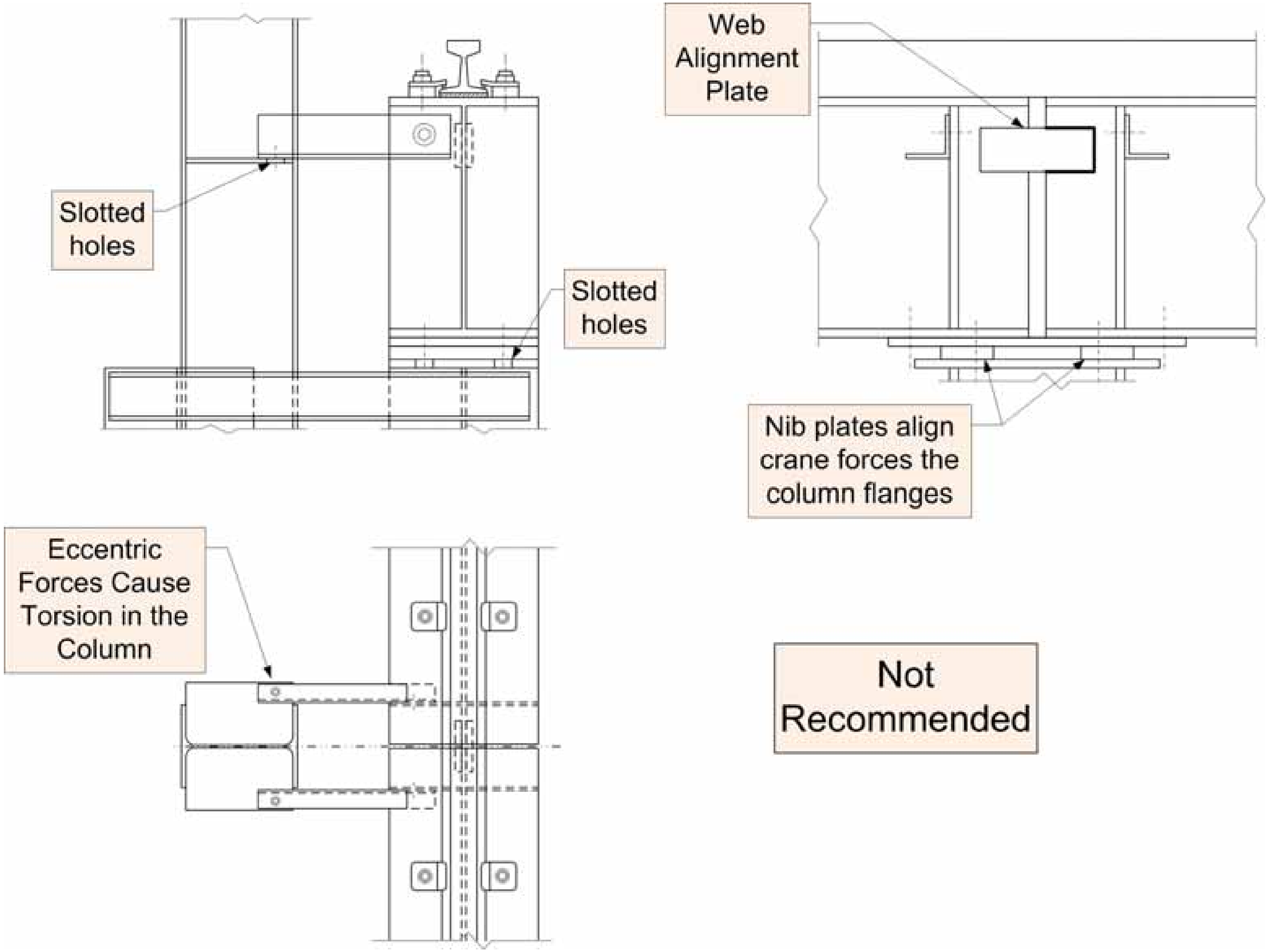


Figure E.13: A detail that is not recommended because of the large torsional forces imposed on the column.

