Development of a crane load software application for electric driven overhead travelling bridge cranes in accordance with SANS 10160-6:2010

by

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Synopsis

Development of a crane load application for electric driven overhead travelling bridge cranes in accordance to SANS 10160-6:2010

Electric driven overhead travelling bridge cranes (EOHTC) form a vital part of industrial plants where heavy objects require moving. Overhead travelling cranes aid in production by allowing an uninterrupted work process on the ground while heavy loads are moved to their required locations.

Various factors need consideration in determining the loads induced by an EOHTC on its support structure. In order to design such a support structure, the designer must understand and take into account the various loads that the support structure will be subject to during its lifetime.

The procedure for determining the loads induced by the EOHTC on its support structure is laid out in the SANS 10160-6:2010 code of practice. This document was published in June 2010 and as a result very few worked examples exist to test the coherence of the procedure.

This thesis presents an investigation into the procedure for determining the actions induced by overhead travelling bridge cranes adopted in the SANS 10160-6:2010 code of practice. The investigation was conducted by developing a software application to automatically determine the necessary crane actions needed for the design of the crane support structure, given certain input parameters. The motivation behind this was to have a tool that can calculate the crane induced loads automatically. And by developing such a tool the procedure given in the code of practice is better understood.

The Java programming language was used to code the calculations with an object oriented programming approach (OOP). NetBeans, the integrated development environment for developing with Java was used to generate the required graphical user interface of the application. In addition, a Microsoft Excel calculation sheet was also developed for the purpose of comparison and verification.

Whilst developing the software application, it was found that the model for the acceleration or deceleration of the crane was specific for four wheel cranes only. This model was then extended to accommodate eight and sixteen wheel cranes and incorporated into the algorithm architecture of the application.

The application was successfully completed and verified using benchmarked examples.

Samevatting

Ontwikkeling van sagteware vir die bepaling van elektriese oorhoofse brugkraanlaste, volgens SANS 10160-6:2010

Elektriese oorhoofse brugkrane vorm ‘n belangrike deel van baie nywerheidsprosesse, waar dit gebruik word om swaar laste in die nywerheidsaanleg te verskuif. Oorhoofse brugkrane voeg waarde by die produksie lyn deur te sorg dat die werksproses op die grond onversteurd voortgaan terwyl swaar laste na hul vereiste posisies verskuif word.

Verskillende faktore moet in ag geneem word om die nodige kraanlaste te bepaal. Hierdie laste word benodig om die kraan se ondersteuningstruktuur te ontwerp. Die ontwerper moet die nodige kundigheid hê en moet ook die verskeie laste in ag neem wat die ondersteuningstruktuur gedurende sy leeftyd sal dra.

SANS 10160-6:2010 verskaf riglyne vir die bepaling van die laste wat deur oorhoofse brugkrane uitgeoefen word. Hierdie dokument is in Junie 2010 gepubliseer dus bestaan daar min uitgewerkte voorbeelde om die korrektheid van die riglyne te toets en toepassing te demonstreer.

Hierdie proefskrif ondersoek die riglyne vir die bepaling van oorhoofse brugkraan aksies soos uiteengesit in die SANS 10160-6:2010. Die navorsing is uitgevoer deur middel van die ontwikkeling van ‘n sagteware toepassing wat die nodige oorhoofse brugkraanlaste automaties bepaal, gegee sekere invoer waardes. Die rede hiervoor was om ‘n hulpmiddel te ontwikkel vir die outomatiese bepaling van oorhoofse brugkraan. Deur die bogenoemde hulpmiddel te ontwikkel word die riglyne, soos gegee in die kode beter verstaan.

Java is gebruik as programmeringstaal waar die objek geörienteerde programeringstyl toegepas was. Die geintegreerde ontwikkelingsomgewing vir ontwikkeling met Java, naamlik NetBeans is gebruik om die nodige gebruikers koppelvlak op te bou. ‘n Microsoft Excel sigblad is ook ontwikkel vir kontrolerings doeleindes.

Gedurende die ontwikkeling van die sagtewarepakket is dit bevind dat die lasmodel vir die versnelling of vertraging van die oorhoofse brugkraan slegs op vierwiel krane van toepasing is. Hierdie lasmodel is dus uitgebrei om agt- en sestienwiel krane ook te bevat. Die lasmodel aanpassing is dan ook in die program se algoritme-argitektuur ingebou.

Die sagteware toepassing is suksesvol ontwikkel en gekontroleer met ‘n maatstaf voorbeeld.

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List of acronyms

CFF	Coupled Fixed Fixed
CFM	Coupled Fixed Movable
DVL	Dynamic Vertical Loads

EOT	Electric Overhead Travelling
EOHTC	Electric Overhead Travelling Crane
FEA	Finite Element Analysis
IFF	Independent Fixed Fixed
IFM	Independent Fixed Movable
OOP	Object Oriented Programming
SANS	South African National Standards
SVL	Static Vertical Loads

Chapter 1

1 Introduction

1.1 Electric Overhead Travelling (EOT) Cranes

Overhead travelling cranes form a vital part of industrial plants where heavy objects require moving. Overhead travelling cranes aid in production by allowing an uninterrupted work process on the ground while heavy loads are moved to their required locations.

An overhead travelling crane system consists of 3 major components namely:

- The crane bridge which traverses the runway in a longitudinal direction along the length of the building.
- The crab which houses both the hoisting equipment which travels along the bridge and the lifting mechanism which usually constitutes either a hook, a grab or a magnet.
- The runway which is tied to the supporting structure.

There are various configurations for EOT cranes depending on their application, the layout of the industrial building and the type of load to be hoisted. The configurations are bridge cranes, portal cranes and semi-portal cranes. Portal cranes are portal frame structures where the base of the frame legs is running on rails. Semi portal cranes are semi-portal frames where one end of the crane bridge runs on an elevated rail and the other end is connected to a column with the base of the column running on a lower rail. Bridge cranes are cranes where both rails are at the same elevated level. Bridge cranes will be the focal point of this research.

Bridge cranes can further be categorised into two distinct configurations, being influenced by factors such as headroom utilization, the load to be hoisted and the layout of the building which the crane support structure occupies. EOT bridge cranes can either be top mounted or under slung. In this thesis the terms top running and under running are used instead of top mounted and under slung. Under running cranes are supported on the bottom flanges of the crane runway girder where top running cranes are supported on the top of the runway girder. Top running EOT bridge cranes can be configured in several different ways. For example top running bridge cranes lifting lighter loads usually have I or H sections as end carriages and a single I or H section for the crane bridge, with the crab running on the bottom flanges of the bridge. Top running bridge cranes required to lift heavier loads have box girders for end carriages and the crane bridge. The crane bridge would typically comprise of two parallel box girders with the crab mounted on rails on top of the bridge girders.

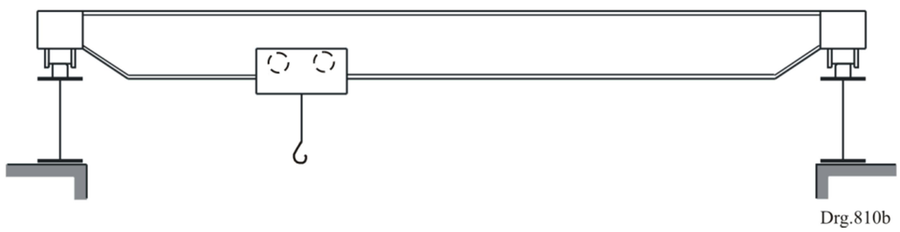


Figure 1.1 Top running bridge crane with hoist block

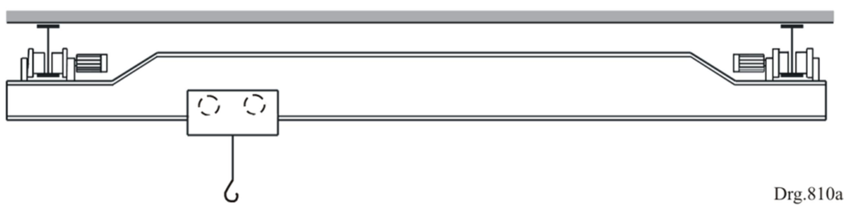


Figure 1.2 Under running bridge crane with hoist block

Generally the hook is the most common lifting mechanism found in practice, but other lifting mechanisms do exist. The choice is governed by the type of material to be hoisted. In metal works, where molten metal requires hauling, ladles would work best. Grabs are used to transport scrap metal or granular material while cranes fitted with magnets would be more suitable for lifting steel plates.

The wheels are important components of the crane, because they transfer the crane loads to the supporting structure and ensure the smooth longitudinal movement of the crane. Four wheeler cranes are the most common cranes but larger cranes required to lift heavier loads can have eight or sixteen wheels in total. Wheel pairs in EOT cranes can either be coupled or independent with either movable or fixed wheels. In this context a wheel pair is two wheels opposite each other, one on each end carriage. Wheel pairs can either be coupled; they are mechanically or electrically synchronized, or independent with the wheels on opposite ends rotating independently of each other. Furthermore movable wheels have a lateral degree of freedom, whereas fixed wheels are horizontally fixed. Although there are several combinations of coupled or independent and movable or fixed wheel pairs, see Figure 1.3, only the Independent fixed, fixed (IFF) combination is of relevance in this research as this is the most common wheel pair configuration used in the South African industry. The wheel pairs are independent but the wheels on both end carriages are fixed on their axes for the IFF configuration.

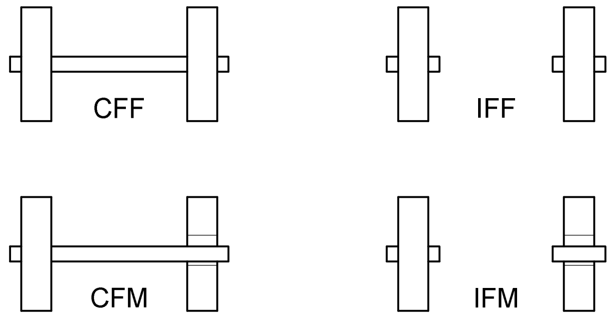


Figure 1.3 Wheel pair combinations as per prEN 1991-3

All cranes must be equipped with buffers on their end carriages. Buffers reduce the impact forces if the crane runs into the end stops at the end of the runway. Three different types of buffers are encountered, namely rubber, cellular plastic and hydraulic buffers. (Dymond, 2005)

1.2 Background and Motivation for Research

1.2.1 *Background*

The loads induced by the crane on its support structure as result of its day to day operations are used by the engineer to design the supporting structure, ensuring that the structure is robust enough to withstand the loads. It is therefore important to have a proper means to determine the correct loads induced by these overhead cranes. Various crane design codes of practice give load models for calculating the loads that overhead cranes exert on their support structures.

The load models in the former SABS 0160:1989 were found to be over simplistic and were therefore reviewed by the South Africa loading code committee. As a result more sophisticated load models were derived and incorporated in the new South African loading code, SANS 10160-6:2010. The prEN 1991-3 crane load models, which have been developed from DIN 15018 and ISO 8686-1:1989 served as basis for the load models used in the new SANS 10160-6:2010 hereinafter referred to as the code (Dymond, 2005).

The loads induced by cranes on their supporting structures can be classified into 3 categories (Dymond, 2005).

1. Loads arising from normal crane operation
2. Loads arising from accidental situations
3. Loads arising from improper construction, lack of maintenance or misuse of crane

An important factor to note is that the crane loads are a result of hoisting heavy objects and the movement of the crane and the crab in order to transport these objects around the work place.

The loads arising from the crane operation are primarily dynamic loads but are treated in the code as quasi-static loads that are amplified with the necessary dynamic factors accounting for the various dynamic effects. Hence the denotation dynamic factors, φ (Dymond, 2005).

The code divides category 1 loads above, into vertical and horizontal loads.

1.2.1.1 Category 1 Loads: Loads arising from normal crane operations

(a) *Vertical Loads*

Vertical loads consist of static vertical loads (SVL's) and dynamic vertical loads (DVL's). SVL's arise from the gravitational effects on the crane whereas DVL's arise from the inertial effects acting on the weight of the crane and the hoist load.

SVL's are calculated using the nominal weights of the crane bridge, crab and pay load supplied by the crane manufacturer.

DVL's are a result of the following inertial effects.

1. Dynamic effects as a result of lifting a hoist load from rest position
2. Dynamic effect of transferring the hoist load from the ground to the crane
3. Dynamic effects induced when the crane is travelling on uneven rails or runways
4. Dynamic effects as a result of the sudden release of part of the hoist load
5. Dynamic effects as a result of a test load

(b) *Horizontal Loads*

Horizontal loads are divided into two types, namely horizontal transverse loads and horizontal longitudinal loads. Both of these are developed when the hoisted load and crab are at an eccentricity to the longitudinal axis of the crab or when the long travel motion of the crane does not coincide with the longitudinal axis of the rails. The horizontal load cases catered for in the code are:

- Horizontal loads caused by the acceleration and deceleration of the crane bridge
- Horizontal loads caused by skewing of the crane in plan
- Horizontal loads cause by the acceleration and deceleration of the crab
- Horizontal loads caused by misalignment of the crane wheels
- Horizontal loads due to testing (test loads)

1.2.1.2 Category 2 Loads: Loads arising from accidental situations

The following loads which result from accidental situations are of relevance for this thesis:

- Horizontal loads caused by the crane running into end stops.
- Crab running into the end stops.

1.2.2 *Motivation*

From the background given above it can be seen that various factors need consideration in determining the loads exerted by an EOT crane on its support structure. In order to design such a support structure the designer must understand and take into account the various loads that the support structure will be subject to during its lifetime.

The procedure for determining the loads induced by the EOHTC on its support structure is laid out in the SANS 10160-6:2010 code of practice. This document was published in June 2010 and as a result very few worked examples exist to test the coherence of the procedure.

The scope of this research includes a detailed investigation into the procedure for determining the actions induced by overhead travelling cranes adopted in the SANS 10160-6:2010. This investigation was conducted by developing a software application to automatically determine the necessary crane actions needed for the design of the crane support structure, given certain input parameters. The motivation behind this was to have a tool that can calculate the crane induced loads automatically. And by developing such a tool the procedure given in the code of practice is better understood.

1.3 Scope and Limitations

The scope will entail an investigation into the procedure for determining the actions induced by overhead travelling cranes adopted in the SANS 10160-6:2010, with the objective to develop an application to determine the crane induced loads for the design of the supporting structure. In addition, a Microsoft Excel calculation sheet will also be developed for the purpose of comparison and control.

1.3.3 *Crane Design Application*

Certain specifications and assumptions were required in order to have a properly defined framework within which this application should be developed.

The Java programming language is used to code the calculations with an object oriented programming approach (OOP).

The application should have a comprehensive input console or interface. It should be in line with the input parameters provided by the crane supplier, see Table 1.1. An output interface should also be developed to display calculated loads in a comprehensive format. Both the input and output interfaces will be developed with Java Swing and NetBeans. Java Swing is the Java graphical user interface (GUI) toolkit that is used to develop user interfaces that has the look and feel of your native operating system's GUI components. NetBeans is a framework for simplifying the development of Java Swing components.

The output data must be made available for archiving; therefore some form of archiving format is vital. It was suggested to have the output stored in an Adobe PDF format, enabling the end user to either store the PDF documents as soft copy or print them for filing.

1.3.4 *Further assumptions and specifications for the application*

1.3.4.1 Actions

Only actions induced by the EOHTC will be determined by this application. Furthermore, only cranes inside industrial buildings will be considered. Thus the effects of wind will be ignored. Wind on crane and hoist load on open gantry installations are determined in accordance with SANS 10160-3 and therefore fall outside the scope of this research.

The following actions will be determined.

- Vertical loads caused by the dynamic effect of:
  - lifting a hoist load from rest position
  - hoisting a load from the ground to the crane
  - the sudden release of part of the hoist load
  - a test load moved in the manner of normal operation

- Horizontal actions caused by:
  - the acceleration and deceleration of the crane bridge
  - skewing of the crane in plan
  - the acceleration and deceleration of the crab
  - misalignment of the crane wheels
  - testing (test loads)

The necessary information required to determine the above mentioned actions are summarised in Table 1.1.

Table 1.1 Required crane information to determine the various groups of loads

Group of Loads	**Crane Information Required from Manufacturer**
Static vertical wheel loads	Minimum distance between hoist & rail
	Span of crane bridge
	Maximum hoist load
	Weight of crane bridge and carriages
	Weight of crab
Dynamic effect hoisting a load	Steady hoisting speed
	Hoisting class
Dynamic effect of releasing a load	Mass of hoist load
	Type of hoist
	Part of the hoist load released
Dynamic effect of travelling on uneven	Travelling velocity
(for tolerances outside the	Wheel Diameter
of SANS 2001 CSI)	Gap / step sizes
Acceleration / Deceleration of crane	Number of wheel drives
	Behaviour of drive
	Number of rails
	Number of single wheel drives
	Behaviour of drive
Skewing of the crane bridge in plan	Clearance between rail and wheel flange
	Width of rail head
	Presence of guide rollers
	Wheel spacing
	Number of wheel pairs
Acceleration / deceleration of the crab	Crab weight
	Hoist free to swing
	Number of wheels on crane
	Hoist load
Misalignment of wheels	Hoisting class
	Number of wheels
	Self weight of crane
	Hoist load
Test Loads	Hoist load
	Steady hoisting speed
	Hoisting class
	Number of wheel drives
	Behaviour of drive
	Number of rails
	Number of single wheel drives
	Behaviour of drive
Buffer Forces	Buffer Type
	Buffer Characteristic
	Weight of crane bridge and carriages
	Weight of crab
	Long Travel Speed

Certain input parameters are available from the crane manufacturer. These are listed below.

1. Weight
    - Crane bridge & end carriage weight
    - Crab weight
    - Maximum hoist load
2. Geometry of crane
    - Span of crane bridge
    - Minimum hook distance
    - Rail type
    - Width of top rail
    - Height of rail
    - Wheel diameter
3. Speeds
    - Hoisting
    - Long & Cross travel
4. Guide Means (present or not)
    - Flanges on wheels
    - Horizontal guidance wheels
5. Crane Classification
    - Crane class
    - Hoist type
    - Is hoisted load allowed to swing?
6. Buffers
    - Buffer Type
    - Buffer characteristic
7. End Carriage Information
    - Type of wheel drive
    - Number of single wheel drives
    - Behaviour of drive
    - Combination of wheel pairs
    - Clearance between rail and wheel flange
    - Number of wheel pairs
    - Wheel spacing

- Combination of wheel pairs (Only IFF considered)

Only the situation where the payload is free to swing will be accounted for. This eliminates the need to consider horizontal loads caused by crane tilting.

1.3.4.2 EOT bridge crane types and classes

Only EOT bridge cranes on runway beams at the same level will be considered. As seen before EOT bridge cranes are divided into two distinctive configurations, namely under running and top running bridge cranes. Both these EOT bridge crane types will be accounted for.

The loads discussed in section 1.3.2.1 above are carried over to the support structure via the wheels of the crane. For the case of vertical loads, the SANS 10160-6:2010 divides the vertical force, for each end carriage, equally among the wheels on that end carriage. Therefore EOT bridge cranes, whose end carriage setup is such that it does not adhere to this assumption about the equal distribution of loads among wheels on an end carriage, are automatically excluded.

Very often in industry multiple EOT bridge cranes are required to operate together however, the application will only look at the forces generated by a single crane.

EOT bridge cranes of all hoist classes, as recommended in Table A.1 of SANS 10160-6:2010 (mast cranes excluded) will be accounted for.

1.3.4.3 Rails and wheels

Only EOT cranes with the IFF wheel pair combination will be considered. This is the only wheel pair combination on which the SANS 10160-6:2010 is based.

It is further assumed that the tolerances for rail tracks specified in SANS 2001 CSI are observed as a result, the model suggested in Annex B of SANS 10160-6:2010 for estimating the dynamic factor φ_4 falls outside the scope of this project.

All the crane wheels are assumed to be made of steel. Some cranes are fitted with rubber wheels but this is very rare in the South African industry, therefore only steel wheels are considered. This assumption comes in handy when the friction factor μ need to be determined, see section 3.2.6.1.

1.3.4.4 Output Results

The result of all eight ultimate limit state groups of loads, one test load and two accidental groups of loads must be presented, see Table 1.2 below. Only some groups of loads where applicable, will be critical for the verification of the ultimate limit state design for the support structure, but all groups of loads must be presented in order to give an overall picture of the behaviour of the crane for fatigue purposes.

Table 1.2 gives a summary of the crane induced loads expected from the output. For the 8 groups of loads for the ultimate limit state a partial load factor of 1.6 will be applied to obtain the design loads. A partial load factor of 1.0 will be applied to test group of loads as well as the 2 accidental groups of loads.

For the fatigue design, the group of loads 1 to 4, 6 and 8, the characteristics loads will serve as the fatigue design loads.

Table 1.2 Groups of loads and dynamic factors to be considered as one characteristic crane action

	Symbol	Ultimate Limit States (Partial Load Factor: 1.6)								Test Loads (Partial Load Factor: 1.0)	Accidental Loads (Partial Load Factor: 1.0)	
		1	2	3	4	5	6	7	8	9	10	11
Self weight of Crane	$Q_{c,k}$	Φ_1	Φ_1	1	Φ_4	Φ_4	Φ_4	Φ_4	1	Φ_1	1	1
Hoist load	$Q_{hl,k}$	Φ_2	Φ_3		Φ_4	Φ_4	Φ_4	Φ_4				
Part of hoist load	$\eta Q_{hl,k}$								1			
Acceleration of crane bridge	H_T, H_L	Φ_5	Φ_5	Φ_5	Φ_5					Φ_5		
Skewing of crane bridge	H_S					1						
Acceleration of braking of crab	$H_{T,3}$						1					
Misalignment	H_M							1				
Test Load	Q_T									Φ_6		
Buffer Force	H_B										Φ_7	
Tilting Force	H_{TLT}											1

		Fatigue Design (Partial Load Factor: 1.0)							
		1	2	3	4	5	6	7	8
Self weight of Crane	$Q_{c,k}$	Φ_1	Φ_1	1	Φ_4	Φ_4	Φ_4	Φ_4	1
Hoist load	$Q_{hl,k}$	Φ_2	Φ_3		Φ_4	Φ_4	Φ_4	Φ_4	
Part of hoist load	$\eta Q_{hl,k}$								1
Acceleration of crane bridge	H_T, H_L	Φ_5	Φ_5	Φ_5	Φ_5				
Acceleration or braking of crab	$H_{T,3}$						1		

Chapter 2

2 Technical Background

2.1 Preceding Projects

Several electrical overhead travelling crane (EOHTC) projects were conducted and completed before this thesis study commenced. Various aspects relating the overhead crane and its supporting structure were investigated by former students at the University of Stellenbosch. The ultimate goal for the EOHTC study is to gain a better understanding of the EOHTC and to provide guidelines for the design of the crane support structure.

In this section several preceding EOHTC projects which bares most relevance to the research covered in this document, will be discussed briefly.

- Dymond J, 2005: Reliability based codification for the design of overhead travelling crane support structures.

  Dymond investigated the electric overhead travelling crane support structure; focussing on the crane load models from the prEN 1991-3.The investigation took the form of two parts: calibration to current practice and a reliability calibration.

  The calibration to current practice investigated the load models from the prEN 1991-3 to determine their suitability for inclusion in the SANS 10160. In addition, an assessment of the effect on the cost of the support structure and the design effort required, of calculating crane loads using the models from prEN 1991-3 instead of the SABS 0160:1989, was also conducted.

  The reliability calibration investigated the current level of reliability of crane support structures designed using crane loads calculated form prEN 1991-3 and SABS 0160:1989. Partial load factors were determined to achieve a consistent, minimum level of reliability.

  Dymond's research showed that the current level of reliability was inadequate and partial load factors were determined for the ultimate limit state, the accidental limit state and fatigue.

- De Lange J, 2007: An experimental investigation into the behaviour of a 5 ton electric overhead travelling crane and its support structure.

The forces induced by overhead travelling bridge cranes on their support structures are treated as static forces amplified with dynamic factors and applied as pseudo static forces, neglecting the interaction between the crane and the support structure.

De Lange investigated the validity of this approach by doing experiments on a 5 ton EOHTC and its support structure. The setup was fitted with a data acquisition system to capture the forces, strains, deflections on the crane and support structure as well as accelerations and velocities of the crane.

Forces generated at the crane wheels were measured, as the crane traversed the support structure. The interaction of the wheels and the support structure was visually recorded.

The captured experimental data was interpreted to describe the behaviour of the EOHTC travelling crane and its support structure. This data was also used by other students in research that followed.

- Haas T, 2007: Numerical (FEA) evaluation of crane end buffer impact forces.

  Haas developed a Finite Element Analysis (FEA) model of the full scale experimental EOHTC testing facility in the structural engineering laboratory of Stellenbosch University. The purpose of this model was to capture the global interactions of all the components of the EOHTC and its support structure. The FEA model was used by several other students in research that followed.

  Haas also determined the maximum end buffer force response when the crane collides with the end stops. The FEA model was calibrated against the result of the experimental investigations. Afterwards the FEA model was used to perform more advanced simulations to assess the maximum end buffer impact force. A FEA sensitivity analysis was conducted on a set of identified parameters which have a significant effect on the structural response of the end buffer impact.

2.2 Classification of loads

2.2.1 *Dynamic factors*

The code treats crane wheel loads as quasi-static loads, where the effect of the crane dynamics is taken into account by applying dynamic amplification factors to the static wheel loads (Dunaiski & Retief, 2009).

A brief description of the dynamic factors follows:

- φ_1: The SANS 10160-6 specifies that φ_1 should be applied to the crane self weight to account for the dynamic effects of lifting a hoist load off the ground. A value of 1.1 is specified in SANS 10160-6
- φ_2: This factor is applied to the hoist load to account for the dynamic effects of lifting a load off the ground. The value of φ_2 depends on the hoist class of the crane as well as the steady hoisting speed, v_h in m/s. See Equation 2.1 for calculating φ_2.

$$\varphi_2=\varphi_{2,min}+\beta_2\times v_h \tag{2.1}$$

The values for β_2 and $\varphi_{2,min}$ are summarised in Table 2.1 below. C1, C2, C3 and C4 are defined in Annex A of SANS 10160-6.

Table 2.1 Values for β_2 and $\varphi_{2,min}$

Class of crane	β_2	$\varphi_{2,min}$
C1	0.17	1.05
C2	0.34	1.10
C3	0.51	1.15
C4	0.68	1.20

- φ_3: Cranes fitted with grabs or magnets often release their loads suddenly as part of the normal operation of the crane. In order to account for the sudden release of the hoist load, the SANS 10160-6 specifies a dynamic factor φ_3 to be applied to the hoist load. φ_3 is calculated using Equation 2.2.

$$\varphi_3=1-\frac{\Delta m}{m}(1+\beta_3) \tag{2.2}$$

Where:

Δm is the released part of the hoist load

m the total hoist load

β_3 0.5 for cranes with slow release devices like grabs

β_3 0.5 for cranes with rapid release devices like magnets

φ_3 will always be less than one and is therefore not critical for overhead travelling bridge cranes, but rather for cranes for which stability is critical (Dunaiski & Retief, 2009).

- φ_4: SANS 10160-6 states that if construction tolerances meet the specification set out in SANS 2001 CSI the value of φ_4 may be taken as 1.0. In the event where the rail tolerances are not met, the dynamic factor φ_4 may be determined using the model in Annex B of SANS 10160-6. This model is based on elasto-kinetic principles. However, in this document under the section where specifications and assumptions are made for the crane load application, refer to 1.3.4.3, it is assumed that the construction tolerances meet the SANS 2001 CSI specifications.

- φ_5: In order to determine loads caused by the acceleration and deceleration of the crane bridge, discussed in more detail in section 2.2.3, the SANS 10160-6 specifies a dynamic factor φ_5 to be applied to allow for the elastic effects of the drives of the crane. The value of φ_5 depends on the smoothness of change of the drive forces and is summarised in Table 2.2.

Table 2.2 Dynamic factor φ_5

Force description	**Dynamic factor φ_5**
For centrifugal forces	1,0
Corresponding to systems in which forces change smoothly	1,5
For when sudden changes occur	2,0
For drives with considerable backlash	3,0

- φ_6: SANS 10160-6 specifies two values for φ_6. One to be applied to the dynamic test load and the other to the static test load.

  The dynamic test load of 110% of the safe working load is assumed to be moved by the crane in the way in which the crane will be used during normal operating conditions. The application of φ_6 to the dynamic test loads accounts for the vertical inertial effects of lifting the test load. Equation 2.3 is used to determine the value for φ_6 to be applied to the dynamic test load.

$$\varphi_6 = \frac{1+\varphi_2}{2} \tag{2.3}$$

The static test load is taken as 125% of the safe working load. The SANS 10160-6 specifies a value of 1.0 for φ_6 to be applied to the static test load.

- φ_7: The value of the dynamic factor φ_7 depends on the non-linearity of the end buffer which is represented by the buffer characteristic, ξ_b.

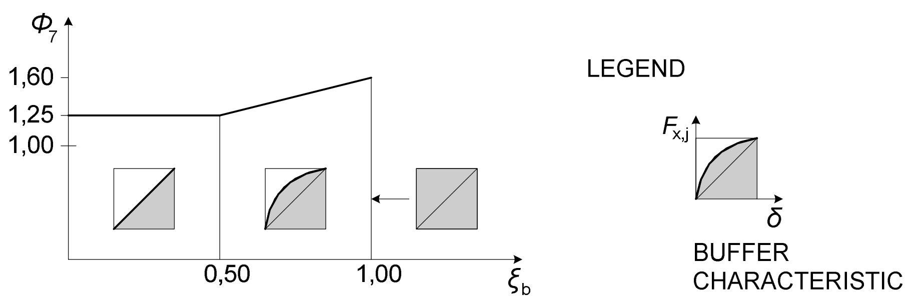


Figure 2.1 Buffer force displacement characteristic curve

SANS 10160-6 recommends values for the dynamic factor φ_7 as shown in Figure 2.1 and given by the equations in Table 2.3.

Table 2.3 Dynamic factor φ_7

$\varphi_7 = 1{,}25$	if $0{,}0 \leq \xi_b \leq 0{,}5$
$\varphi_7 = 1{,}25+0{,}7(\xi_b - 0{,}5)$	if $0{,}5 \leq \xi_b \leq 1.0$
NOTE ξ_b may be approximately determined from Figure 2.1, depending on buffer characteristics.	

The degree of non-linearity of the buffer, ξ_b is the ratio of the area under the force displacement curve to the product of the maximum force and maximum displacement as depicted in Figure 2.1 (Dymond, 2005).

The various dynamic factors and their applications are summarised in Table 2.4.

Table 2.4 Dynamic factors

Dynamic factors	Effects to be considered	To be applied to	SANS 10160-6:2010 Clause
φ_1	Excitation of the crane structure due to lifting the hoist load off the ground	self-weight of the crane	5.6.3
φ_2	Dynamic effects of transferring the hoist load from the ground to the crane		5.6.3
φ_3	Dynamic effect of sudden release of the payload if for example grabs or magnets are used	hoist load	5.6.3
φ_4	Dynamic effects induced when the crane is travelling on uneven rails or runways.	self-weight of the crane and hoist load	5.6.3
φ_5	Dynamic effects caused by drive forces	drive forces	5.7.2(b)
φ_6	Dynamic effects of a test load moved by the drives in the way the crane is used	test load	5.10.4
φ_7	Dynamic effect of buffer characteristics	buffer loads	5.12.1.2

2.2.2 *Variable and accidental loads*

The code classifies crane loads as variable and accidental which are represented by several models.

Given normal service conditions, variable loads result from variations in time and location. The variable loads are separated into vertical crane loads and horizontal loads. Vertical loads are a result of the crane's self weight and hoist loads, and horizontal loads result from the acceleration and deceleration of the crane and crab, misalignment of crane wheel or crane rails, skewing and other dynamic effects (SANS 10160-6, 2010).

Accidental loads are generated as a result of collisions with buffers or the collision of lifting mechanisms with obstacles (SANS 10160-6, 2010).

Both variable and accidental loads are represented with various load models which are used to determine the relevant crane induced loads on the support structure. Figure 2.2 gives a graphical representation of a load hierarchy of the load types discussed in SANS 10160-6:2010. The concept of group of loads is introduced in SANS 10160-6:2010 to account for the simultaneity of the crane load components. See Table 1.2 for further clarity.

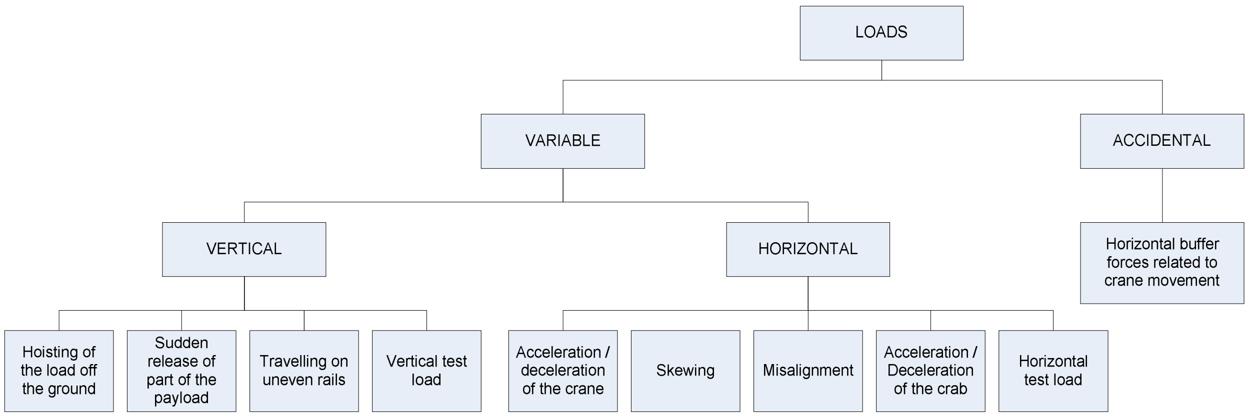


Figure 2.2 Load hierarchy

2.2.3 *Crane load models in SANS 10160-6:2010*

2.2.3.1 Load model for vertical wheel loads

SANS 10160-6:2010 specifies that the vertical wheel loads from a crane on a runway beam shall be determined considering the two loading scenarios given in Figure 2.3 and Figure 2.4.

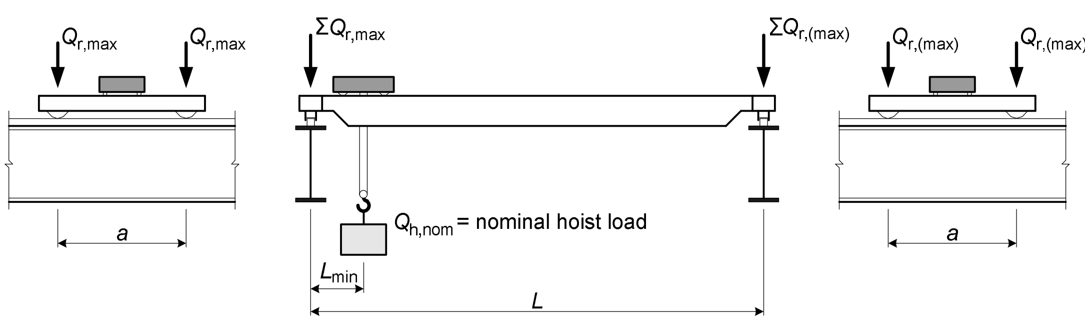


Figure 2.3 Maximum vertical action on the runway beams

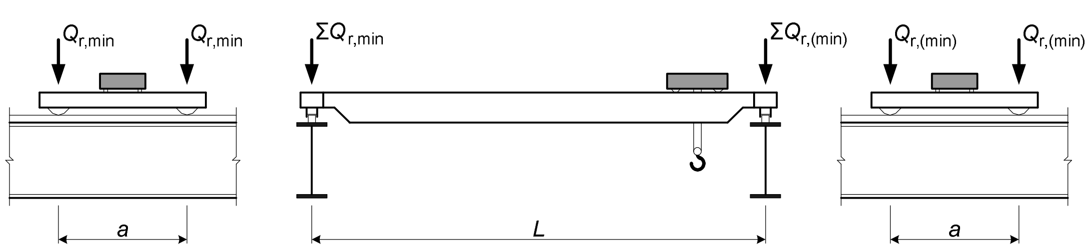


Figure 2.4 Minimum vertical action on the runway beam

Where

$Q_{r,max}$ maximum load per wheel of the loaded crane

$Q_{r,(max)}$ accompanying load per wheel of the loaded crane

$\Sigma Q_{r,max}$ sum of the maximum loads, $Q_{r,max}$ per runway of the loaded crane

$\Sigma Q_{r,(max)}$ sum of the accompanying maximum loads $Q_{r,(max)}$ per runway of the loaded crane

$Q_{r,min}$ minimum load per wheel of the unloaded crane

$Q_{r,(min)}$ accompanying load per wheel of the unloaded crane

$\Sigma Q_{r,min}$ sum of the minimum loads $Q_{r,min}$ per runway of the unloaded crane

$\Sigma Q_{r,(min)}$ sum of the accompanying minimum loads $Q_{r,(min)}$ per runway of the unloaded crane

$Q_{h,nom}$ nominal hoist load

The load scenario depicted in Figure 2.3 assumes the crane to be carrying the maximum hoist load with the crab at the extreme position of its travel across the bridge. Figure 2.4 depicts an unloaded crane with the crab at the extreme position of its travel across the bridge.

The vertical wheel loads are calculated using static equilibrium, with the assumption that the vertical load on one end carriage is evenly distributed between the wheels on that end carriage (Dunaiski & Retief, 2009). Equation 2.4 and Equation 2.5 give the load models for calculating the maximum wheel load per wheel of the crane and the accompanying maximum wheel load per wheel of the crane, respectively. The load models for the minimum and the accompanying minimum wheel load per wheel of the crane are given by Equation 2.6 and Equation 2.7, respectively.

$$Q_{r,max}=\frac{1}{n}\left[\frac{Q_{br}}{2}+\frac{L\text{-}e_{min}}{L}(Q_{cr}+Q_h)\right] \tag{2.4}$$

$$Q_{r,(max)}=\frac{1}{n}\left[\frac{Q_{br}}{2}+\frac{e_{min}}{L}(Q_{cr}+Q_h)\right] \tag{2.5}$$

$$Q_{r,min}=\frac{1}{n}\left[\frac{Q_{br}}{2}+\frac{e_{min}}{L}(Q_{cr}+Q_h)\right] \tag{2.6}$$

$$Q_{r,(min)}=\frac{1}{n}\left[\frac{Q_{br}}{2}+\frac{L\text{-}e_{min}}{L}(Q_{cr}+Q_h)\right] \tag{2.7}$$

Where n is the number of wheel pairs.

The dynamic effects taken into account for the vertical crane wheel loads are:

(a) *Hoisting of the load off the ground*

The dynamic effects on the crane self-weight and hoist load are caused by the hoist mechanism coming up to speed before the lifting attachment engages the loads and are a result of the build-up of kinetic energy and drive torque (Dymond, 2005).

The dynamic factor φ_1 is applied to the crane self-weight and dynamic factor φ_2 is applied to the hoist load, to account for the dynamic effects of lifting a load off the ground. The load model for calculating the maximum wheel load per wheel of the crane for hoisting a load is given by Equation 2.8.

$$Q_{r,max}=\frac{1}{n}\left[\frac{\varphi_1 Q_{br}}{2}+\frac{L\text{-}e_{min}}{L}\left(\varphi_1 Q_{cr}+\varphi_2 Q_h\right)\right] \tag{2.8}$$

(b) *Sudden release of part of the hoist load*

This is only applicable to cranes which are equipped with grabs or magnets as they often release their loads suddenly as part of their normal operative procedures. The SANS 10160-1:2010 specifies a dynamic factor φ_3 to be applied to the hoist load to account for the resulting dynamic effects. The load model for calculating the maximum wheel load per wheel of the crane for sudden release of part of the hoist load is given by Equation 2.9

$$Q_{r,max}=\frac{1}{n}\left[\frac{\varphi_1 Q_{br}}{2}+\frac{L\text{-}e_{min}}{L}\left(\varphi_1 Q_{cr}+\varphi_3 Q_h\right)\right] \tag{2.9}$$

(c) *Travelling on uneven rails*

Rails with steps or gaps at the rail splices induce large dynamic forces while the crane travels over the joint. Fatigue failure in the web of the crane girder at the weld to the flange or stiffener, may result even at low number of cycles. This may lead to increased wear of the crane rails or wheels (Dymond, 2005). SANS 10160-6:2010 specifies a dynamic factor φ_4 to be applied to the crane self weight and hoist load which can be taken as 1.0, if and only if the rail tolerances meet the specification set out in SANS 2001 CSI. Otherwise φ_4 will be calculated according the elasto kinetic model suggested in Annex B of SANS 10160-6. The load model for calculating the maximum wheel load per wheel of the crane for travelling on rails is given by Equation 2.10.

$$Q_{r,max}=\frac{\varphi_4}{n}\left[\frac{Q_{br}}{2}+\frac{L-e_{min}}{L}(Q_{cr}+Q_h)\right] \tag{2.10}$$

2.2.3.2 Load models for horizontal wheel loads

Horizontal transverse and longitudinal loads are generated as a result of the crane traversing the runway with masses eccentric to its centre of mass, as seen in plan view, or because the long travel motion of the crane does not coincide with the longitudinal axis of the rails. The horizontal load models specified in SANS 10160-6:2010 are discussed below.

(a) *Acceleration or deceleration of the crane*

The acceleration and deceleration model incorporates both longitudinal and horizontal loads. The longitudinal loads are a result of the drive force acting at the contact between the wheel and the rail. The transverse loads are result of the crane accelerating or decelerating with the crab eccentric to the centre of mass (Dunaiski & Retief, 2009). The forces generated are shown in Figure 2.5 for a four wheel crane setup.

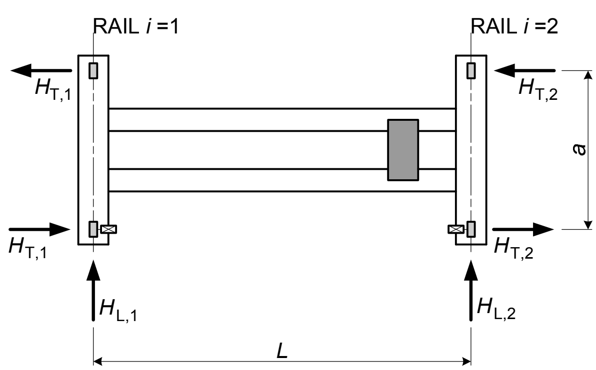


Figure 2.5 Load arrangement of longitudinal and transverse horizontal wheel forces caused by acceleration and deceleration

For the independent fixed-fixed wheel pair configuration, the drive force is taken as, assuming no slip, the product of the minimum possible wheel loads and the friction coefficient between the wheel and the rail. This is shown in Equation 2.11 and. Equation 2.12.

$$K = \mu \times \Sigma Q^{*}_{r,min} \quad (2.11)$$

$$\Sigma Q^{*}_{r,min} = m_w \times Q_{r,min} \quad (2.12)$$

An offset between the geometric centre of the crane and the centre of gravity of the crane is created as a result of the crane's acceleration or deceleration movement with the crab at eccentricity. The drive force then causes a moment about the centre of mass of the crane which is resisted by the horizontal transverse couple forces at the wheels (Dymond, 2005), (Dunaiski & Retief, 2009). This explanation is depicted graphically in Figure 2.6.

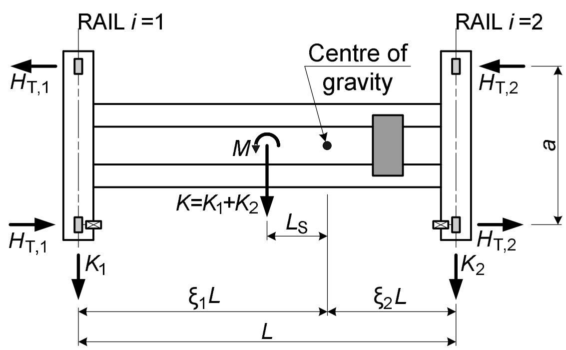


Figure 2.6 Horizontal loads caused by the acceleration or deceleration of the crane

Where:

$K_1 = K_2 = \frac{K}{2}$

Values for the horizontal transverse loads are calculated using Equation 2.13 and Equation 2.14 (SANS 10160-6, 2010).

$$H_{T,1} = \varphi_5 \xi_2 \frac{M}{a} \quad (2.13)$$

$$H_{T,2} = \varphi_5 \xi_1 \frac{M}{a} \quad (2.14)$$

Where:

φ_5 the dynamic factor to take into account the dynamic effects of the change of the drive forces

$\xi_1 = \frac{\Sigma Q_{r,max}}{\Sigma Q_r}$ the distance from rail 1 to the centre of gravity of the crane

$\xi_2 = 1 - \xi_1$ the distance from rail 2 to the centre of gravity of the crane

$M = KL_s = K(\xi_1 - 0.50)L$

L_s the distance between the geometric centre and centre of mass of the crane

a the distance between the guide rollers or flanged wheels

(b) *Skewing of the crane in plan*

Skewing is caused when a difference between the long travel speeds on one side of the crane occurs with regards to its other side. This causes the crane to run at an angle to the line of the rails, as result additional friction is generated at the wheels thereby causing transverse longitudinal forces to be induced on the runway (Dymond, 2005), (Dunaiski & Retief, 2009).

Typical situations in the workplace which result in skewing of the crane are when one of the drive motors fails; applying brakes suddenly so that one side takes before the other or different diameters due to wear of wheels on either side of the crane or uneven surfaces of rails (Dymond, 2005).

Figure 2.7 graphically depicts the skewing model incorporated into the SANS 10160-6:2010.

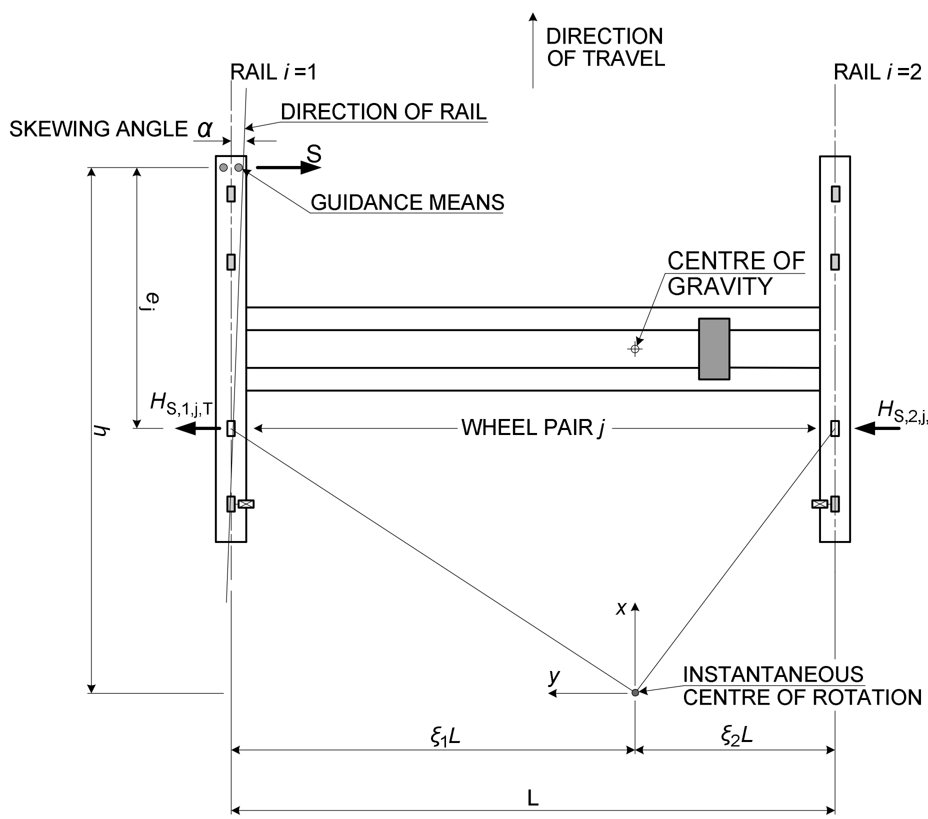


Figure 2.7 Loads due to skewing of the crane on plan

The model further assumes the crane to be rotating about an instantaneous centre of rotation, which depends on factors such as the number and type of wheels, the guidance means and the position of the centre of mass (Dunaiski & Retief, 2009).

A guide force develops on the front guidance means as a result of this angular motion of travel. The guide force comes into contact with the rail and tries to straighten the crane, where it is resisted by horizontal transverse forces on the wheels which are due to the transverse component of friction as the wheels slide horizontally (Dymond, 2005).

The guide force and transverse force due to skewing are shown in Equation 2.15 and Equation 2.16 below

$$S = f\lambda_{s,j}\sum Q_r \tag{2.15}$$

$$H_{s,i,j,k} = f\lambda_{s,i,j,k}\sum Q_r \tag{2.16}$$

Where:

f is the friction factor. SANS 10160-6:2010 gives a simplified empirical expression for the effective friction factor, which depends only on the skewing angle α and is given by Equation 2.17. The skewing angle takes into account the initial skewness from slight rail and wheel misalignment, clearance between the rail and wheel flange and guidance means, and the wear of the rail and guidance means with time. α is determined using Equation 2.18 and Table 2.5 as seen below.

$$f = 0.3\left(1 - e^{(-250\alpha)}\right) \le 0.30 \tag{2.17}$$

α is the skewing angle in radians.