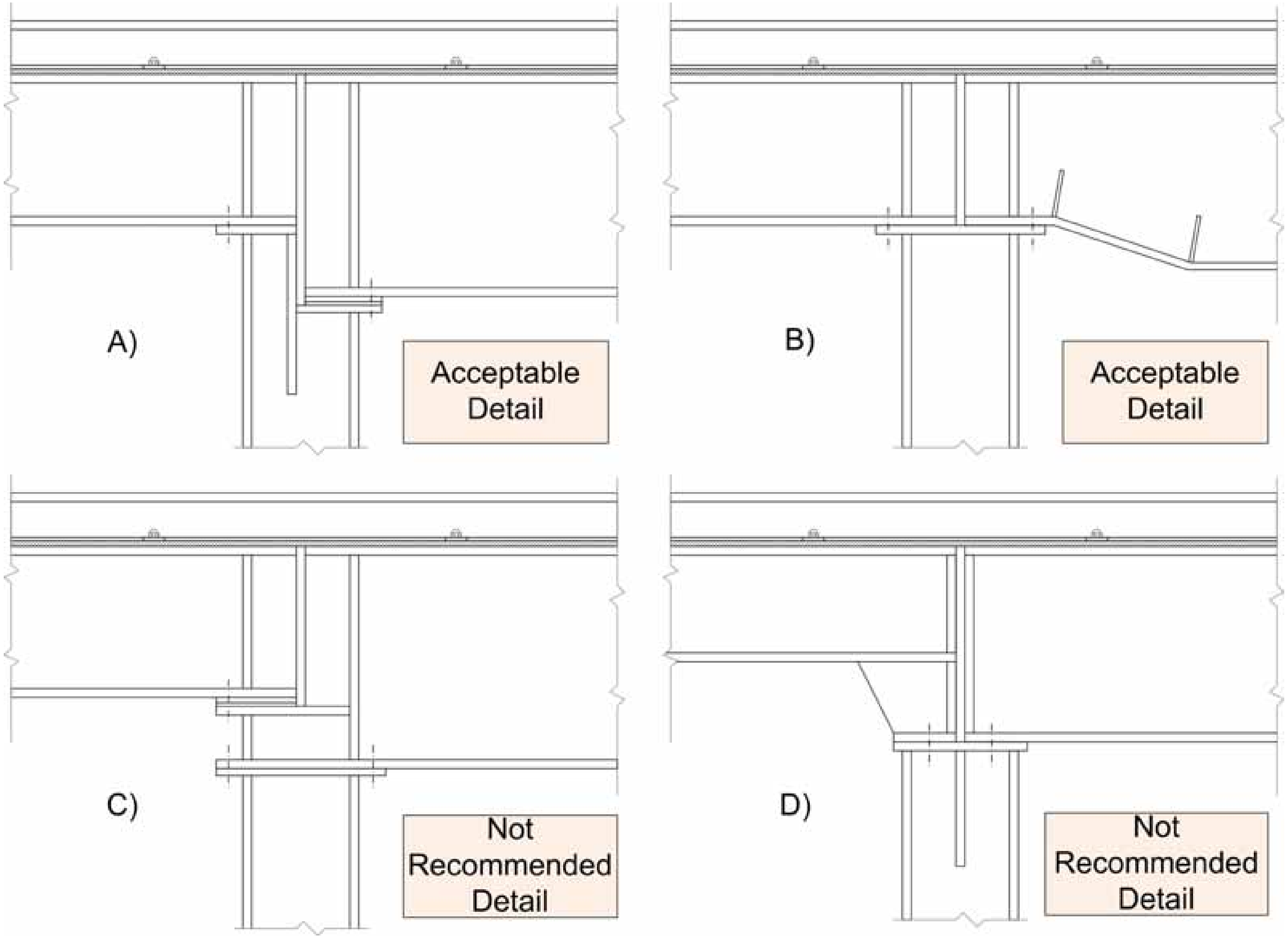


Figure E.14: Details proposing solutions to different depth runway girders.