$\lambda_{s,i,j,k}$ is the force factor accounting for the wheel position relative to the guidance means and instantaneous centre of rotation

- i refers to the rail
- j is the wheel pair
- k is the direction of forces, T = transverse and L = longitudinal

$\sum Q_r$ is the combined weight of the crane and hoist load

$$\alpha = \alpha_F + \alpha_v + \alpha_0 \quad (2.18)$$

Table 2.5 Definition of α_F ,α_v ,α_{ext}

Angles α_i	**Minimum values of** α_i
$\alpha_F = \frac{0.75 \times x}{a_{ext}}$	0,75 x ≥ 5 mm for guide rollers 0,75 x ≥ 10 mm for flanged wheels
$\alpha_v = \frac{y}{a_{ext}}$	y ≥ 0,03 b in mm for guide rollers y ≥ 0,10 b in mm for flanged wheels
α_0	$\alpha_0 = 0{,}001$

α_{ext} is the spacing of the outer guidance means or flanged wheels on the guiding rail, expressed in millimetres (mm); (see Figure 2.8)

b is the width of the rail head, expressed in millimetres (mm)

x is the track clearance between the rail and the guidance means (lateral slip including lateral float at wheels), expressed in millimetres (mm)

Y is the wear of the rail and the guidance means, expressed in millimetres (mm)

α_0 is the tolerances of wheel and rail directions

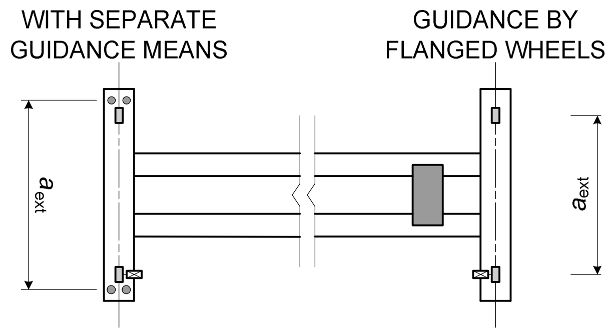


Figure 2.8 Definition of α_{ext}

Wheels are considered either independent or coupled and either fixed or movable. Independent wheels are not coupled in any way with the wheels on the opposite end carriage whereas coupled wheels are coupled either electrically or mechanically. Movable wheels allow lateral displacement of the wheels along the axle and fixed wheels cannot move laterally. In order to determine the appropriate force factor, the wheel configuration of the crane under consideration needs to be taken into account. However manufacturers in South Africa determined that it is current practice to use only independent, fixed, fixed wheels therefore only the force factors relating to this wheel configuration were incorporated into SANS 10160-6:2010 (Dunaiski & Retief, 2009). As a result the longitudinal force factor $\lambda_{s,i,j,L}$ equals 0, and thus $H_{s,i,j,L}$ equals 0.

(c) *Misalignment*

The misalignment model used in SANS 10160-6:2010 is graphically depicted in Figure 2.9 and calculated using Equation 2.19.

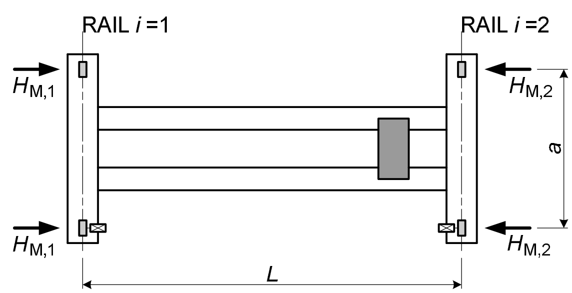


Figure 2.9 Loads due to misalignment of crane wheels

$$H_{M,i} = \frac{\mu_m (Q_{br} + Q_{cr} + Q_h)}{n_w} \tag{2.19}$$

Where:

μ_m is the factor that depends on the hoisting class (class of the crane) and are given in Table 2.6

n_w is the number of wheels on the crane

Q_{cr} is the weight of the crab

Q_{br} is the weight of the bridge

Q_h is the weight of the hoist load

Table 2.6 Factors μ_m

Hoisting class	μ_M
C1	0,05
C2	0,12
C3	0,15
C4	0.20

The cause of misalignment could either be due to the misalignment of the crane wheels in a 'toe –in' or 'toe out' manner or misalignment of the gantry rails which causes transverse forces on each side of the crane tending to either pull the rails together or push them apart (Dymond, 2005).

(d) *Acceleration or deceleration of the crab*

This load situation occurs when the crab runs into the end stops on the end of the crane bridge. Given the hoist load is free to swing, the SANS 10160-6:2010 specifies that the total buffer force relating to crab movement shall be taken as 10% of the weight of the crab and hoist load. Figure 2.10 and Equation 2.20 shows the load model introduced into the SANS 10160-6:2010 for acceleration or braking of the crab as a regular, frequently occurring load.

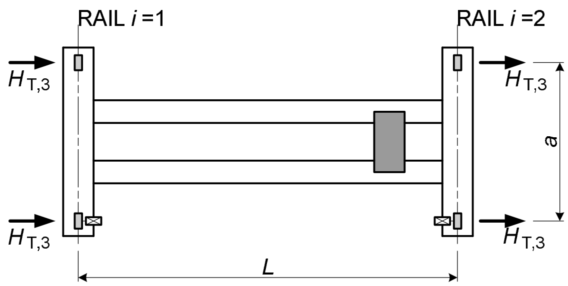


Figure 2.10 Loads due to the acceleration or deceleration of crab

$$H_{T,3} = \frac{0.10(Q_{cr}+Q_h)}{n_w} \tag{2.20}$$

Where n_w is the number of wheels on the crane.

(e) *Horizontal loads caused by test loads*

The load test is done with a load equal to 110% of the safe working load. The purpose of this is to verify the safe working condition of the crane mechanisms and brakes. During the dynamic load test procedure the crane is controlled in the manner in which it will normally operate. With the vertical load test the load is lifted in the centre of the bridge and not next to an end carriage therefore the dynamic test load is the critical load test for the support structure (Dunaiski & Retief, 2009).

The horizontal loads as a result of the test loads are determined in the similar manner as discussed in section 2.2.3.2 (a) above, the only difference being that Q_h is replaced by the dynamic test load Q_T.

(f) *Buffer forces related to crane movement*

Buffer forces as a result of the crane running into the end stops at the extreme of its travel on the gantry is considered an accidental crane action, because most cranes are equipped with limit switches which automatically slow and stop the crab before the end of its travel. An impact would therefore only occur in the event of failure of the limit switches (Dunaiski & Retief, 2009). SANS 10160-6:2010 suggest the buffer forces to be calculated by considering the kinetic energy from all relevant parts of the crane moving at 70% - 100% of the long travel speed taking into account the distribution of mass and the buffer characteristics of the buffer provided at the end stops. The buffer force is multiplied with the dynamic factor φ_7 to account for the dynamic effects. The load model suggested by SANS 10160-6:2010 is given by Figure 2.11 and Equation 2.21.

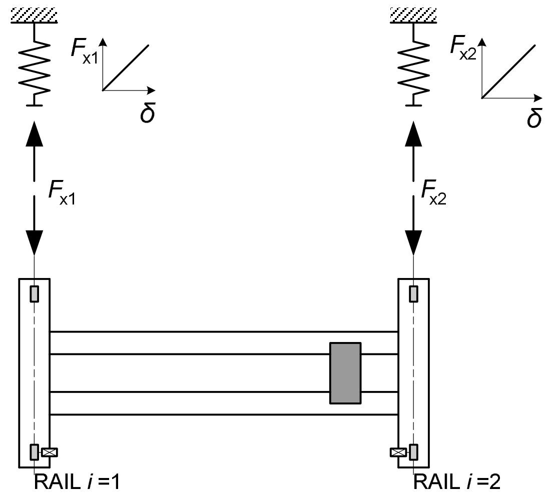


Figure 2.11 End Stop buffer forces

$$H_{B,i} = \varphi_7 v_l \sqrt{m_c s_B} \tag{2.21}$$

Where:

φ_7 is the dynamic factor which depends on the non linearity of the of the end buffer, determined according to Table 2.3

v_l 70% of the long travel speed of the crane

m_c the total mass of the crane and the hoist load

s_B is the spring constant of the buffer in [N/m]

Chapter 3

3 Program Architecture

A two-level or two tier approach was used to design the crane load application. Each layer serves its own unique purpose. The first layer is known as the Presentation layer. The objects in this layer are responsible for all the direct interaction with the user. Java Swing and NetBeans were used to create the necessary objects in this layer for the graphical user interface (GUI). The second layer is the Logic layer. The objects in this layer represent the core of the program. For example, in this layer each horizontal crane load model is represented by an object and each object is responsible for applying the necessary algorithms to determine the respective longitudinal and horizontal loads required for the design of the crane support structure.

The entities that make up the two layers mentioned above namely the Presentation layer and the Logic layer will be described in more detail in section 3.1 and section 3.2, respectively.

Under section 1.3.3 it was stated that Java was used as programming language where an object oriented programming approach was adopted. Java is inherently object-oriented; this implies that Java programs are made up of programming elements referred to as objects. An object is a programming entity that represents either some real world object or an abstract concept. Usually an object-oriented program (OOP) is a group of objects that function together to achieve the required outcome, but in some cases an OOP may only be one object.

3.1 GUI Architecture

The components that make up the user interface are discussed in this section. The source code needed to generate these components and the design pattern followed will not be discussed in this section, but is covered in detail in Annex A.

The user interface comprises 3 tabs, namely the Project Information tab, the Input tab and the Output tab.

3.1.1 *The Project Information Tab*

The Project Information tab allows the user to enter specific information about the project. This information will appear on the calculation sheets and is important for future referencing.

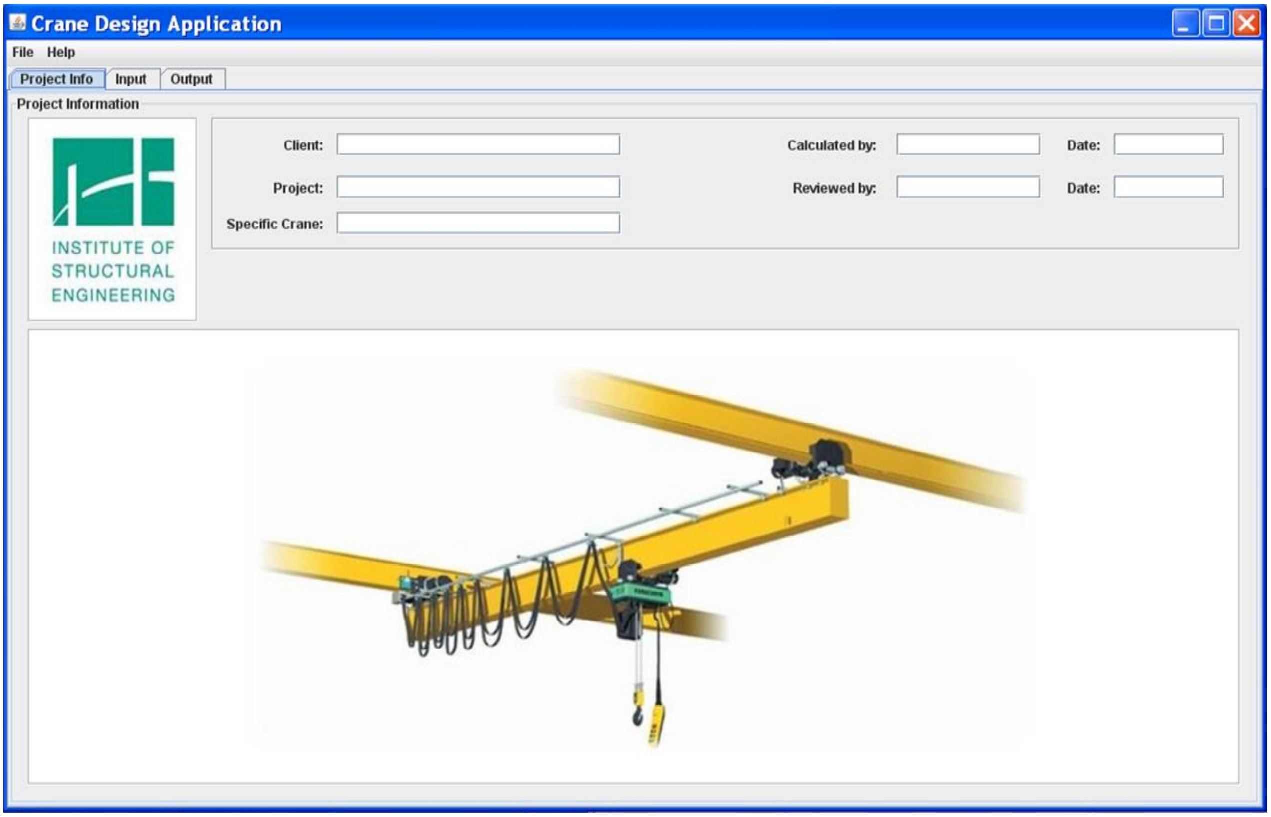


Figure 3.1 Project Information Panel

The information required is:

- The name of the client.
- The name of the project
- The specific crane under consideration
- The name of the person who did the calculations
- The date these calculations were done
- The name of the person who reviewed the calculations
- The date the calculations were reviewed

3.1.2 *The Input Tab*

The Input tab is made up of the Input Panel and the Progress Panel. These are discussed below.

3.1.2.1 Input Panel

The Input Panel consists of seven sub panels which serve as an interface for the user to enter specific information about the EOHTC in order to determine the loads required for the design of the support structure. These sub panels are discussed below.

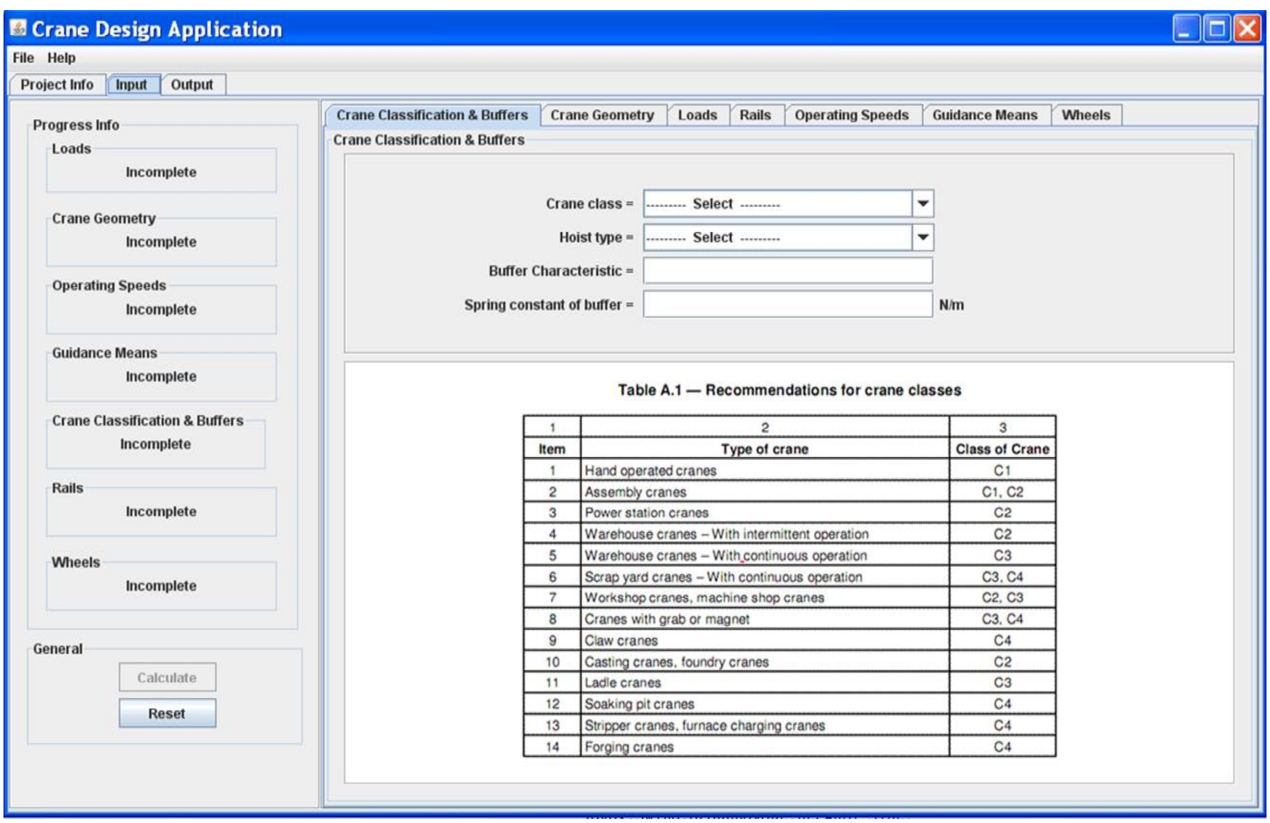
(a) *Crane classification and buffers panel*

This panel requires the user to enter the crane class, hoist type and buffer characteristic. A selection can be made from 4 crane classes, based on the type of crane. A table is shown at the bottom of the pane, which is a duplicate of table A.1 in annex A of SANS 10160-6:2010, Table A.1 is added to assist in selecting the right crane class, provided this information is not already given by the crane supplier.

A choice of 3 hoisting mechanisms is given to select from, namely a hook, a grab or a magnet. This information should also be available from the crane supplier.

The buffer characteristic represents the non-linearity behaviour of the buffer at the end stops. The crane supplier should be able to supply information on what buffer type is being used on the crane and its buffer characteristic which is generally expressed as a fraction.

The spring constant of the buffer is used to determine the buffer impact forces as a result of the movement of the crane. This parameter must be by the user from specific graphs supplied by the crane manufacturer. Once the spring constant for the buffer has been determined, it can be entered into the text field provided on the input panel.



1	2	3
Item	Type of crane	Class of Crane
1	Hand operated cranes	C1
2	Assembly cranes	C1, C2
3	Power station cranes	C2
4	Warehouse cranes – With intermittent operation	C2
5	Warehouse cranes – With continuous operation	C3
6	Scrap yard cranes – With continuous operation	C3, C4
7	Workshop cranes, machine shop cranes	C2, C3
8	Cranes with grab or magnet	C3, C4
9	Claw cranes	C4
10	Casting cranes, foundry cranes	C2
11	Ladle cranes	C3
12	Soaking pit cranes	C4
13	Stripper cranes, furnace charging cranes	C4
14	Forging cranes	C4

Figure 3.2 Crane Classification Input Panel

(b) *Crane geometry panel*

Two dimensions of the crane are important for the vertical load model. These are the span of the crane bridge and the minimum distance between the hoist and the rail. These two parameters need specification on the 'Crane Geometry Panel'. A sketch is given at the bottom of the panel to graphically show the two dimensions required.

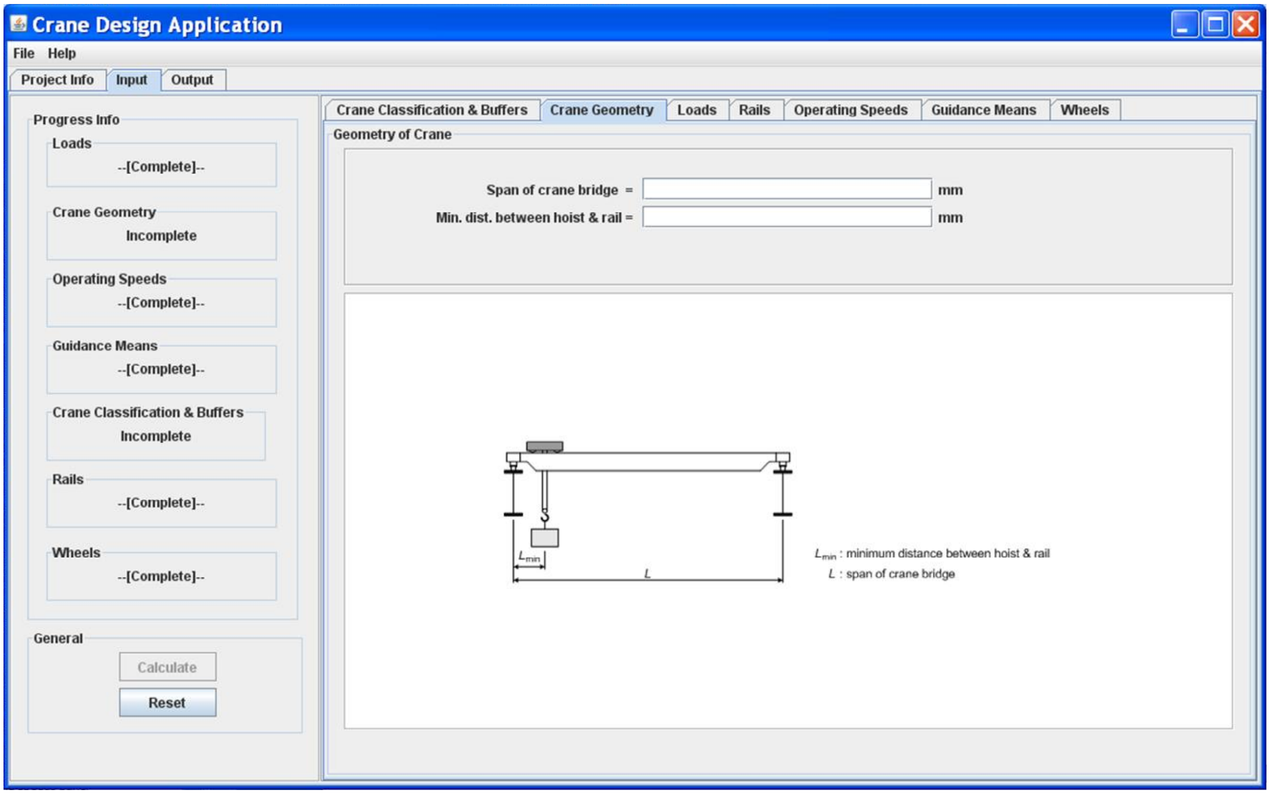


Figure 3.3 Crane Geometry Panel

(c) *Loads panel*

The weight of the crane bridge, the weight of the crab and the weight of the hoist load need to be specified on this panel. A fourth entry namely the retained part of the hoist load also needs to be given, but this is only applicable when hoisting devices such as grabs or magnets are used, where a certain portion of the hoist load is dropped. Therefore the user should specify.

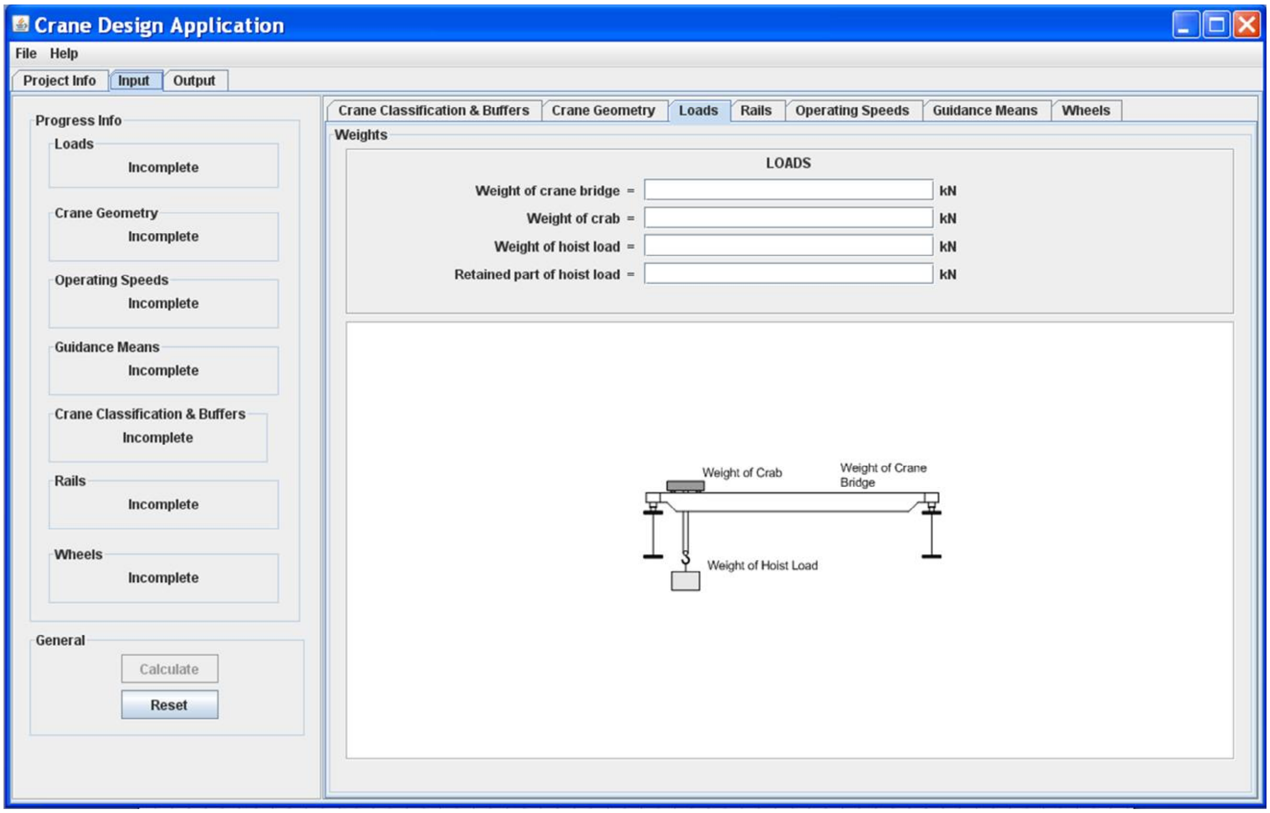


Figure 3.4 Loads Input Panel

(d) *Rails panel*

The rail dimensions are used for calculating the friction factor f; see section 2.2.3.2(b). The rail dimensions are also use to determine φ4 according to the elasto kinetic model described in Annex B of SANS 10160-6:2010 if the rail tolerances as specified in SANS 2001 CSI are not observed. The top width of the rail and the height of the rail need to be specified on this panel. The height and the top width of the rail are graphically shown on a sketch situated at the bottom of rail panel.

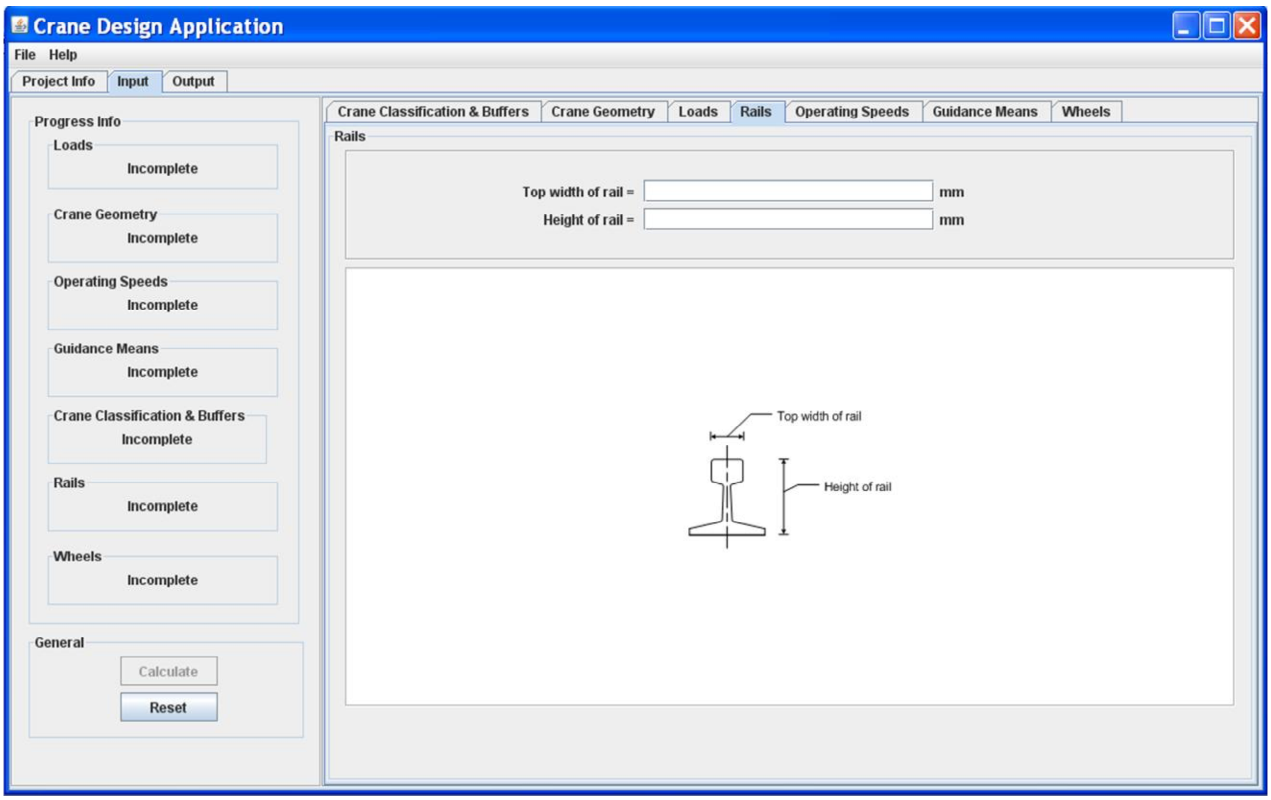


Figure 3.5 Rails Input Panel

(e) *Operating speeds panel*

Three operating speeds need to be entered by the user on this panel. These include the steady hoisting speed, the long travel speed, and the cross travel speed. The steady hoisting speed is required to calculate the value of the dynamic factor φ_2. A sketch is attached in the operating speeds panel for further clarity.

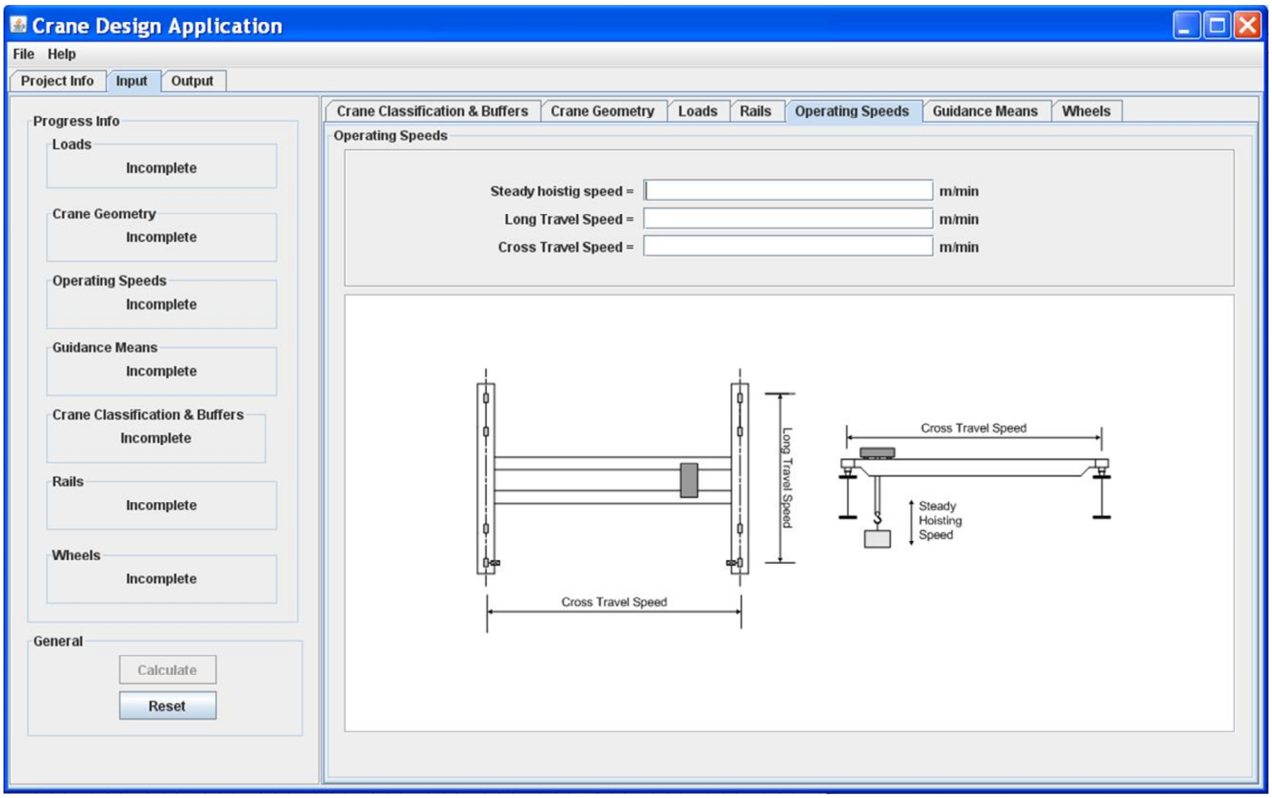


Figure 3.6 Operating Speeds Input Panel

(f) *Guidance means panel*

Guidance means refer to the way in which the crane is guided horizontally on the rails. The crane is guided by either the flanges of the crane wheels or by guide rollers. Flanged wheels are the most widely used form of guidance means, whereas guide rollers are typically used in buildings housing furnaces where one rail is close to the furnace. The heat from the furnace my cause the rail to deform, making it unsuitable for flanged wheels (Dymond, 2005).

The user is posed with the option to specify whether separate guidance means such as guide rollers are used. This is done by selecting either 'yes' or 'no'. If 'no' is selected it implies that no separate guidance means are used, therefore by default it is assumed that the wheel flanges serve as guidance means. However if separate guidance means are used the user is required to enter the spacing of the outer guidance means a_{ext}. On the Guidance means panel this parameter is referred to as the guidance spacing.

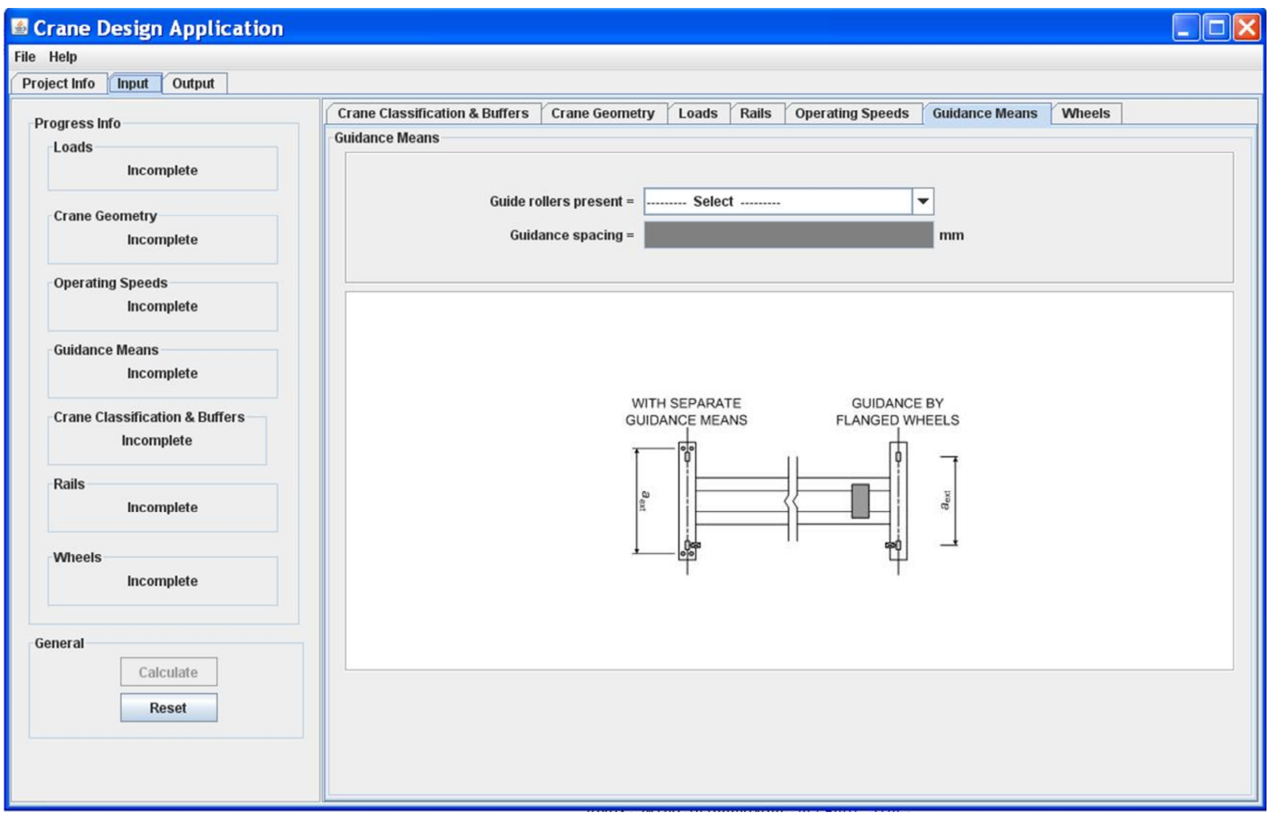


Figure 3.7 Guidance Means Input Panel

(g) *Wheels panel*

This panel encapsulates the information needed for the crane wheels and their configuration. The first parameter to specify is the number of single wheel drives. This can be any even number from 2 to 8, but naturally the number of wheel pairs need to be considered when specifying the number of wheel drives used.

The second parameter to enter is the behaviour of the wheel drives. The user can select from four options namely backlash, centrifugal, sudden or smooth. These four options are extracted from Table 6 in SANS 10160-6:2010. This parameter is required to determine the dynamic factor $\varphi_{5,}$ and is shown in Table 2.2 in this document. As mentioned before in section 2.2.1, the dynamic factor φ_5 depend on the smoothness of change of the drive forces.

The clearance between the rail and the guidance means refers to the clear space between the guide means (typically the wheel flange) and the side of the rail. This distance influences the skewing angle of the crane, required for the calculation of the friction factor as explained in section 2.2.3.2(b) (Dymond, 2005). This value also needs to be specified on this panel.

The user is asked to enter the wheel diameter. This value is used to determine the dynamic factor φ_4, for the situation where the rail tolerances as laid out by SANS 2001 CSI are observed. However one of the assumptions this application is based on, is that the necessary rail tolerances are observed. Therefore the wheel diameter is not used in any of the calculations to determine the crane loads. It is merely included for completion purposes and for expansion purposes; if this application needs to be expanded to incorporate the situation where rail tolerances are not observed.

The last set of parameters refers to the wheel configuration of the crane. At first the number of wheel pairs must be specified. A choice of 3 is provided, namely 2, 4 and 8 wheel pairs. This would refer to a 4, 8 or 16 wheel crane, respectively. The last set of values namely the ‘e’ values specifies the spacing of these wheel pairs. These are e_j, for j = 1 to 8 (the number if wheel pairs). A sketch is provided on this panel to explain what is meant by the e_j values.

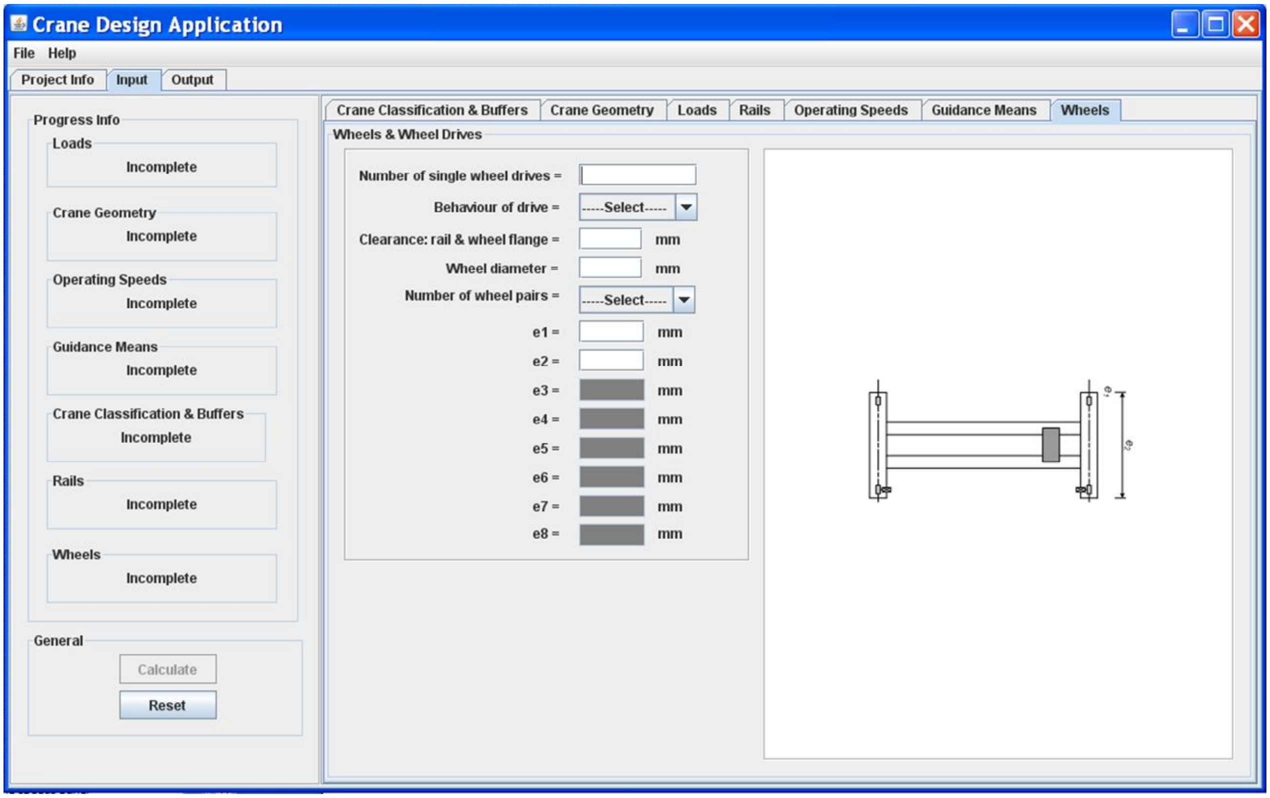


Figure 3.8 Wheels Input Panel

3.1.2.2 The Progress Panel

The Progress panel aids the user in monitoring whether all the parameters are filled in on the Input panel.

The sub panels on the Input panel constantly check to see if all the parameters are filled in on them. Once all the parameters are filled in on a specific sub input panel, the progress panel is informed that this sub panel is filled in completely. The progress panel then flags the sub panel in question as complete and displays the word ‘completed’ for this sub panel. Once all the sub input panels are flagged as complete, the ‘Calculate’ button is set active on the progress panel.

Once the calculate button is pressed the vertical and horizontal loads are displayed on the various output panels on the output tab.

3.1.3 *The Output Tab*

The output tab consists of eight panels to display the crane load information and the various crane induced loads for the design of the support structure. The panels are:

- The Dynamic Factor Panel – displays all the dynamic factors required for the determination of the crane loads.

- The Vertical Loads Tab - displays all the vertical loads as discussed in section 2.2.3.1
- The Crane Bridge Panel – displays the loads that result from the acceleration and deceleration of the crane bridge.
- The Skewing Panel – displays all the loads that result from the crane skewing in plan.
- The Crab Loads Panel – displays the loads that result from the acceleration and deceleration of the crab.
- The Misalignment Panel – displays all the loads that result from the misalignment of the crane wheels or the gantry rails.
- The Test Loads Panel – displays the horizontal loads that result from the crane load test.
- The Buffer Loads Panel – displays the buffer forces as a result of the crane movement

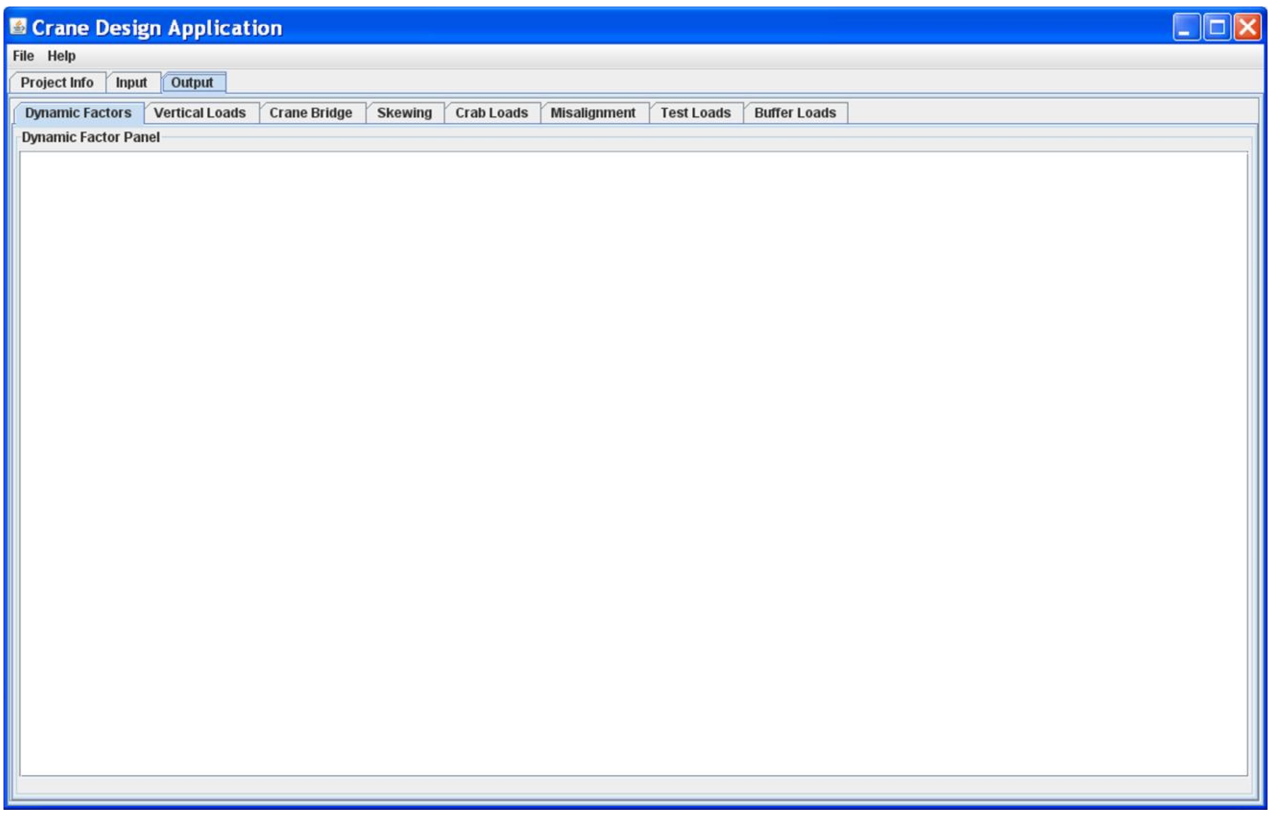


Figure 3.9 Output Panels

3.2 Algorithm Architecture

This section explains how the crane loads are calculated by briefly looking at the algorithms used with minimal reference to the source code. A more in depth explanation of the algorithm architecture can be found in Annex A.

3.2.4 *Static Vertical Wheel Loads*

Both the minimum and maximum static wheel loads are calculated using the vertical load model as explained in section 2.2.3.1. The adjective static is used to imply that the un-factored vertical loads (the vertical loads without the dynamic factors) are used and the system is considered to be in equilibrium and not moving. Stated differently; the system is in static equilibrium. The maximum static vertical wheel loads calculated are $Q_{r,max}$ and $Q_{r,(max)}$, whereas the minimum static vertical wheel loads calculated are $Q_{r,min}$ and $Q_{r,(min)}$.

3.2.5 *Dynamic Vertical Wheel Loads*

Dynamic vertical wheel loads are a result of hoisting the payload off the ground, the sudden release of part of the hoist load, the crane travelling on uneven rails or any combination thereof. Vertical loads as a result of the vertical load test are also calculated. These loads are calculated using the load models discussed in section 2.2.3.1above.

3.2.6 *Horizontal Loads*

3.2.6.1 Acceleration or deceleration of the crane

The horizontal loads caused by the acceleration or deceleration of the crane are calculated using the guidelines given in SANS 10160-6:2010 and as explained in section 2.2.3.2(a).

With reference to Figure 2.5 and Figure 2.6 $H_{L,i}$ is calculated using Equation 3.1.

$$H_{L,i} = \varphi_5 K \frac{1}{n_r} = K_1 = K_2 \qquad (3.1)$$

Where:

n_r is the number of rails. In the crane load application n_r is always taken as 2.

i is either 1 or 2.

K equals $\mu \times \Sigma Q^{*}_{r,min}$

μ is the fiction factor: 0.2 for steel wheels on steel rails

0.5 for rubber wheels on steel rails

However under section 1.3.4.3 it was assumed that only cranes with steel wheels will be considered, thus μ = 0.2.

The model used in the SANS 10160-6:2010 for acceleration or deceleration of the crab is specific to four wheel cranes only. In order to accommodate eight and sixteen wheel cranes in the crane load application the four wheel crane model was extrapolated to eight and sixteen wheel cranes.

SANS 10160-6:2010 recommends the horizontal transverse force for wheel pair 1 and wheel pair 2 as a result of the acceleration or deceleration of the crane to be determined as shown in Equation 3.2 and Equation 3.3 respectively, given the load condition as depicted in Figure 3.10.

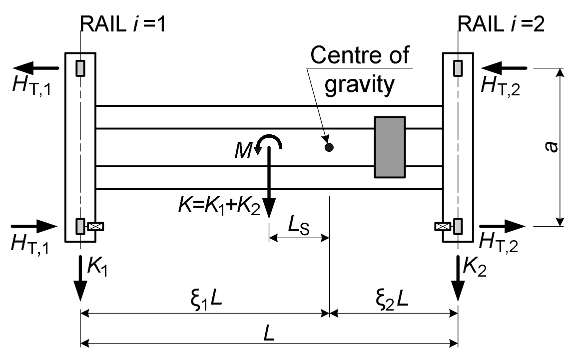


Figure 3.10 Load configuration for the acceleration or deceleration of crane

$$H_{T,1} = \varphi_5 \xi_2 \frac{M}{a} \tag{3.2}$$

$$H_{T,2} = \varphi_5 \xi_1 \frac{M}{a} \tag{3.3}$$

For the explanation that follows below the following notation is adopted.

Horizontal transverse forces $H_{T,i,j}$

Where:

i the rail, either 1 or 2

j the wheel pair

Equation 3.2 can be rewritten as $H_{T,1} \times a = \varphi_5 \xi_2 M$. From this it can be seen that this is an expression for a couple force set; force multiplied by a lever arm equals a moment. With this in mind and with the load scenario depicted in Figure 3.11, Equation 3.4 takes precedence for rail 1.