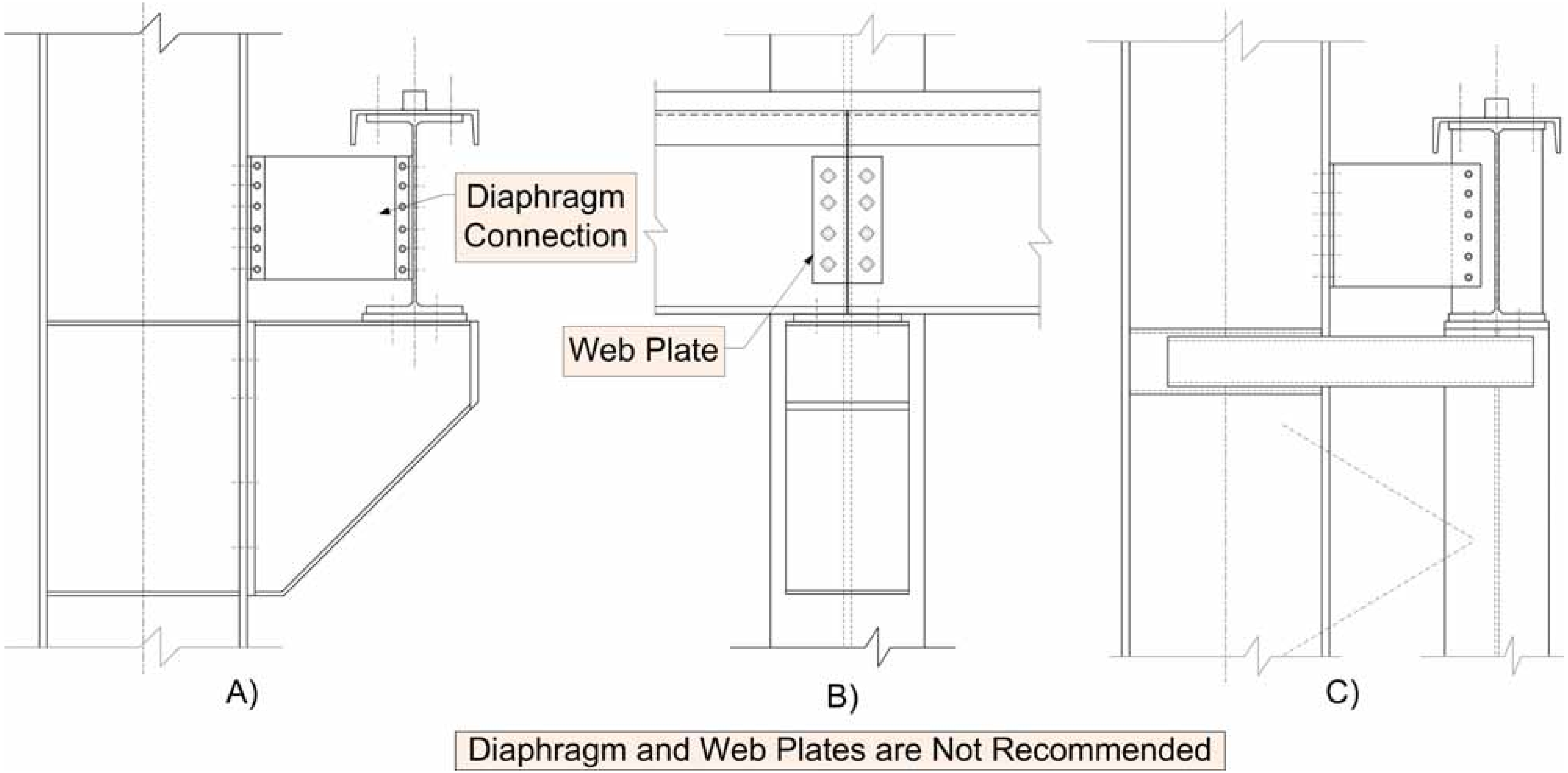


Figure E.15: Details that are strictly not recommended for crane gantry design.

APPENDIX F:
Additional EXPERT OPINION SURVEY details

The information in this appendix serves to complete that given in *chapter 4* of the thesis. In several cases the concepts were applied during the research, but in order not to veer from the original objectives of the study, the information has been included as an appendix.

F.1 Heuristics, Bias and Debiasing

As stated in *chapter 4*, biases stem from heuristics. Heuristics are certain "rules of thumb" applied in determining a degree of belief of what we hear. Heuristics are unintentionally a part of everyone's nature. When heuristics lead to errors, we speak of biases. Four heuristics, which are availability, anchoring, degree of representation and control, were studied by Cooke [1991] and are explained accordingly.

F.1.1 Availability

Availability is the heuristic linked to the ease with which certain information can be obtained. If a question is asked with many answers, it is the answer that is the simplest to comprehend that gets chosen. In other words availability is making use of the answer most easily available, rather than providing an accurate, well assessed, answer according to an expert's best judgement.

F.1.2 Anchoring

Anchoring is based on attaching an estimate (answer) to another easily available figure and adjusting from that point. It has been shown that the adjustment made is commonly insufficient. If an individual was shown a value that is really high and asked to think of another number. The number will generally be of the same order of magnitude - simply the previous number adjusted. Put in the context of a survey – it is understood that if a question has an available answer, this "easy" answer will subsequently be adjusted rather than a pure, outright estimation made. This heuristic is closely linked to availability. Overconfidence is an important sort of bias which can be connected to the anchoring heuristic.

F.1.3 Degree of Representation

When asked to judge the conditional probabilities of an event occurring p(A|B), individuals rely on the degree of similarity between A and B. *Bayes' theorem* gives:

$$p(A|B) = \frac{p(A \, and \, B)}{P(B)} = \frac{p(B|A)p(A)}{p(B)} \qquad (Equation\ F.1)$$

From this it is seen that for symmetry to be true, p(A) must equal p(B). The degree of representation heuristic leads individuals to neglect the base rates of Bayes' theorem and behave as if p(A) = p(B). This is linked closely with the *base rate fallacy* which will not be discussed further in this thesis. To summarise and clarify, the degree of representation heuristic leads people to ignore sample sizes when making estimates.

F.1.4 Control

Control is the last heuristic to be covered and manifests itself when subjects act as if they can influence situations over which they actually have no control at all. Control will be explained by way of a straightforward example from Cooke [1991].

Two sets of office workers were given an opportunity to buy an office lottery ticket for $1 with a prize money of $50. The first group were told they could choose which number they would like, allowing a form of "control". The second group were given numbers without a choice. When asked to resell the tickets to someone in the office who desperately wanted a ticket – the median resale offers were $8.67 for chosen numbers and $1.96 for the assigned numbers. This indicates that the office workers assigned much more value to tickets they "selected" or "controlled" even though the odds were exactly the same for both cases.

The example shows how control can occur, but also exhibits the unintentional way biases can creep into anyone's responses. Availability, anchoring, degree of representation and control are traits found in all experts. If, however, the topics are understood by the interviewer and / or the interviewee, better results can be obtained. An attempt should be made to avoid such biases manifesting themselves in the questions, responses and results. Use of this knowledge can be made in compiling the questionnaire and in eliciting the experts' opinion.

F.2 Attaining Rationally Defendable Results by Expert Opinion

Expert opinion at face value is not scientifically acceptable. Certain measures have been developed to assist building a scientific basis when using expert opinion. These include reproducibility, accountability, empirical control, neutrality and fairness. These concepts are explained now.

F.2.1 Reproducibility

Reproducibility means to make it possible for peers to review and reproduce all of the steps involved in the research. This involves describing the method used in elicitation and analysis. All the background information must be available. The concept simplifies to the following: if another individual attempts to do the same study using the same methods, the results obtained should be the same or at least very similar to those obtained by the original research. Here the thesis itself serves as documentation for possible reproduction.

F.2.2 Accountability

Accountability means that the acquired information must be traceable. Cooke [1991] explains that journal entries are only published if the author is identified. In a similar manner, data should only be used if it can be properly sourced. In certain investigations, such as an expert survey, this is a troublesome issue. Confidentiality clauses and expert anonymity are amongst the obstacles faced.

F.2.3 Empirical Control

A methodology for using expert opinion should incorporate some form of empirical control, at least in principle. Empirical control means to evaluate expert opinion on the basis of possible observations. Moreover the evaluation made should be reflected in the utility value or weight of the expert's opinion in the end results. This essentially is the forerunner of scoring, seed questions and seed values to be discussed later on.