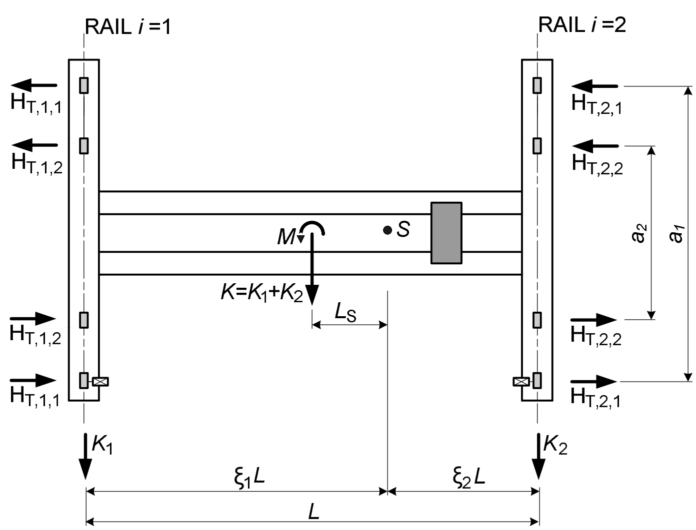


Figure 3.11 Horizontal transverse forces as a result of the acceleration or deceleration of the crane

$$H_{T,1,1} \times a_1 + H_{T,1,2} \times a_2 = \xi_2 M \tag{3.4}$$

Assume a rigid end carriage as seen in plan-view. A linear relation between $H_{T,1,1}$ and $H_{T,1,2}$ can be established resulting in the expression given by Equation 3.5.

$$\frac{H_{T,1,1}}{\left(\frac{a_1}{2}\right)} = \frac{H_{T,1,2}}{\left(\frac{a_2}{2}\right)} \tag{3.5}$$

Equation 3.5 can be rewritten to give the expression in Equation 3.6 and substituting it into Equation 3.4, Equation 3.7 is obtained, which when simplified gives an expression for $H_{T,1,1}$ as seen in Equation 3.8

$$H_{T,1,2} = \frac{a_2}{a_1}\left(H_{T,1,1}\right) \tag{3.6}$$

$$H_{T,1,1}(a_1) + \left(\frac{a_2}{a_1}\left(H_{T,1,1}\right)\right)(a_2) = \xi_2 M \tag{3.7}$$

$$H_{T,1,1} = \left(\frac{a_1}{a_1^2+a_2^2}\right)\xi_2 M \tag{3.8}$$

Furthermore, substituting Equation 3.8 into Equation 3.6 an expression $H_{T,1,2}$ is obtained as seen in Equation 3.9

$$H_{T,1,2} = \frac{a_2}{a_1}\left(\left(\frac{a_1}{a_1^2+a_2^2}\right)\xi_2 M\right) = \left(\frac{a_2}{a_1^2+a_2^2}\right)\xi_2 M \tag{3.9}$$

For rail 2 the same reasoning and procedure is followed to obtain $H_{T,2,1}$ and $H_{T,2,2}$.

$$H_{T,2,1}(a_1) + H_{T,2,2}(a_2) = \xi_1 M \tag{3.10}$$

Assume a rigid end carriage as seen in plan-view. Therefore Equation 3.11 and Equation 3.12 holds true.

$$\frac{H_{T,2,1}}{\left(\frac{a_1}{2}\right)} = \frac{H_{T,2,2}}{\left(\frac{a_2}{2}\right)} \tag{3.11}$$

$$H_{T,2,2} = \frac{a_2}{a_1}\left(H_{T,2,1}\right) \tag{3.12}$$

Substituting Equation 3.12 into Equation 3.10 gives the expression for $H_{T,2,1}$ as seen in Equation 3.13.

$$H_{T,2,1} = \left(\frac{a_1}{a_1^2 + a_2^2}\right)\xi_1 M \tag{3.13}$$

Therefore to obtain the expression for $H_{T,2,2}$ substitute Equation 3.13 into Equation 3.12, refer to Equation 3.14

$$H_{T,2,2} = \frac{a_2}{a_1}\left[\left(\frac{a_1}{a_1^2 + a_2^2}\right)\xi_2 M\right] = \left(\frac{a_2}{a_1^2 + a_2^2}\right)\xi_1 M \tag{3.14}$$

The same argument and procedure is followed for a 16 wheel crane. The derivation of the formulae can be followed in Annex C.

3.2.6.2 Skewing of the crane in plan

The guidelines given in clause 5.7.4 of SANS 10160-6:2010 and as explained in section 2.2.3.2(b) are used to determine the longitudinal and transverse horizontal crane loads and the guide force as a result of skewing of the crane in plan.

3.2.6.3 Misalignment

Misalignment of the crane's wheels or misalignment as a result of the rails is dealt with in accordance to the guidelines given in section 5.7.6 of SANS 10160-6:2010 and is discussed in section 2.2.3.2(c) in this document.

3.2.6.4 Acceleration or deceleration of the crab

Under section 1.3.4 one of the assumptions made for the crane load application was that the pay load is free to swing, thus eliminating situations of the crane tilting as a result of the pay load that is rigidly fixed. Therefore the loads due to the acceleration and deceleration of the crab are calculated according to the guidelines given in 5.12.2 of SANS 10160-6:2010. This load model is also discussed in section 2.2.3.2(d).

3.2.6.5 Horizontal Test Load

This load model is discussed in section 2.2.3.2(e) of this document and horizontal test loads are calculated according to the specifications laid out in SANS 10160-6:2010 under clause 5.10.

3.2.6.6 Buffer forces related to crane movement

The buffer forces as a result of the crane running into the end stops are calculated according to the model given in clause 5.12.1 of SANS 10160-6:2010. This model is discussed in section 2.2.3.2(f) of this document.

Chapter 4

4 Example – A systematic explanation for the use of the crane load application

In this chapter a step by step explanation is given on how the crane load application should be used in order to calculate the required crane loads for the design of the crane support structure. A good practice is to use the SANS 10160-6:2010 design code in conjunction with this application. The rest of the chapter contains screenshots of the Crane Load Application.

4.1 User Input

The user input is divided into two parts. The information about the project and the information required to determine the crane induced loads.

4.1.1 *Project Information*

Figure 4.1 shows the Project Information panel with which the user is welcomed when an instance of the application is run.

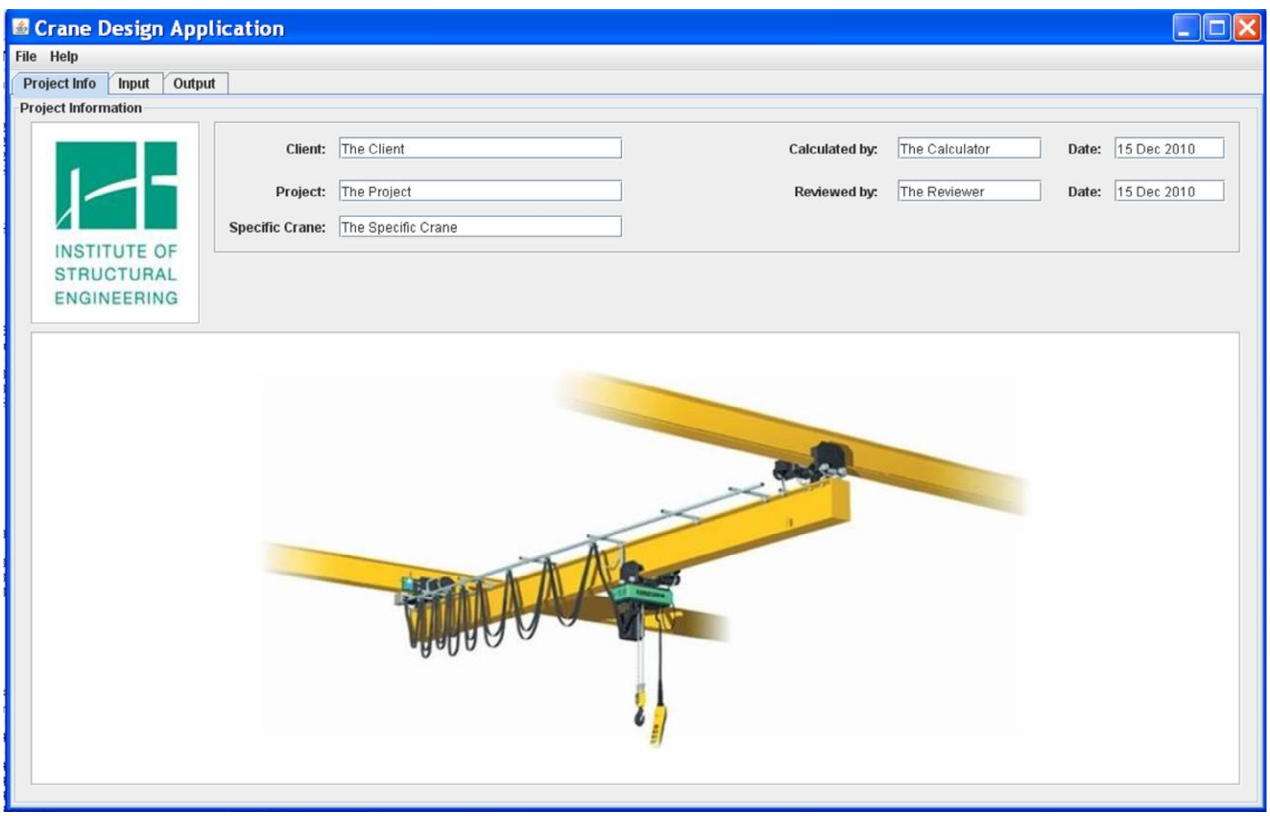


Figure 4.1 Project Information Panel

The following information needs to be entered into the fields:

- Client The name of the client

- Project The name of the project
- Specific crane The location where the crane will be installed
- Calculated by The name of the individual responsible for doing the calculations
- Reviewed by The name of the person who reviewed the calculations
- Date The day the calculations were done and the day it was reviewed.

4.1.2 *Crane Information*

The information required for the support structure design can be grouped into two parts, namely the information to calculate the loads and the information required to carry out the design of the crane support structure.

In practice the crane is only installed near the end of the construction phase of the building and the crane manufacturer is scheduled so as to be completed just before installation. This implies that the support structure is designed before the crane has been manufactured. However this scenario is more relevant to process cranes than standard cranes. Process cranes are custom made for a particular process and are typically the larger cranes. Standard cranes are manufactured by the crane producer and bought in an 'off shelf' manner. The crane parameters would therefore be available in advance. Of the cranes sold, 30% of them are process and 70% are standard cranes (Dymond, 2005). As a result, for 70% of cranes, the crane information would be readily available in advance.

Typical crane information obtained from the crane company is shown in Table 4.1. Assume crane loads need to be calculated for the crane described.

Table 4.1 Information from the crane manufacturer

Weights		
Weight of crane bridge	kN	298
Weight of crab	kN	98
Maximum hoist load	kN	400
Maximum vertical wheel load	kN	306
Minimum vertical wheel load	kN	78
Geometry of crane		
Span of crane bridge	mm	23800
Minimum distance between hoist and rail	mm	1650
Rail type		DIN A100
Width of top of rail	mm	100
Height of rail	mm	95
Speeds		
Steady hoisting speed	m/min	10
Long travel speed	m/min	50
Cross travel speed	m/min	40
Guide means		
Guide rollers present		no
Crane classification		
Class of crane		3
Type of hoist		hook
Hoist load free to swing		yes
Buffers		
Buffer type		hydraulic
Buffer characteristic		0.9
Wheels and wheel drives		
Type of wheel drive		single
Number of single wheel drives		2
Behaviour of drive		smooth
Combination of wheel pairs		IFF (1)
Clearance between rail and wheel flange	mm	25
Number of wheel pairs		2
Wheel spacing	mm	4400
Coefficient of friction		0.20
(1) IFF : *Independent, Fixed/Fixed*		

4.1.2.1 Crane Classification & Buffers

Here the crane needs to be classified and the buffer characteristic needs to be specified by the user.

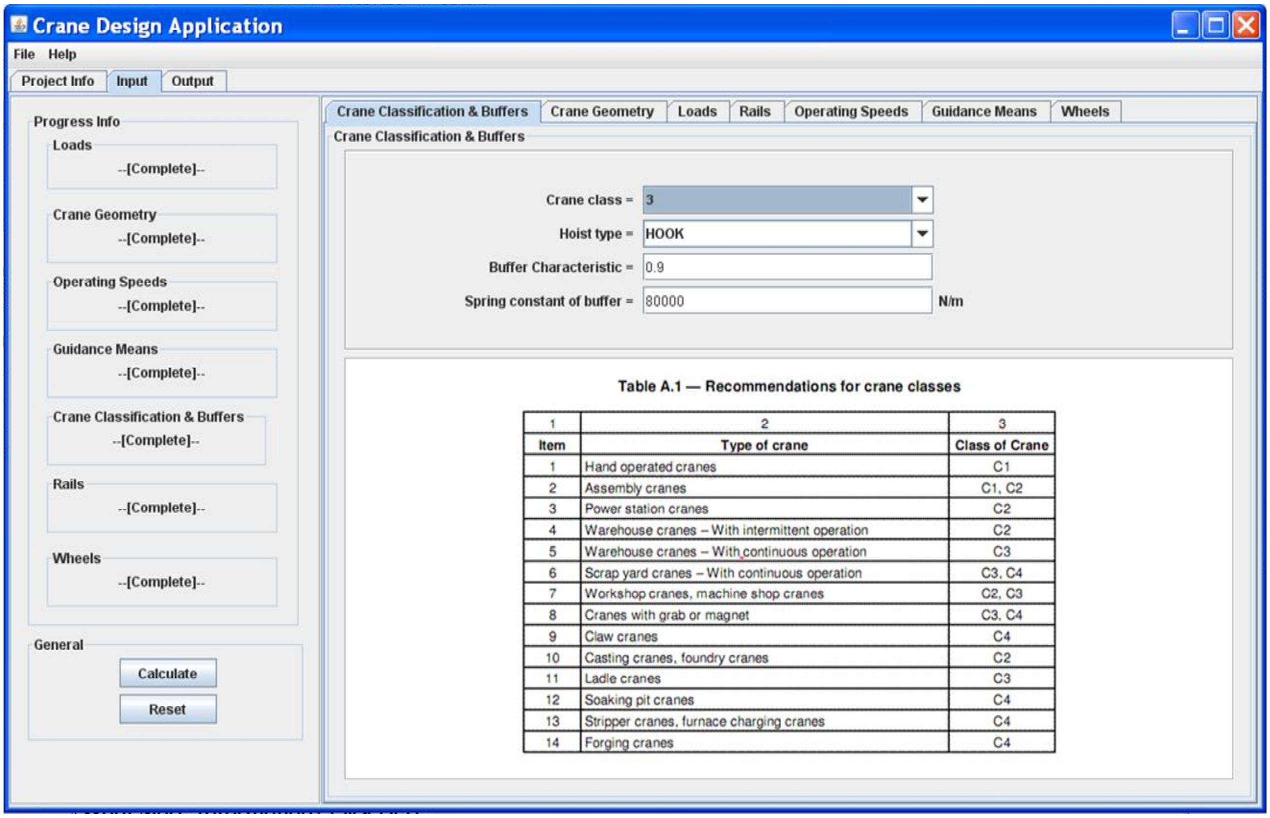


Figure 4.2 Crane Classification & Buffers

Parameters that are needed to entered are:

- Crane class 3
- Hoist type Hook
- Buffer Characteristic 0.9
- Spring constant of buffer 80000 N/m

Note that the word complete is displayed for the Crane Classification & Buffer panel, on the progress panel, which serves to indicate that all the input parameters are filled in correctly on the panel. The Calculate button is set inactive until all the information needed to carry out the crane load calculations are entered.

4.1.2.2 Crane Geometry

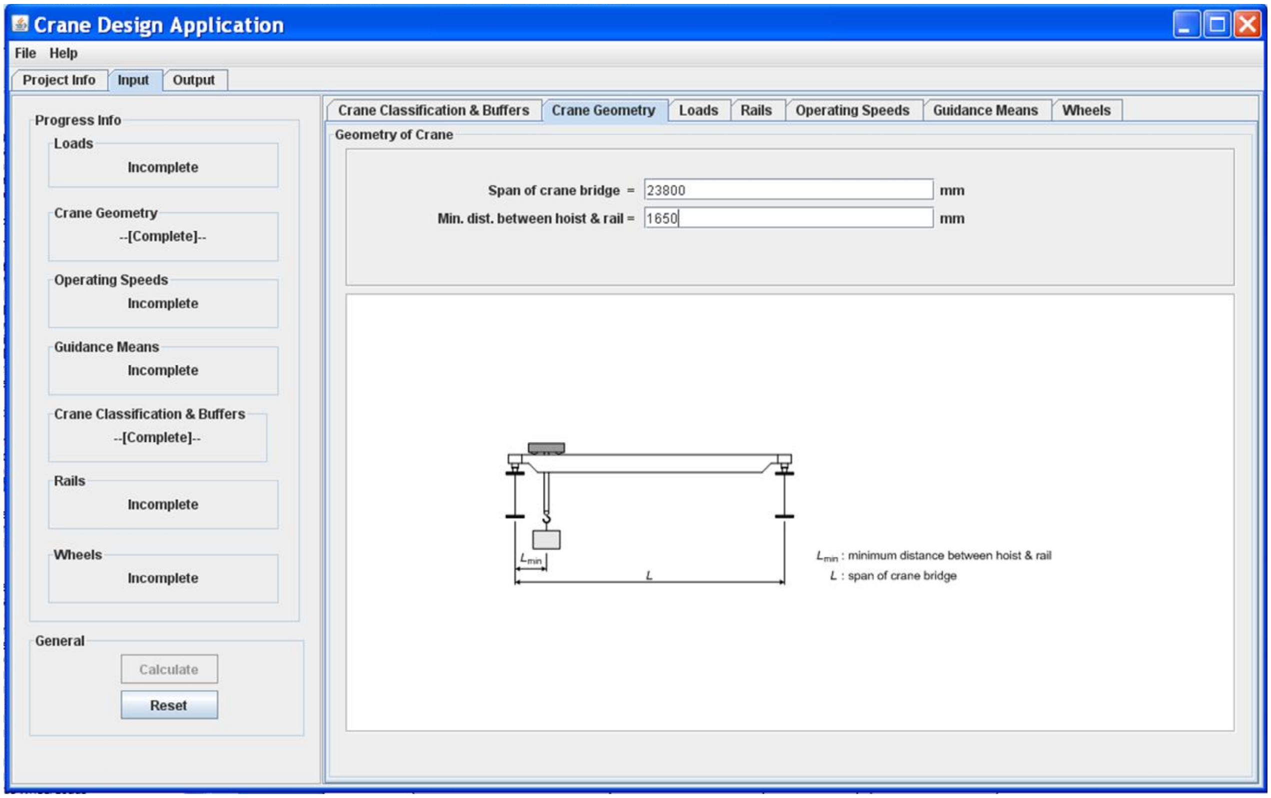


Figure 4.3 Crane Geometry

Figure 4,3 Shows the Crane Geometry Panel. The overall dimension in millimetres, needed for the calculation of the vertical loads needs specification on this panel. These are:

- Span of crane bridge 23800 mm
- Minimum distance between hoist & rail 1650 mm

The word 'Complete' is displayed for the Crane Geometry panel after all the parameters are filled in.

4.1.2.3 Loads

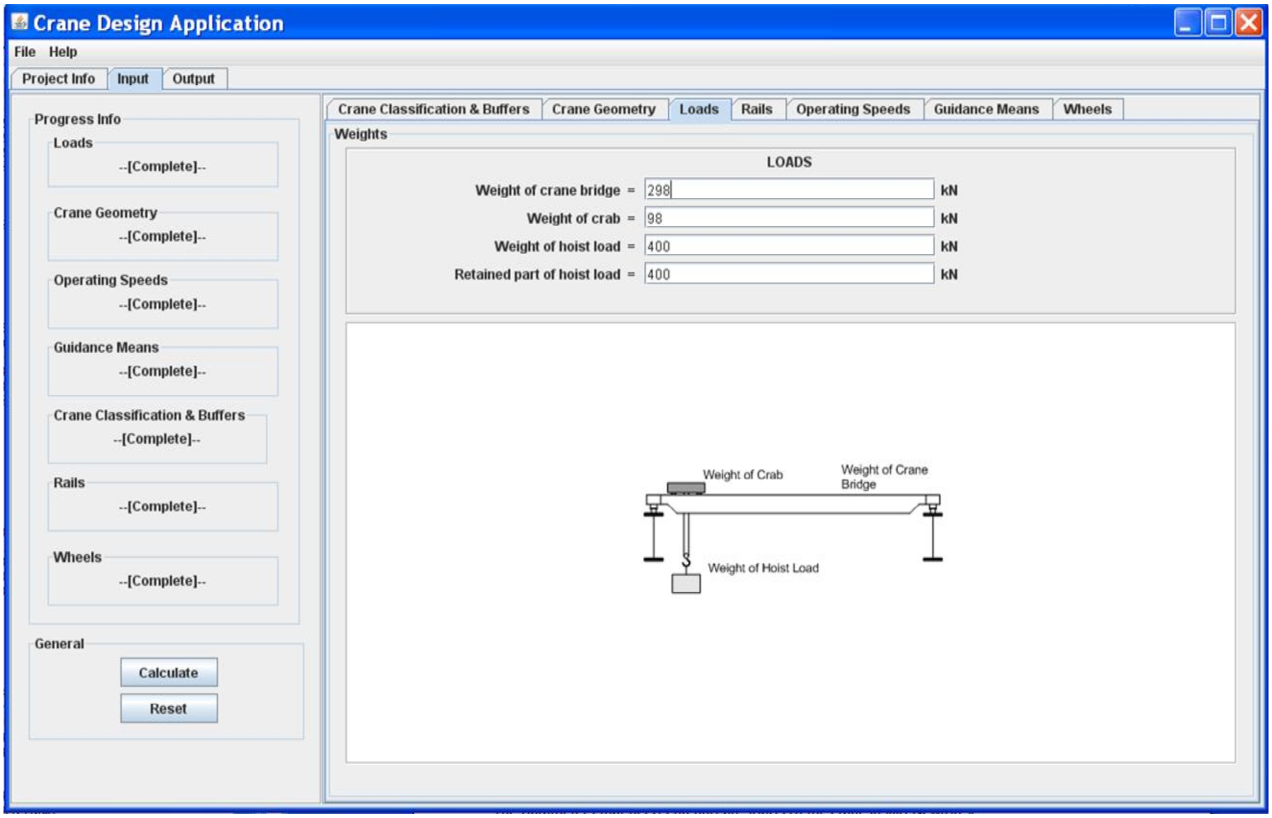


Figure 4.4 Loads Panel

The parameters that need entering are loads of the crane in kilo-Newton:

- Weight of the crane 298 kN
- Weight of the crab 98 kN
- Weight of the hoist load 400 kN
- Retained part of the hoist load 400 kN

The retained part of the hoist load is the same as the hoist load itself, thus implying no part of the hoist load was dropped, as would be the case for hoisting mechanisms such as grab and magnets.

4.1.2.4 Rails

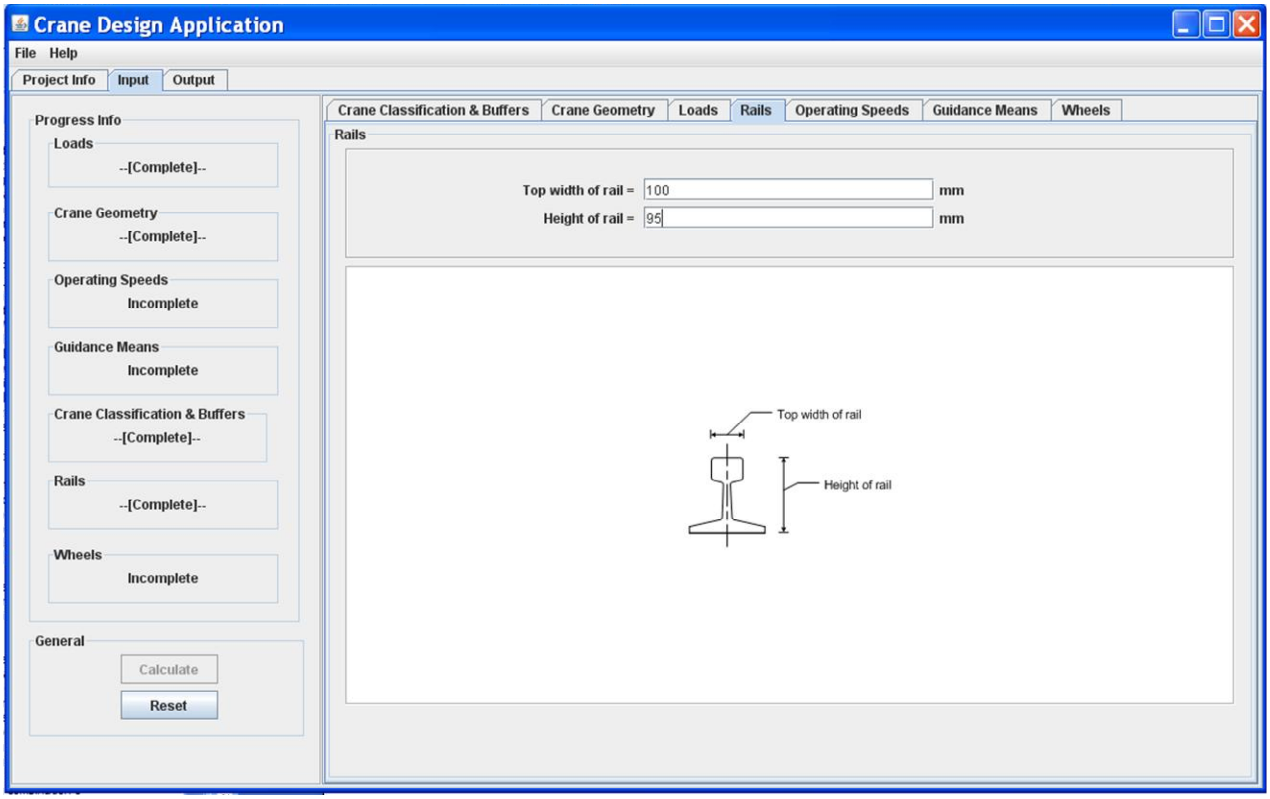


Figure 4.5 Rails Panel

A sketch for a South African manufactured rail is shown in the panel, together with certain dimensions of the rail that need to be entered for the use in the crane calculations.

The parameters that need to be entered from the crane suppliers crane information are:

- Top width of rail 100 mm
- Height of rail 95 mm

The Calculate button is still inactive and the word 'Complete' is displayed for the Rail panel as to show that all information needed on this panel are correctly entered.

4.1.2.5 Speeds

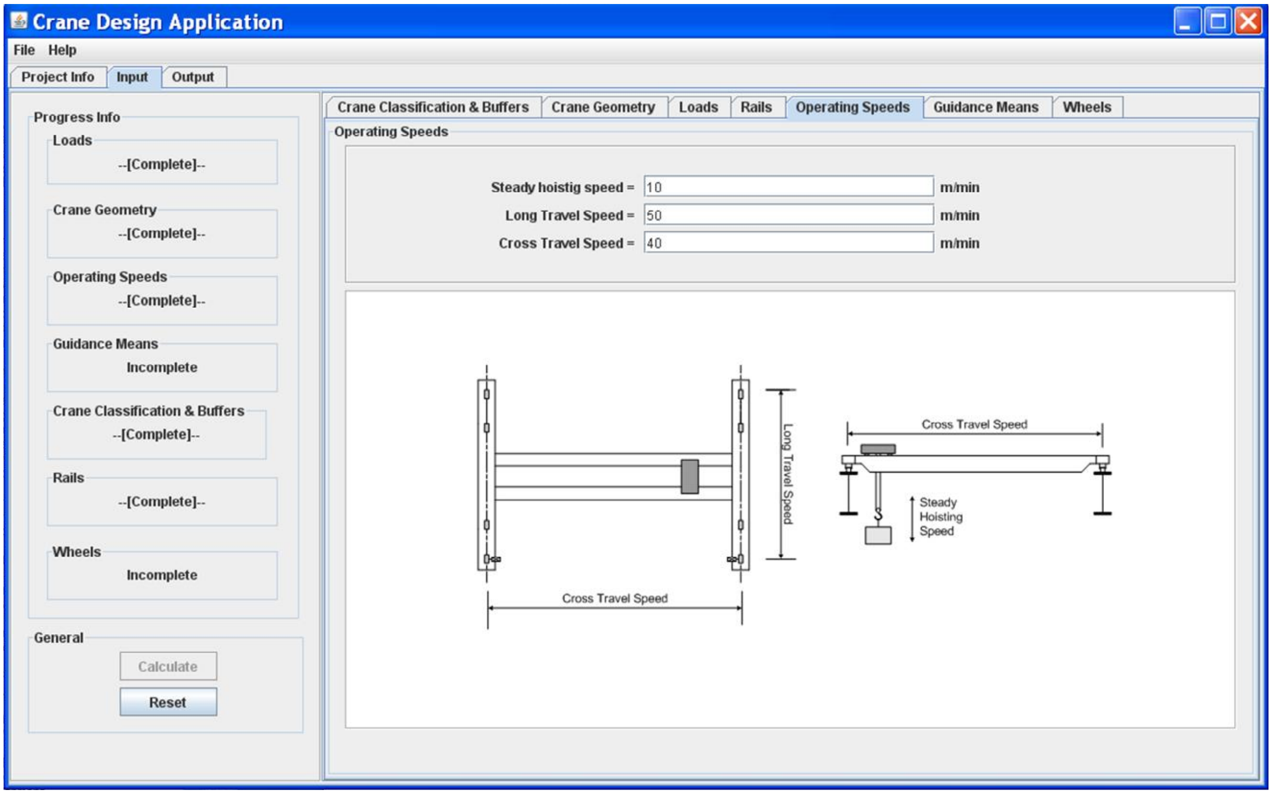


Figure 4.6 Operating Speeds Panel

Three speed parameters are required from the crane information. These are the:

- Steady hoisting speed 10 m/min
- Long travel speed 50 m/min
- Cross travel speed 40 m/min

A descriptive sketch is provided to aid the user in correctly entering what is required. The Calculation button is still inactive and the Progress panel indicates that the Speeds panel status is ‘Complete’.

4.1.2.6 Guidance Means

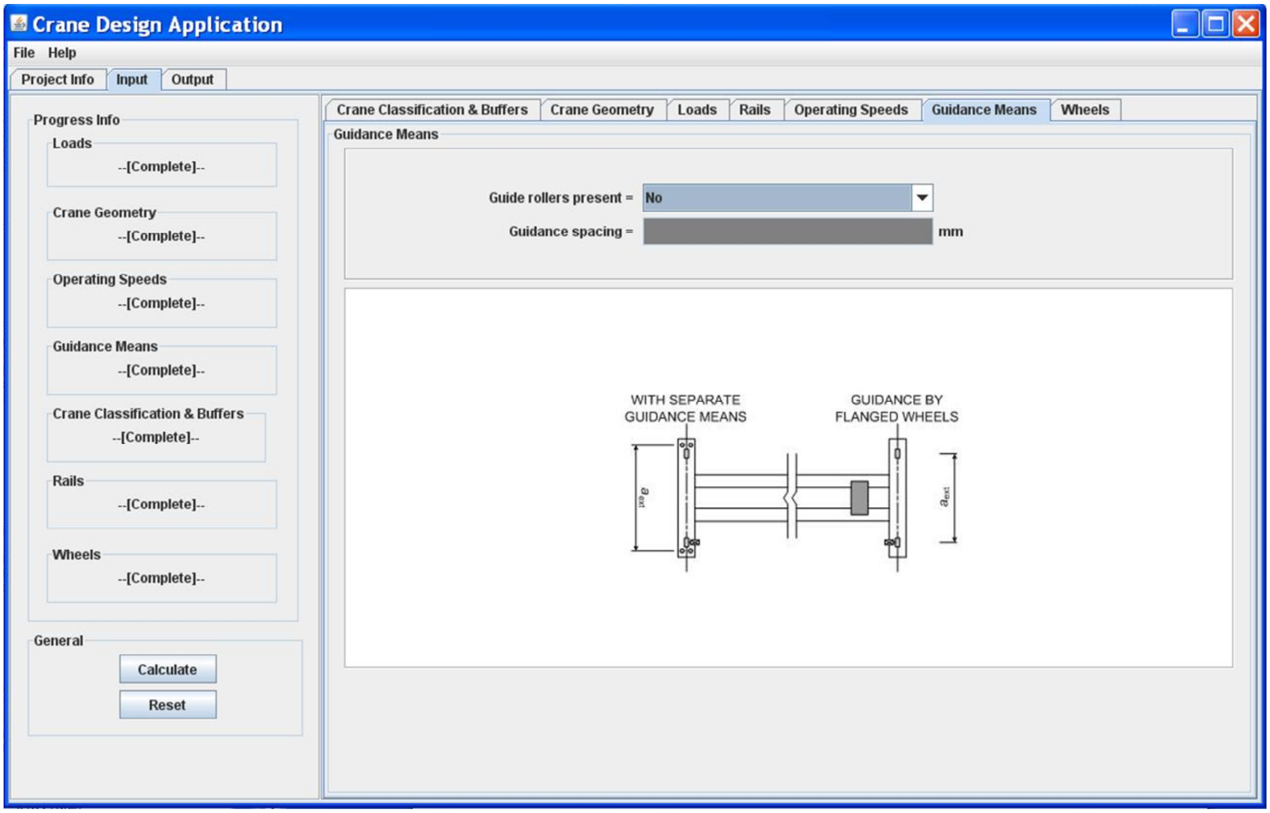


Figure 4.7 Guidance Means Panel

Two guidance means related parameters need to be specified on the Guidance Means panel as seen in Figure 4.7. These are:

- Guide rollers present No
- Guidance spacing Not applicable

When 'No' is selected to indicate the presence of guidance means, the Guidance Spacing text field automatically de activates; no user input is required. The assumption being that if no guidance means is provided the wheel flanges serve as guidance means.

4.1.2.7 Wheels

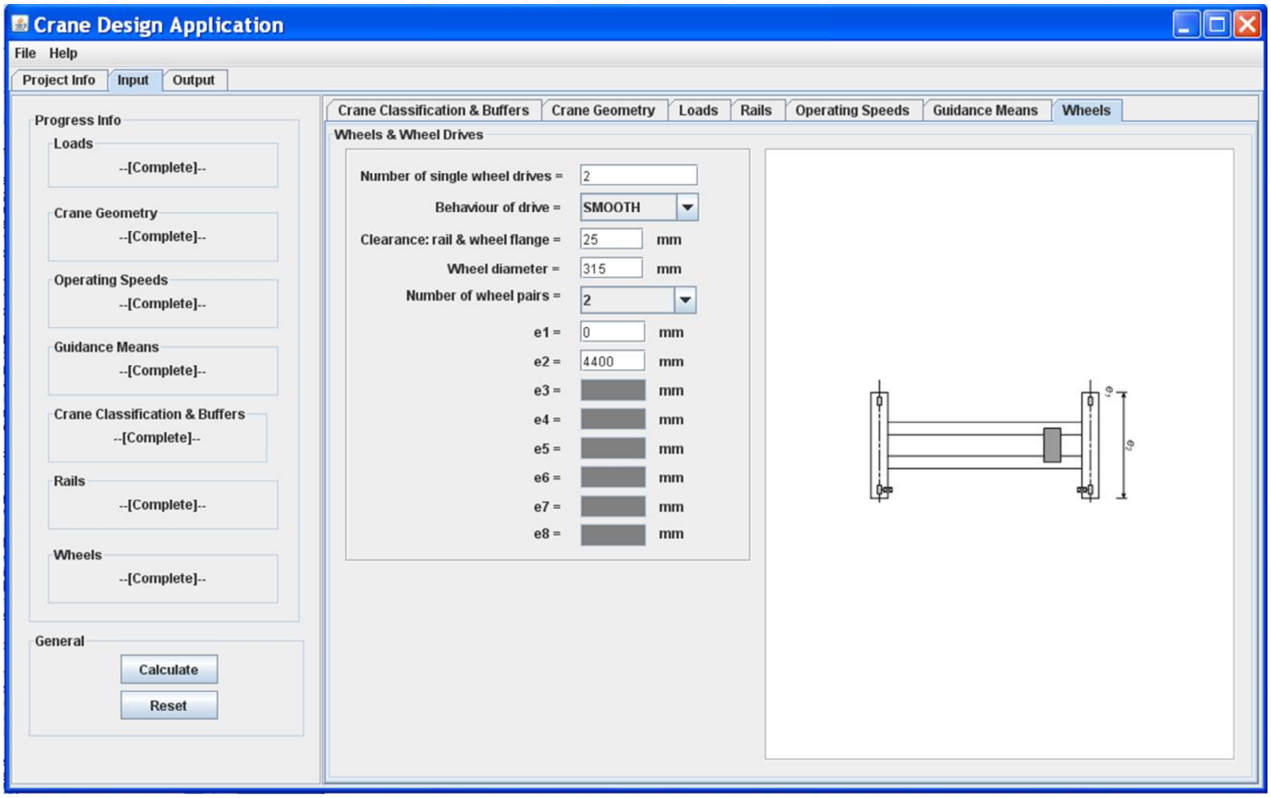


Figure 4.8 Wheels Panel

All information regarding the wheels and their configuration are specified on the Wheels panel as seen in Figure 4.8. The information specified is:

- Number if single wheel drives — 2
- Behaviour of drive — BACKLASH (refer to Table 6 of SANS 101060-6:2010)
- Clearance: between rail & wheel flange — 25 mm
- Wheel diameter — 315 mm
- Number of wheel pairs — 2
- e_1 — 0 mm
- e_2 — 4400 mm

A sketch is provided to explain the parameters e1 and e2. The progress panel displays ‘Complete’ for the wheels panel and it can be seen that the Calculate button is now active. Once pressed the required crane loads will be calculated and displayed in the various output panels.

4.2 Crane Loads Output

The crane loads and various other information that contribute to better explaining how the crane loads are calculated are displayed in several output panels on the output tab. These are explained in the sub sections that follow.

4.2.3 *Dynamic Factors*

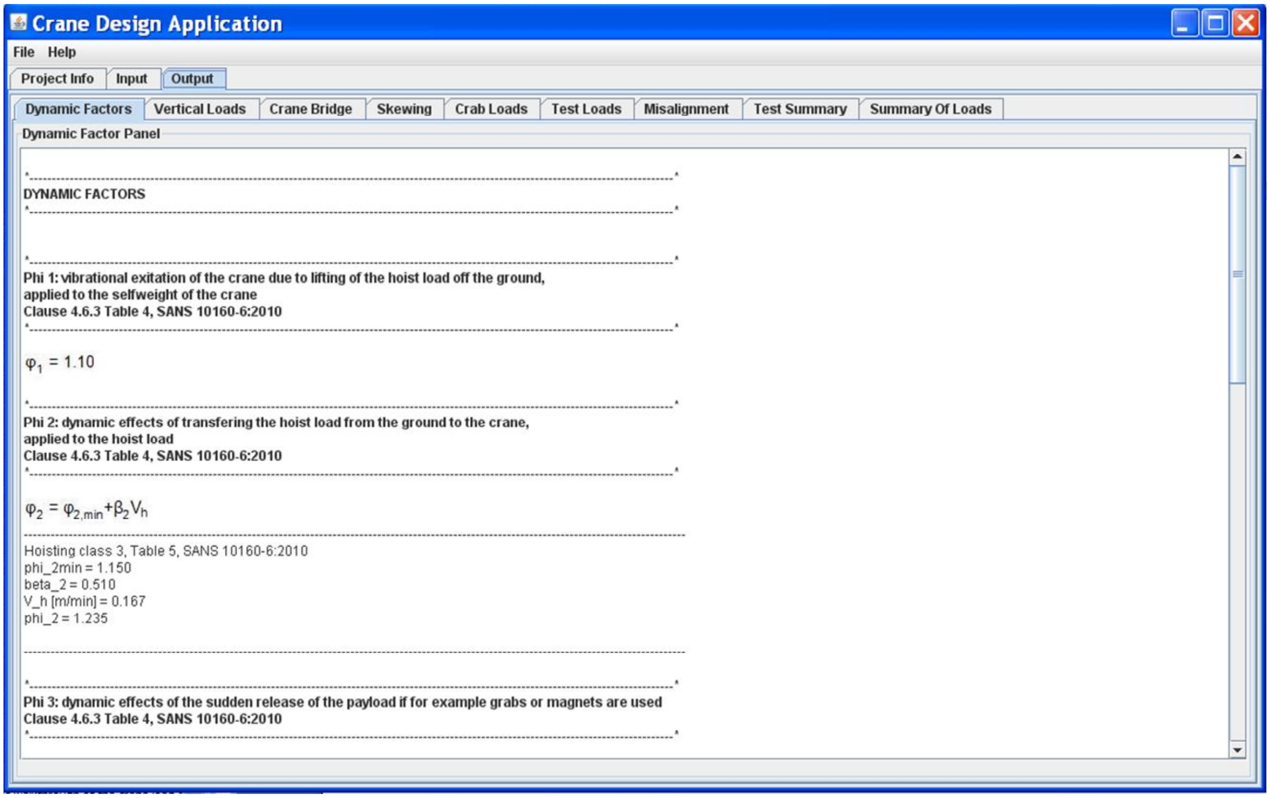


Figure 4.9 Dynamic Factor Panel

The seven dynamic factors are displayed in the Dynamic Factor panel as seen in Figure 4.9.

These dynamic factors calculated are as follows:

- φ_1 1.0
- φ_2 1.235
- φ_3 1.0
- φ_4 1.0
- φ_5 1.5
- $\varphi_{6,dyn}$ 1.118
- $\varphi_{6,stat}$ 1.0
- φ_7 1.53

φ_3 equals 1 as there is no part of the hoist load that was dropped. If this was not the case φ_3 would have been some value greater than 1.

4.2.4 *Vertical Loads*

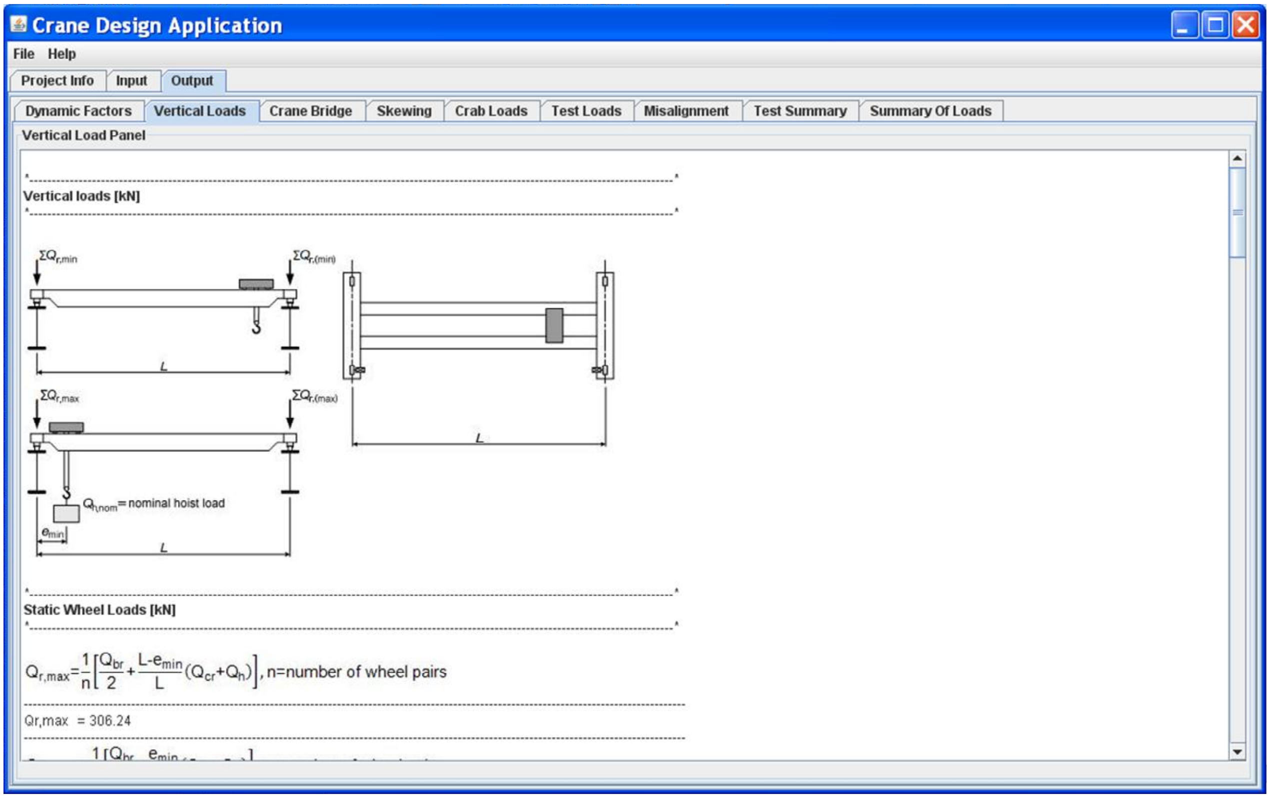


Figure 4.10 Vertical Loads Panel

Figure 4.10 shows the Vertical Loads panel displaying the static and dynamic vertical loads calculated for the 4 wheel crane. The vertical loads displayed are summarised in Table 4.2 below.

Table 4.2 Summary of the Vertical Loads

	Group of Loads [kN]											
	Static	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9_{dyn}**	**9_{stat}**	**10**
$Q_{r,max}$	306	362	319		306	306	306	306	306	361	365	306
$Q_{r,(max)}$	92	103	100		92	92	92	92	92	102	103	92
$Q_{r,min}$	78			78								
$Q_{r,(min)}$	120			120								

Where $Q_{r,max}$, $Q_{r,(max)}$, $Q_{r,min}$, $Q_{r,(min)}$ are defined in section 2.2.3.

4.2.5 *Crane Bridge*

The Crane Bridge panel displays the horizontal loads as a result of the acceleration and deceleration of the crane bridge as seen in Figure 4.11. The horizontal loads obtained are summarised in Table 4.3.

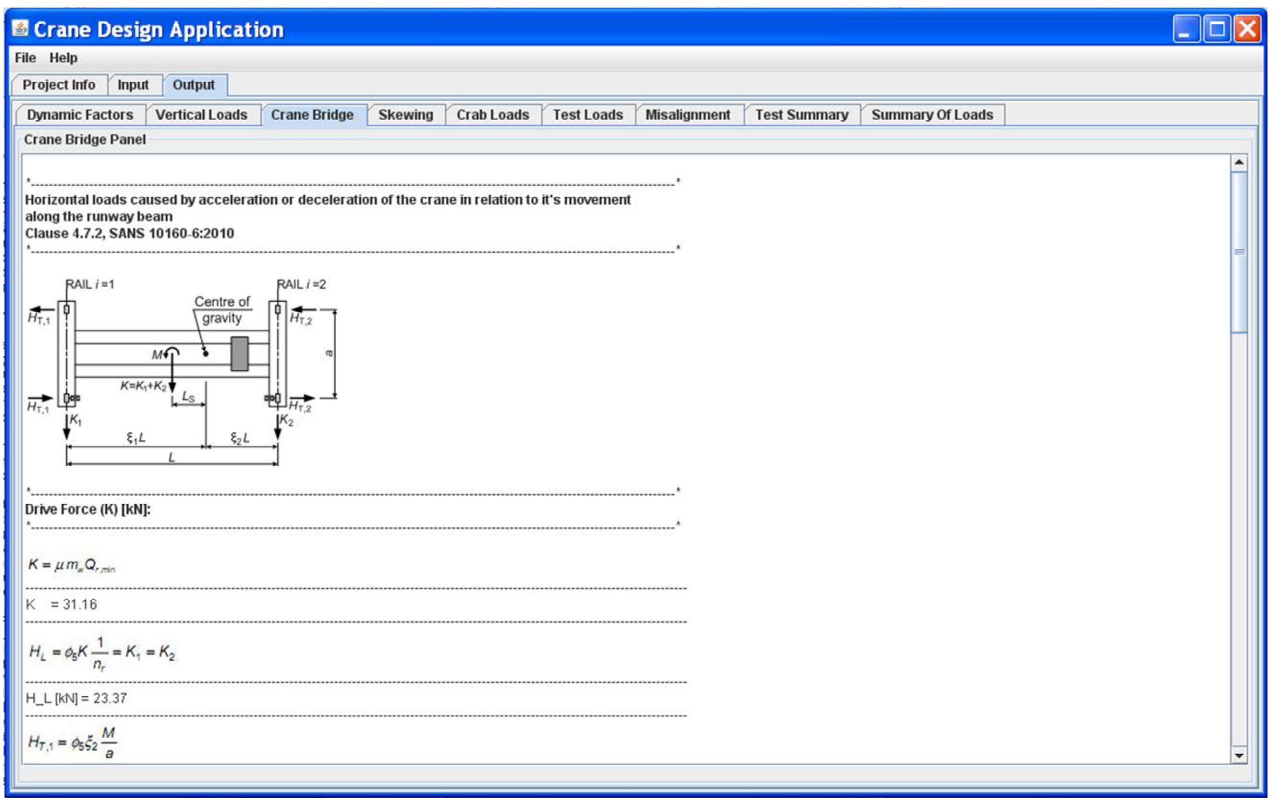


Figure 4.11 Crane Bridge Output Panel

Table 4.3 Loads - Acceleration / Deceleration of Crane Bridge

K [kN]	H_L [kN]	M [kNm]	$H_{T,1}$ [kN]	$H_{T,2}$ [kN]
31.1	23.4	200	15.7	52.4

4.2.6 *Skewing*

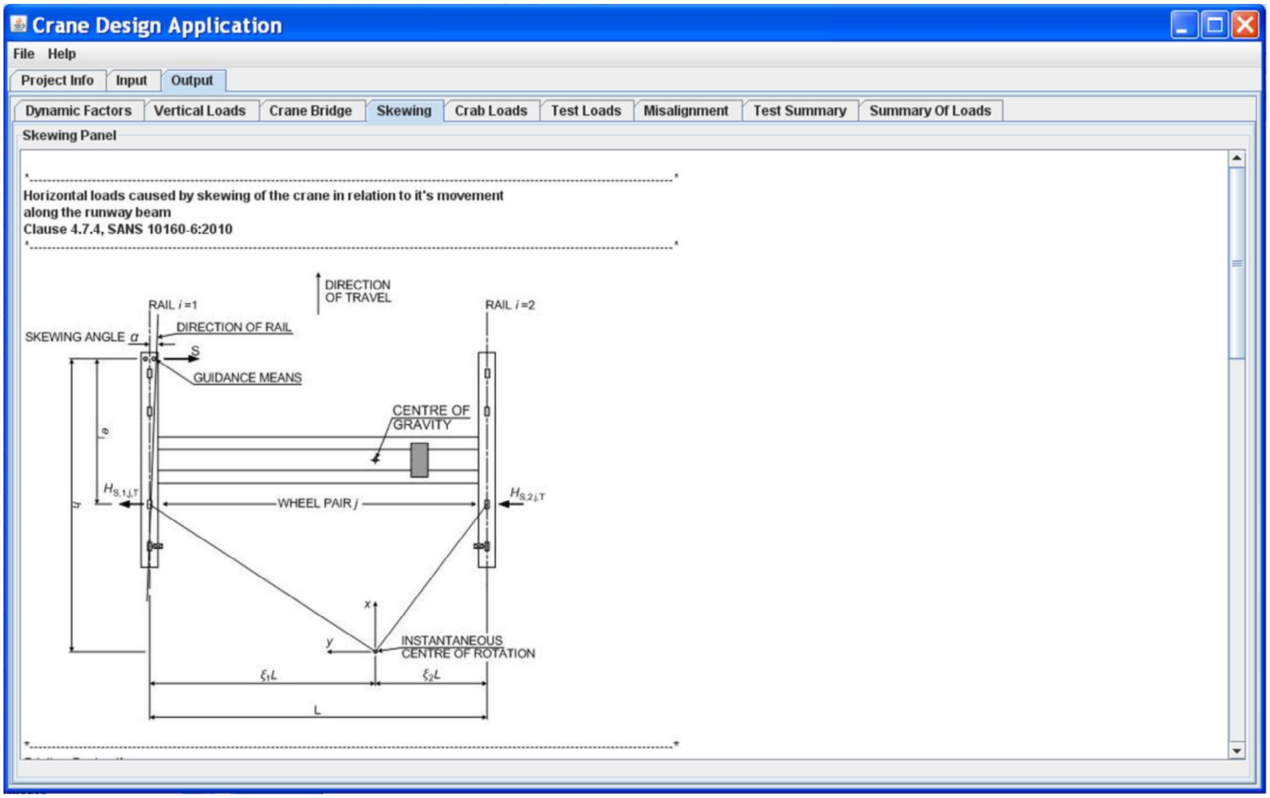


Figure 4.12 Skewing Output Panel

The Skewing Output panel is shown in Figure 4.12 above. This output panel displays the loads that are caused by the skewing of the crane.