F.2.4 Neutrality

Neutrality in a positive sense is the establishment of a method for combining and evaluating expert opinion in a way that encourages the experts to give their honest estimates. This could be understood to comprehend avoidance of biases and heuristics.

F.2.5 Fairness

Fairness involves the equal treatment of all experts prior to processing the results of the observations. The information provided prior to the interview and the guidance supplied to the experts during the interview must all be equivalent, no matter who the expert is. In the interview process it is natural that one expert be preferred to others. It is imperative that this preference should not surface in the elicitation process or during combination and analysis of the results.

F.3 The Delphi Technique

The Delphi technique is discussed because it includes many useful theories that are available for use in an expert opinion survey.

Delphi, or application of the Delphi techniques, is an attempt to elicit expert opinion in a systematic manner for useful results. This, at its core, is a survey model which attempts to manage the aforementioned concepts. It ordinarily involves iterative questionnaires administered to individual experts in a manner protecting the anonymity of their responses. Feedback from the previous iteration accompanies subsequent iterations. The process continues until sufficient convergence has been obtained. [Sackman 1975]

Before a complete subscription to Delphi is made, certain pertinent drawbacks should be understood. Sackman states that analysis using Delphi indicates that differentiation between expert and layman are hard to identify in the process. Furthermore results are often simply manipulated group suggestions (anchoring bias) rather than real consensus. Additionally, ambiguity in results can occur due to vague questions. Hence, in determining expert estimates, the Delphi techniques produce scientifically suspect results.

F.4 Numerical Elicitation and scoring methods

As stated in *chapter 4* this thesis deals with non-numeric expert responses. The different methods of eliciting numeric values for subsequent mathematical and statistical combination therefore become irrelevant. Nonetheless, certain numerical methods are listed.

i) Indirect methods, betting rates – involves betting on the estimates made to attain a degree of certainty in the responses.

i) Direct methods –involves asking directly what the expert's degree of belief in the answers are. Cooke [1991] does not recommend this method though it is often used.

ii) Parametric elicitation –a two step process involving attaining a best estimate and a degree of certainty.

F.5 Qualitative Questions

Interviews can be handled from a qualitative approach in which case the interview is less structured and more conversational. In qualitative research, questioning should be as open ended as possible to encourage the expert to give his own opinion. Care must be taken to ensure the correct information is still elicited. Hoinville et al. [1978] warn of four ways a qualitative interview can be impeded. These topics are quite similar to biases and heuristics which have been discussed previously.

i) Attempts at rationalisation – respondents try to remain logical at the expense of their true opinions.

ii) Lack of awareness – respondents are not accustomed to the interview survey process and battle to explain themselves objectively.

iii) Fear of being shown up – respondents avoid sharing their beliefs in fear of being wrong.

iv) Over politeness – shy or over anxious respondents may tailor their answers to match what they believe is wanted by the surveyor.

Problems like these can be partially avoided by good interview conducting skills. Encouraging someone to talk or using the correct question techniques are skills available to the surveyor that will help the survey process. Care must be taken by the surveyor not to err on the other side and lead the experts.

F.6 Data Collection Questions

Data collection is an in depth interview format. The order of the topics is required to be structured in order to ensure flow. The questions are less interpretive and more to the point. Clearly the personal impeding factors listed above are less likely to have an effect with this approach.

When constructing a structured questionnaire the different types of questions must be assessed. Inclusion of the question styles that will best suite the answer formats wanted, must then be selected. The main question types are:

i) Direct questions – “yes or no” answers are expected.
ii) Indirect questions – the question attempts to avoid the direct approach.
iii) Monkey puzzles – questions with precoded answers.
iv) Open-ended questions – some questions are asked without any precodes. Answers will generally be unique.
v) Rating questions – answers are given according to a rating system appropriate to the question. e.g. Strongly disagree; disagree; neutral; agree, strongly agree.
vi) Score value questions – similar to the rating questions, only using a numerical scale.
vii) Preference questions – e.g. Do you prefer A or B?