The parameters calculated and displayed on the Skewing Panel are summarised in Table 4.4.

Table 4.4 Summary of parameters displayed on Skewing Panel

f	S [kN]	HS,1,1,T [kN]	HS,1,2,T [kN]	HS,2,1,T [kN]	HS,2,2,T [kN]
0.254	101	23.34	0	78	0

4.2.7 *Crab*

Forces as a result of the acceleration and deceleration of the crab are displayed in the Crab Loads Output panel as seen in Figure 4.12.

$H_{T,3}$ = 12.5 kN

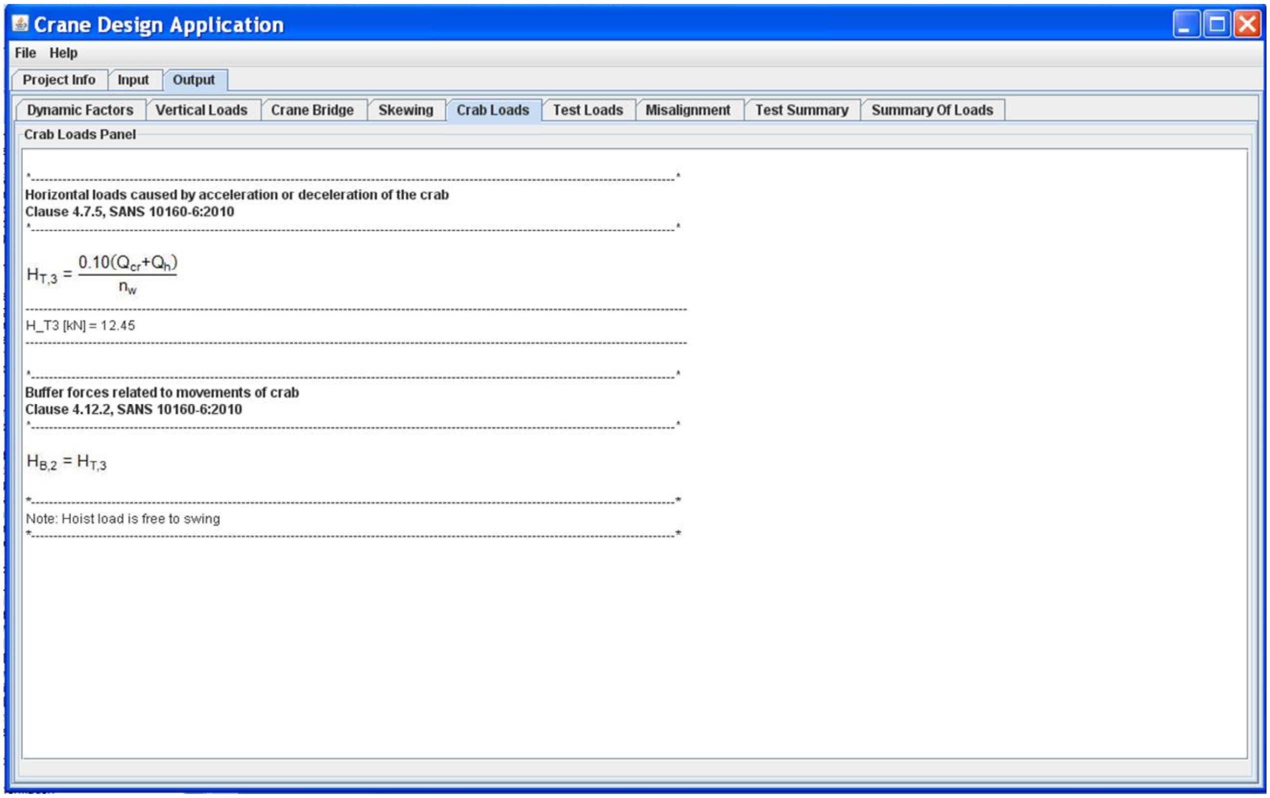


Figure 4.13 Crab Loads Output Panel

4.2.8 *Test Loads*

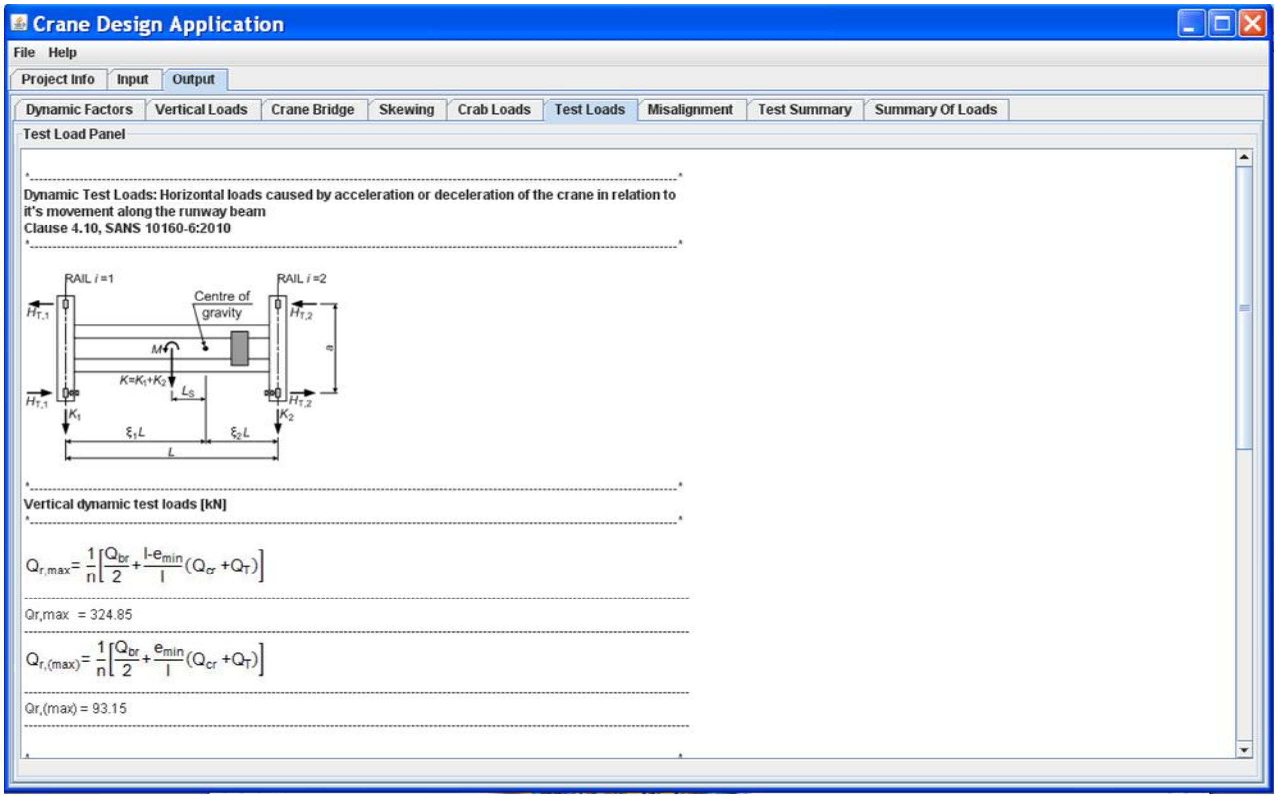


Figure 4.14 Test loads output panel

The Test Loads panel displays the horizontal loads that result from load test. The horizontal loads as displayed on the Test Loads panel is summarised in Table 4.5. This refers to group of loads 9 as defined in Table 1.2.

Table 4.5 Summary of loads from load test

$Q_{r,max}$ [kN]	$Q_{r(max)}$ [kN]	K [kN]	H_L [kN]	M [kNm]	$H_{T,1}$ [kN]	$H_{T,2}$ [kN]
325	93	31.1	23.4	206	16	54

4.2.9 *Misalignment*

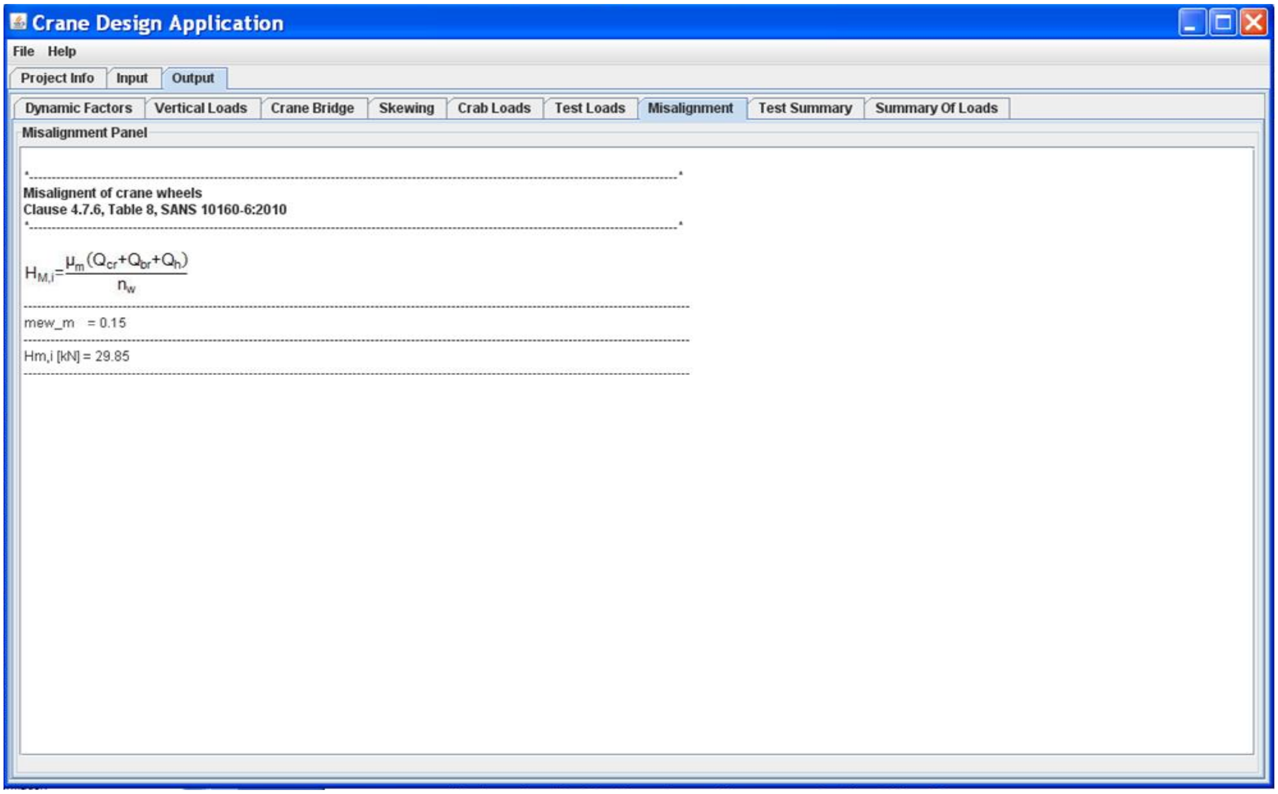


Figure 4.15 Misalignment output panel

The horizontal loads as a result of misalignment of the crane wheels or the misalignment of the rails that cause the horizontal transverse force.

The horizontal misalignment for is given by H_m = 29.9kN

4.2.10 *Buffer Loads*

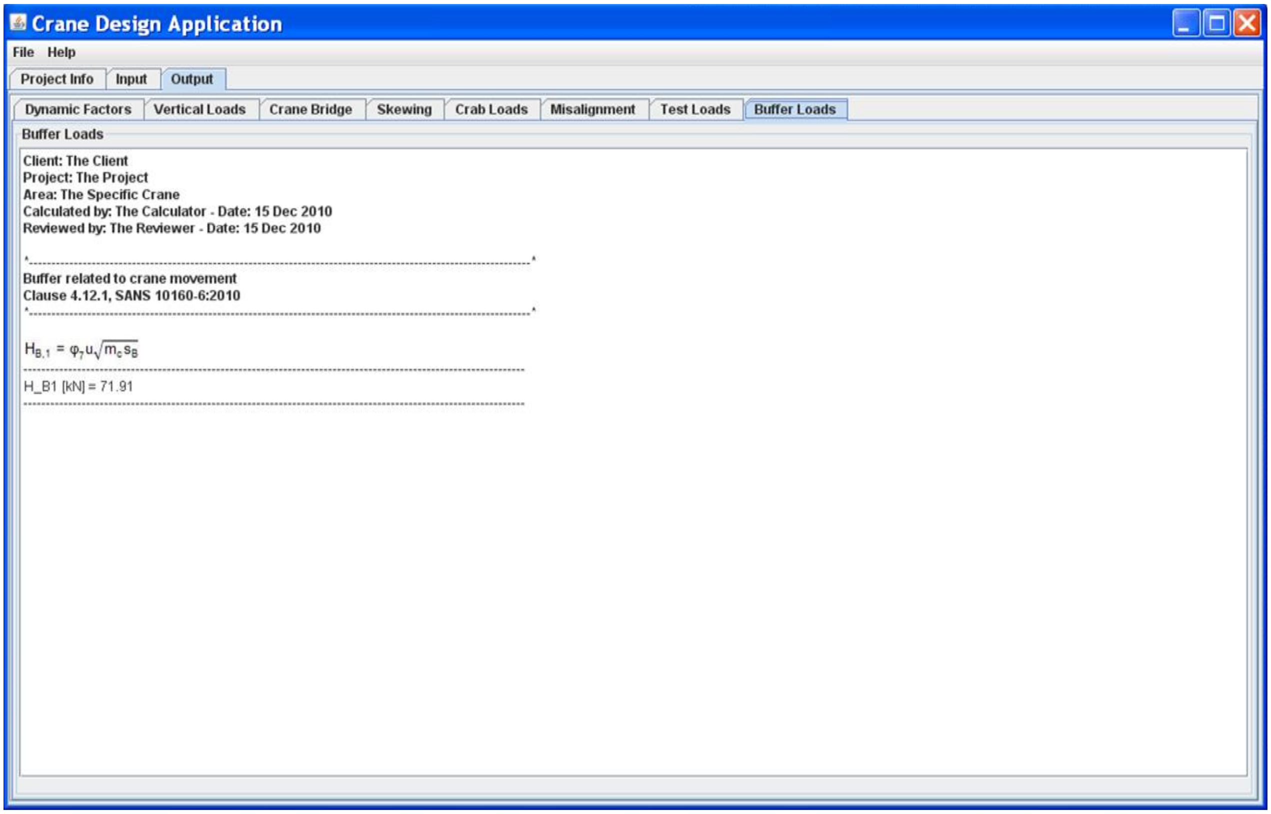


Figure 4.16 Buffer loads output panel

The buffer impact force is displayed in the Buffer loads panel. The value for $H_{B,1}$ = 71.91 kN. However this value is merely hypothetical for this exercise. The spring constant of the buffer, S_B was a random guess as input in order to demonstrate the crane load application. In industry this value has to be determined from force displacement curves supplied by the crane manufacturer for a specific buffer type.

The results of the crane load application can be compared with the results obtained from the Microsoft Excel sheet, refer to Annex D.

4.3 Storing the Input and Output data

Once the output has been generated and displayed on the output panels the user has the option to save this information as hard copy by sending the information displayed to a printer. This can be done by selecting the output panel that needs to be printed. Then select the file menu in the menu bar in the top of the console and then select print. Figure 4.17 shows the skewing panel selected for print. Once print is selected a print dialog box will appear.

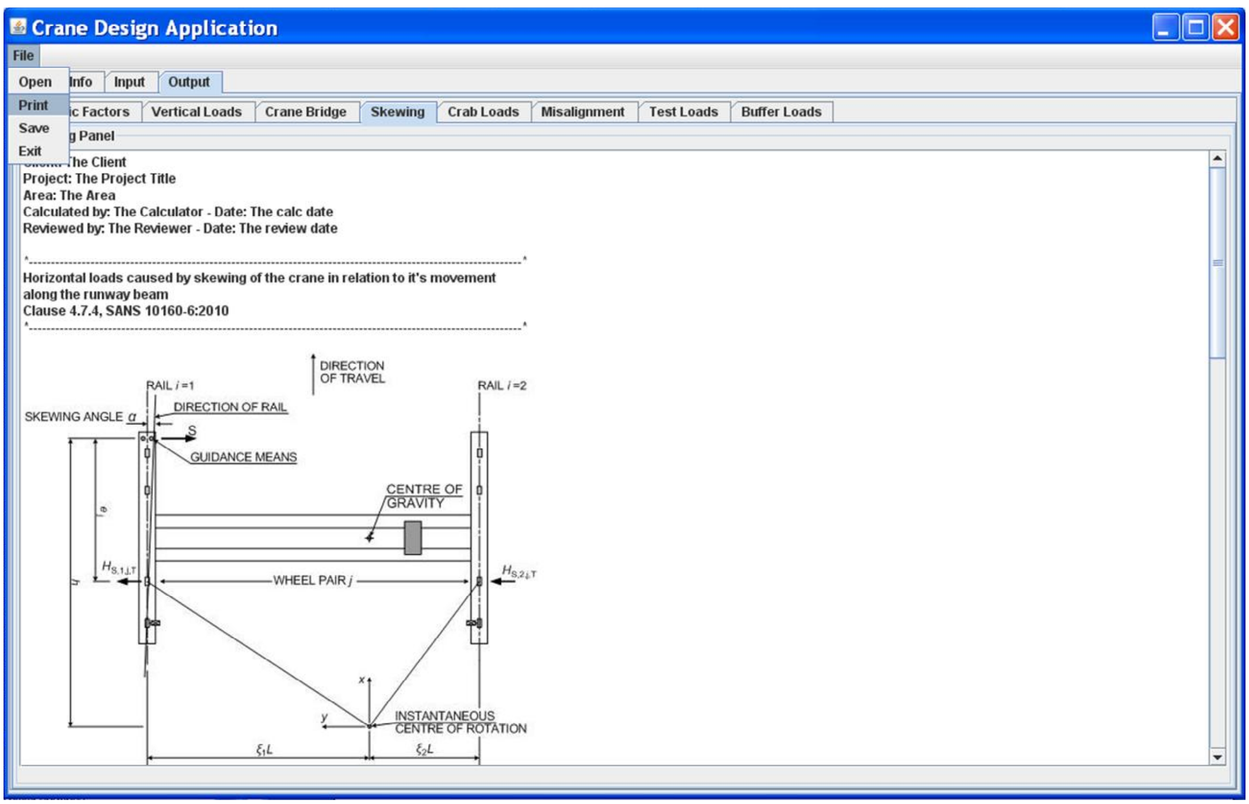


Figure 4.17 Printing the Skewing output panel

The print dialog box will list all the printers installed for the workstation. Figure 4.18 shows the print dialog box after print has been selected. The user simply needs to select the desired printer from the drop down menu and then click ok. Portable document format (PDF) is generally a good file format for representing two-dimensional documents in a manner independent of the application software, hardware, and operating system. Therefore, instead of printing the output data to a printer the user can print the data to a PDF writer and save the output data as PDF document for digital archiving.

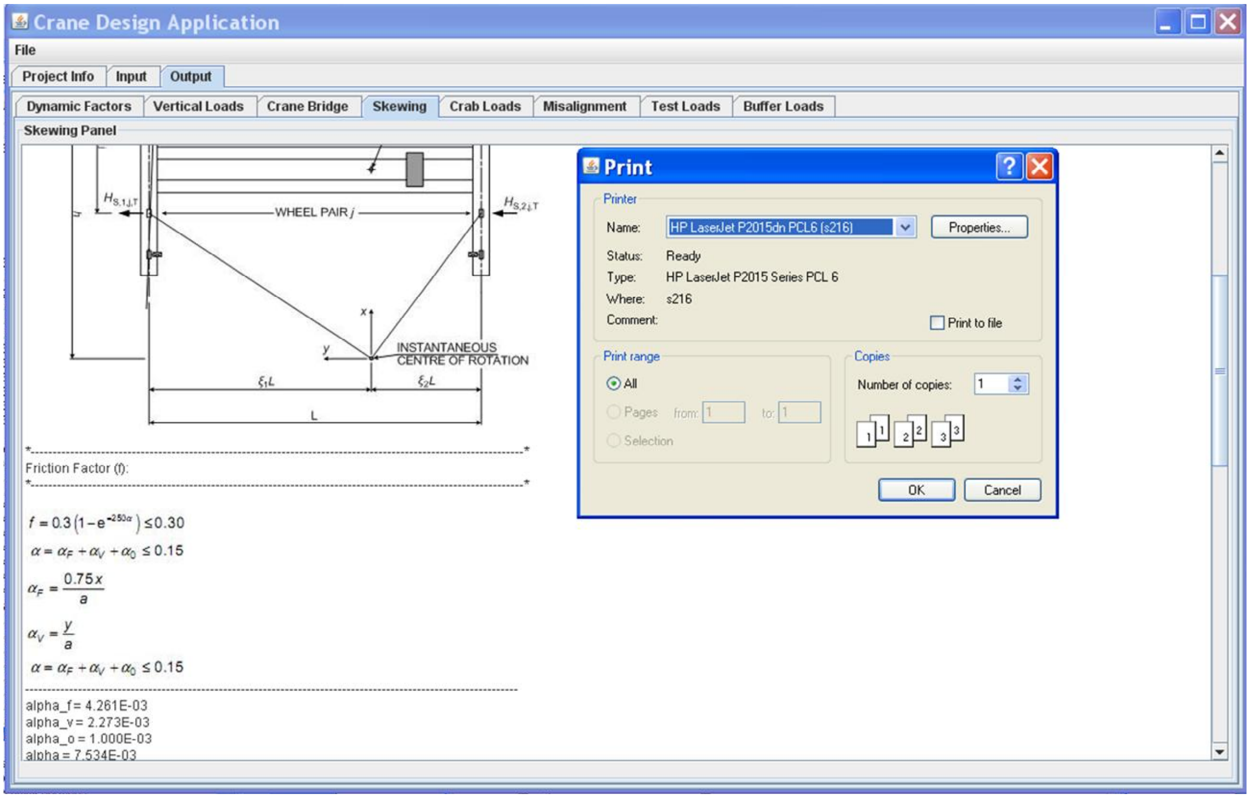


Figure 4.18 Print dialog box

The user also has the option to save the input data in a text file and then reload this data at a later stage, thus avoiding the nuisance of re-entering the same input data. This is achieved by selecting save under the file menu after all the required input parameters are entered into the input panels. Figure 4.19 shows the save dialog box which appears after save has been selected. The user needs to specify a name for the file and a location for the text file in the save dialog box. The text file can then be reloaded at a later stage by selecting open under the file menu item. When open is selected, the user prompted with an open dialog box. Here the file location is need to be specified by browsing to the location where the file is saved and selecting the text file.

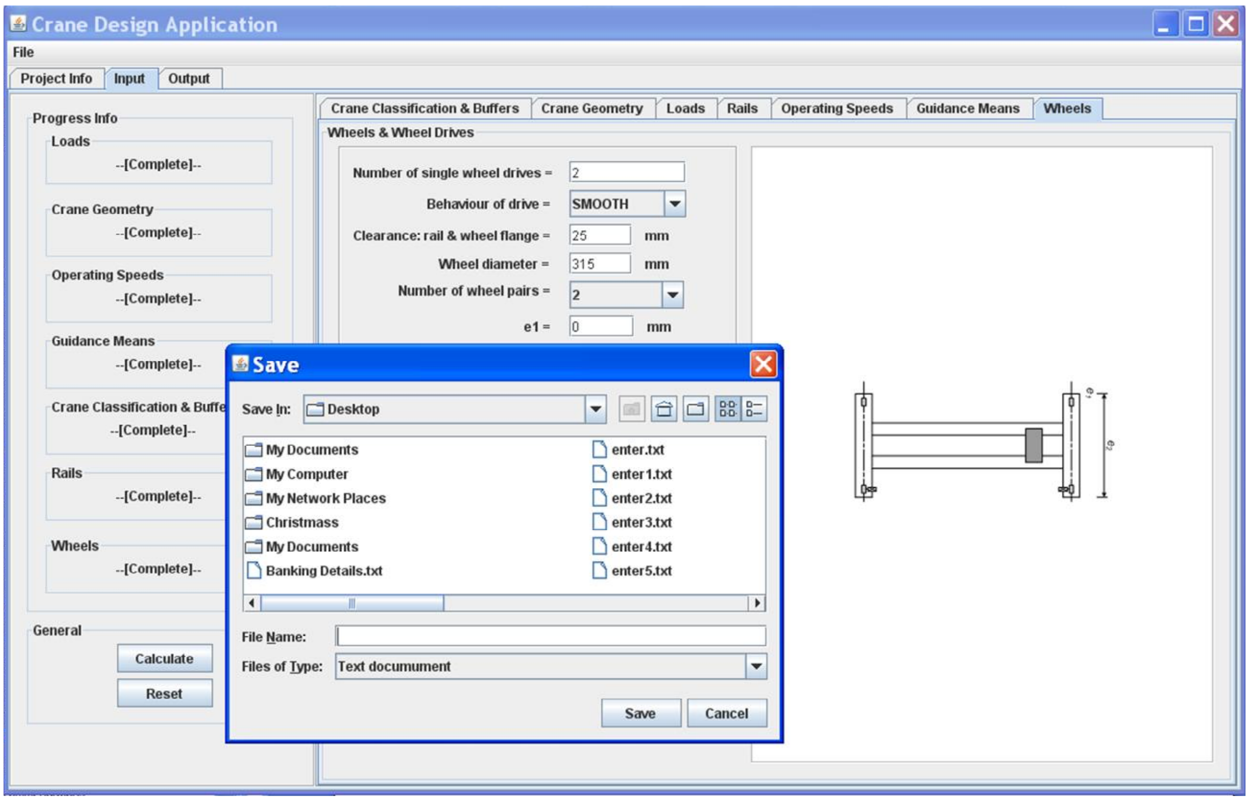


Figure 4.19 Save dialog box

Chapter 5

5 Conclusions and Recommendations

5.1 Conclusions

The initial aim with this investigation was to develop a crane software application to automatically determine the crane induced loads that will act on its supporting structure. This would aid in better understanding the crane load design procedure in the SANS 10160-6:2010 code of practice.

From section 3.2.6.1 above it was seen that the current model for loads as a result of the acceleration or deceleration of the crane bridge is specific for a 4 wheel crane only. This required that the current formulae specified by SANS 10160-6: 2010 had to be extrapolated to accommodate 8 and 16 wheel cranes as well. In order to do this an assumption was made that the end carriages of cranes are rigid in plan-view as to draw a relation between the horizontal transverse wheel loads acting on the end carriage in question. See section 3.2.6.1 for more detail.

Another such contingency that surfaced during this study was related to the procedure to calculate φ_4 using the elasto-kinetic model suggested in Annex B of SANS 10160-6:2010, if rail tolerances are not observed as per the SANS 2001 CSI. Unless the designer has a sound knowledge of structural dynamics, this model tends to be complex in the sense that there are too many unknown variables that need to be determined. It is for this reason that the crane load application was based on the assumption that rail tolerances will always be observed as per SANS 2001 CSI.

The SANS 10160-6:2010 specifies that buffer forces related to crane movement shall be calculated according to Equation 5.1.

$$H_{B,i} = \varphi_7 v_l \sqrt{m_c s_B} \qquad (5.1)$$

Where:

s_B the spring constant of the buffer

The spring constant of the buffer is determined by dividing the estimated end buffer force with the buffer deformation using the appropriate graphs supplied by the manufacturer (Haas, 2007). This method of determining s_B assumes a linear relation between the estimated end buffer force and the buffer deformation. For some buffer types this relation may be linear, however for hydraulic buffers this is not the case. Therefore to determine the buffer impact force according to the code, s_B need to be calculated separately by the engineer and must then be specified as an input parameter in the crane load application. Alternatively the buffer impact force can be estimated from the relevant graphs produced by the crane manufacturers.

5.2 Recommendations

With regards to the horizontal loads that arise from the acceleration or deceleration of the crane bridge for 8 and 16 wheel cranes, further investigation is to gain a better understanding of the behaviour of the horizontal transverse loads. This can be done by either conducting practical experiments or setting up and analysing a crane model in an analysis package.

Further investigation should be conducted to find a more effective method for determining the spring buffer constant for a given buffer.

The elasto-kinetic model suggested in the SANS 10160-6:2010 needs simplification and better clarification.

The crane design load application can perhaps be extended to incorporate the design of the crane support structure. This can prove to be a handy tool to quickly compare results and get an idea of the behaviour of the crane and its support structure as one unit.

Annex A

Programmers Manual

In Chapter 3 it was mentioned that a two level approach was used to develop the crane load application, where each level served its own unique purpose. The first level was referred to as the Presentation level. The objects in this level were created using Java Swing and NetBeans and are primarily responsible for all direct interaction with the user. They are therefore the components that make up the graphical user interface (GUI). The GUI architecture will be discussed in detail in section 0, with regular reference to the source code, where required.

The second level mentioned in Chapter 3 was referred to as the Logic level. The objects in this level represent the core of the crane load application. The objects created in this level contain the necessary algorithms to use the input data obtained from the GUI to calculate the loads the crane will exert on its supporting structure. The components of this level; the Algorithm architecture will be discussed in detail in section 0.

File Structure

The java file structure for the crane software application will be described in short in this section.

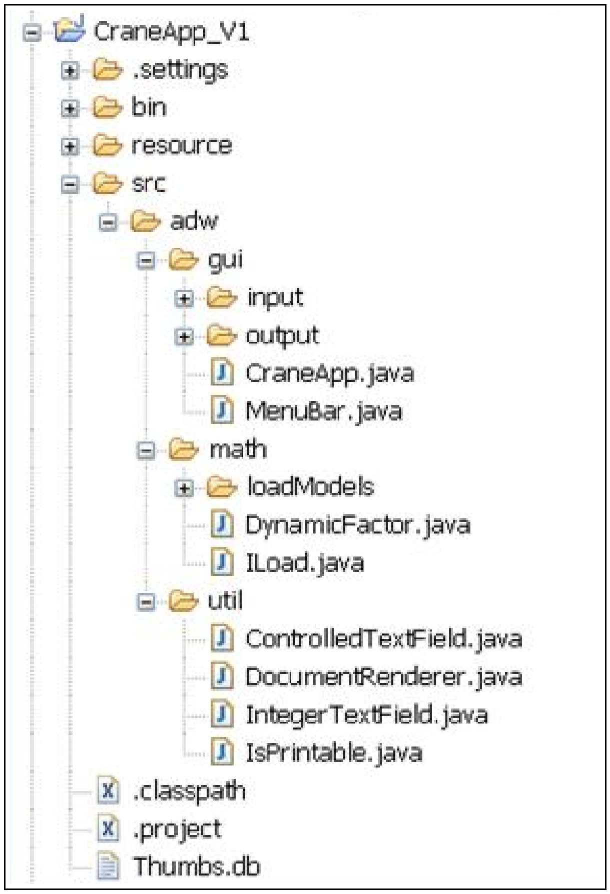


Figure 0.1 Crane Application File Structure

The package hierarchy for the Crane Application project can be seen in Figure 0.1. All the needed classes are filed in a package named adw under the source package. The adw package consists of 3 sub packages namely the gui, math and util packages.

Gui package

The gui package contains the class files that create the required objects that make up the user inter face. An important class, namely the CraneApp class is found in this package. This class contains the main method which has the required statements that are executed when CraneApp class is loaded or read into the computer memory. The gui package contains two sub packages namely the input and output package. The input package contains the required classes that are used to create the objects that make up the input part of the user interface. While the output package contains the required classes that are used to create the objects that make up the output part of the user interface. See Figure 0.2 for more detail.

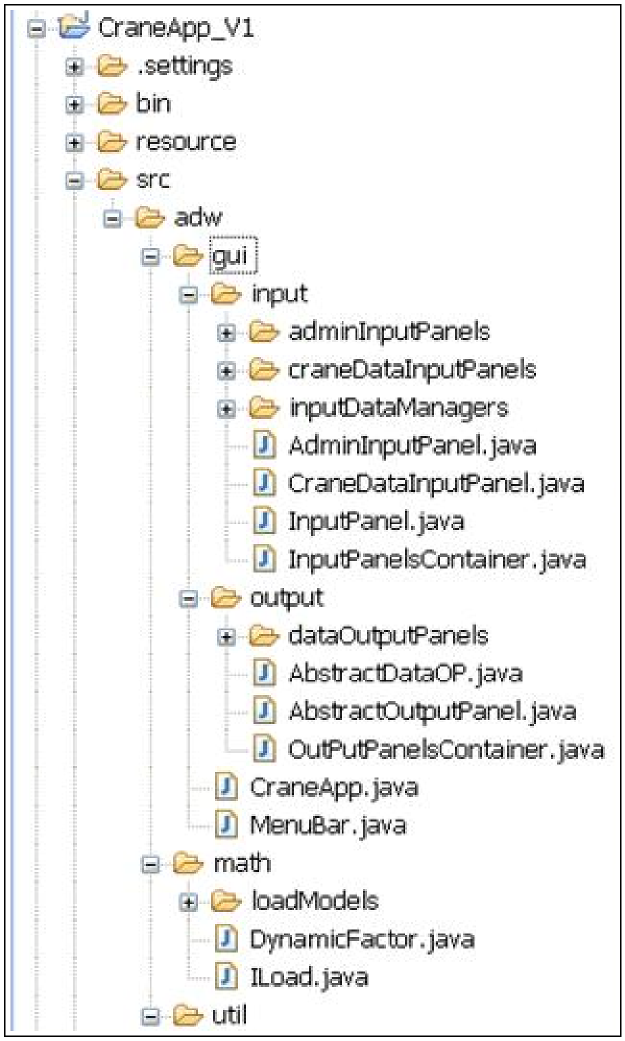


Figure 0.2 Input folder

Math package

The math package contains the classes that make up the algorithm architecture of the crane software application.

Util package

This package contains class files that are used as tools by all other classes, see Figure 0.1. The tools include formatting of text, the document renderer which provides functionality that allows the user to print the contents of the output panels and a class that provides functionality to the algorithm classes display their required data on the output panels.

GUI Architecture (Presentation Level)

The GUI components are made up of two parts. The first part is the crane data input panels and the second part is the admin input panels. Figure 0.3 shows the class hierarchy of the GUI components.

All crane data input panels extend the abstract class `CraneDataInputPanel`. This class provide its subclasses with functionality to update the `ProgressPanel` on its status; whether all its parameters are filled in or not.

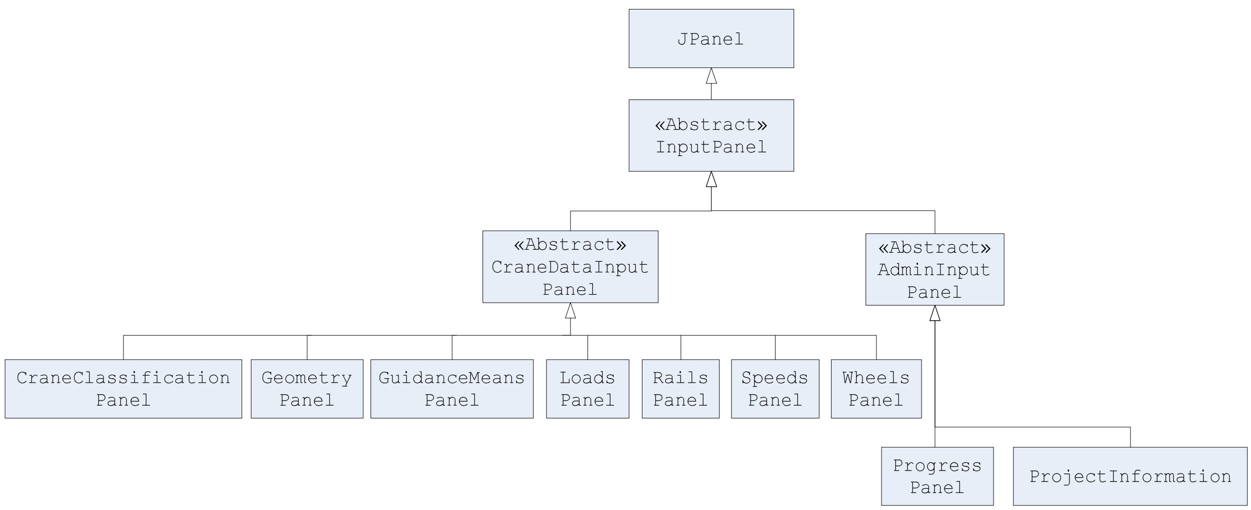


Figure 0.3 GUI - Class hierarchy

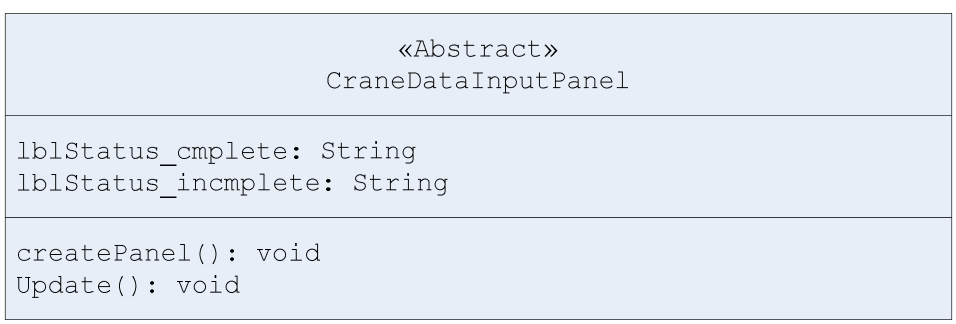


Figure 0.4 Class CraneDataInputPanel

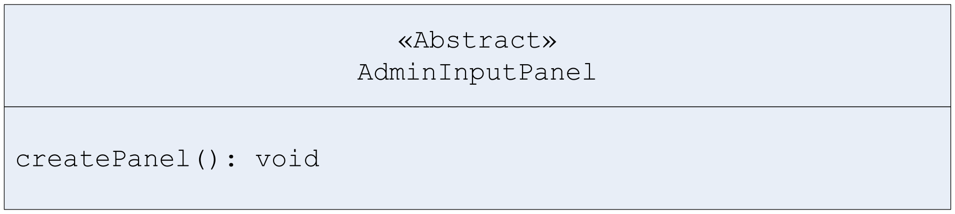


Figure 0.5 Class AdminInputPanel

Class `CraneDataInputPanel` extends the abstract class `InputPanel` which implies that all instances of `CraneDataInputPanel` are in essence `JPanels` which serve as input panels.

Both `ProgressPanel` class and `ProjectInformation` class as seen in Figure 0.3, extend the class `AdminInputPanel` which in return extends the `InputPanel` abstract class. No extra functionality is provided with this inheritance pattern other than that all subclasses can function as `JPanels`. The inheritance pattern is merely adopted for generic purposes and it ensures consistency in the class hierarchy.

Figure 0.6 shows the how the GUI classes are associated with each other.

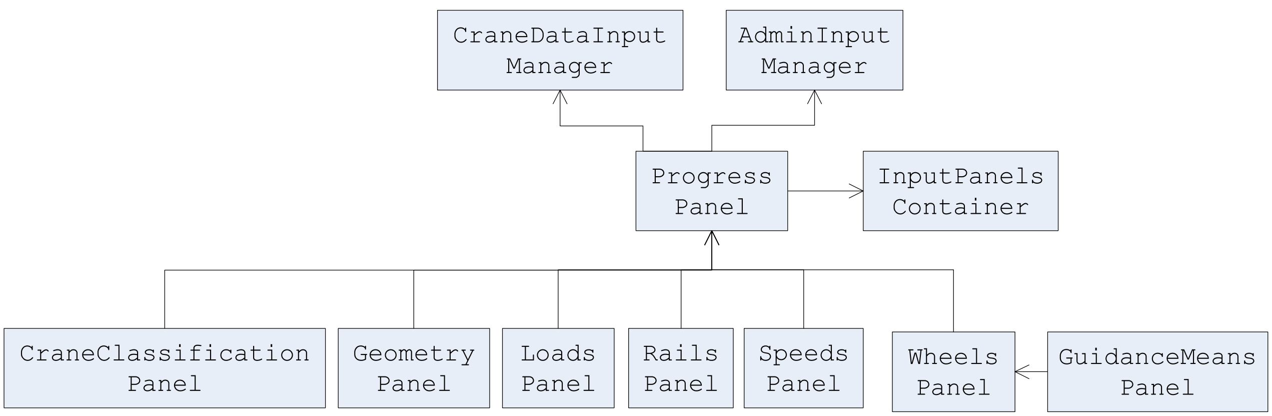


Figure 0.6 Association of GUI classes

The `ProgressPanel` class wraps an instance of the `CraneDataInputManager` class , an instance of the `AdminInputManager` class as well as an instance of the `InputPanelsContainer` class, refer to Figure 0.8. The `CraneClassificationPanel` class wraps an instance of `ProgressPanel`, refer to Figure 0.7. Once the user selects or enters a parameter on the crane classification panel, the `CraneClassificationPanel` object passes the input to the `CraneDataInputManager` object by obtaining its reference via the `ProgressPanel` instance. `ActionEvent` and `KeyEvent` listeners assigned to the

JComboBox and JTextField objects in the CraneClassificationPanel class ensures that the CraneDataInputManager stays up to date with the data entered by the user on the crane classification panel. The same procedure is also followed in the GeometryPanel, LoadsPanel, RailsPanel, SpeedsPanel and WheelsPanel class.

```
public class CraneClassificationPanel extends CraneDataInputPanel{

      public JComboBox craneclassCombo, hoisttypeCombo;
      public boolean _craneClassCombo = false;
      public boolean _hoistTypeCombo = false;
      public ControlledTextField bufferChar;
      public boolean _bufferChar = false;
      private ProgressPanel progPanel;

      public CraneClassificationPanel(ProgressPanel pp){
            super();
            this.progPanel = pp;
            createPanel();
      }

      protected void createPanel(){
            this.setBorder(new TitledBorder(
                        "Crane Classification & Buffers"));
            ...
      } void craneClassComboActionPerformed(ActionEvent e){
            ...
            update();
      }

      void hoisTypeComboActionPerformed(ActionEvent e){
            ...
            update();
      }

      void bufferCharListener(KeyEvent e){
            ...
            update();
      }

      protected void update() {
            if(_bufferChar && _hoistTypeCombo && _craneClassCombo){
            progPanel.craneClassificationLabel.setText(lblStatus_cmplete);
            }else{
            progPanel.craneClassificationLabel.setText(lblStatus_incmplete);
            }
            progPanel.check();
      }

}
```

Figure 0.7 CraneClassificationPanel source code

```java
public class ProgressPanel extends AdminInputPanel{
      private InputPanelsContainer ip;
      public CraneDataInputManager im;
      private String lblStatus_cmplete = "--[Complete]--";
      public ProgressPanel(CraneDataInputManager im, AdminInputManager aim,
InputPanelsContainer ip){
                  this.im = im;
                  this.ip = ip;
                  createPanel();
            }

      protected void createPanel() {...}

      private void calcButtonActionPerformed(ActionEvent evt){
            if (_obj.isEmpty()) {
                  df = new DynamicFactor(im);
                  vl = new VerticalLoad(im, df);
                  cb = new AccelDecel_CraneBridge(vl);
                  buffer = new Buffer(vl);
                  crab = new Crab(vl);
                  ma = new Missalignment(vl);
                  s = new Skewing(vl);

                  _obj.put("DynamicFactor", df);
                  _obj.put("VerticalLoad", vl);
                  _obj.put("AccelDecel_CraneBridge", cb);
                  _obj.put("Buffer", buffer);
                  _obj.put("Crab", crab);
                  _obj.put("Missalignment", ma);
                  _obj.put("Skewing", s);
                  print();
            } else {
                  print();
            }
      }

      private void jButton2ActionPerformed(ActionEvent evt){...}

      public void check() {
            if(loadsLabel.getText().equals(lblStatus_cmplete)&&
                  geometryLabel.getText().equals(lblStatus_cmplete)&&
                  speedsLabel.getText().equals(lblStatus_cmplete)&&
                  guidanceMeansLabel.getText().equals(lblStatus_cmplete)&&
                  craneClassificationLabel.getText().equals(lblStatus_cmplete
                  &&railsLabel.getText().equals(lblStatus_cmplete)&&
                  wheelsLabel.getText().equals(lblStatus_cmplete)){
                        calcButton.setEnabled(true);
```

```
                } else {
                        calcButton.setEnabled(false);
                }
        }

        void print() {...}
}
```

Figure 0.8 ProgressPanel source code

When the user crane input parameter is being altered or entered into the various text fields on the input panels, the `ProgressPanel` object instance is notified that a specific parameter has been changed, with the help of the `ActionEvent` and `KeyEvent` listeners. Once all the parameters on a specific input panel are reported as complete the `ProgressPanel` object flags the input panel object as completed. The text label, “Completed” is then displayed on the progress panel for the specific input panel in question. When all the input panels are marked as complete the ProgressPanel object sets the Calculate button active, refer to method `calcButtonActionPerformed(ActionEvent evt)` in Figure 0.8. Once the CalcButton is pressed the necessary crane loads are calculated and displayed on the various output panels.

Algorithm Architecture (Logic Level)

After the necessary crane input parameters are obtained via user input, the algorithm classes compute the crane loads that act on the crane support structure. Figure 0.9 shows the class hierarchy of the algorithm architecture. Each crane load model as described in the SANS 10160-6:2010 is modelled as an object.

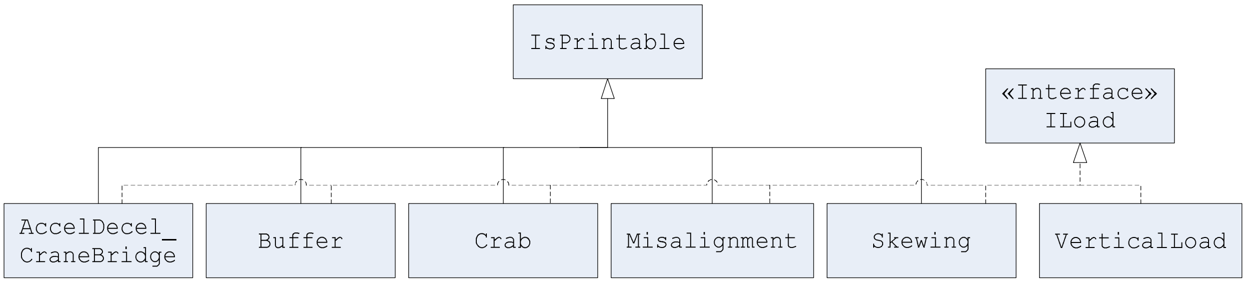


Figure 0.9 Algorithm - Class hierarchy

Each load model object implements the ILoad interface, which provides the `show()` and `print()` methods. All load model objects extend class `IsPrintable`, which implies the all instances of any of the load model objects' calculated loads are printable. Refer to Figure 0.10 and Figure 0.11 for the class diagrams of `ILoad` and `IsPrintable` respectively, for further clarity.

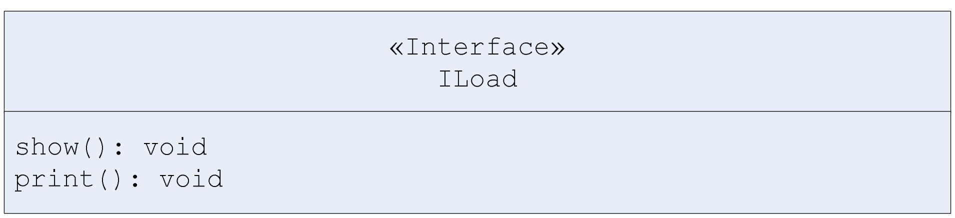


Figure 0.10 Interface ILoad

```
IsPrintable
-----------------------------------------------------------------
line_1: String
-----------------------------------------------------------------
message(string:String, stream:PrintStream): void
newL(stream:PrintStream): void
putS(s:String, stream:PrintStream): void
putS(w:int, s:String, stream:PrintStream): void
newL(n:int, stream:PrintStream): void
printLine(stream:PrintStream): void
putD(w:int, d:int, zahl:double, stream:PrintStream): void
addTextStyles(doc:StyledDocument): void
addImageIcon(doc:StyledDocument, _s: String): void
```

Figure 0.11 Class IsPrintable

Figure 0.12 presents the design pattern adopted to determine the horizontal and vertical crane loads.

- Class `AccelDecel_CraneBridge` calculates the horizontal crane loads due to the acceleration or deceleration of the crane bridge.
- Class `Buffer` calculated the horizontal buffer forces as a result of the crane bridge colliding with the buffer end stops on the carriageway.
- Class `Crab` calculates the loads that arise as a result of the acceleration or deceleration of the crab.
- Class `Misalignment` determines the horizontal crane loads due to the misalignment of either the crane wheels or the rails.
- Class `Skewing` calculates the horizontal crane loads as a result of the crane skewing.
- Class `VerticalLoad` calculates all the static vertical loads of the crane as well as the vertical loads as a result of the movement of the crane and the hoisting of the payload.

Classes `AccelDecel_CraneBridge`, `Buffer`, `Crab`, `Misalignment` and `Skewing` all wrap an instance of `VerticalLoad` which in turn wrap an instance of `DynamicFactor` and an instance of `CraneInputManager`.

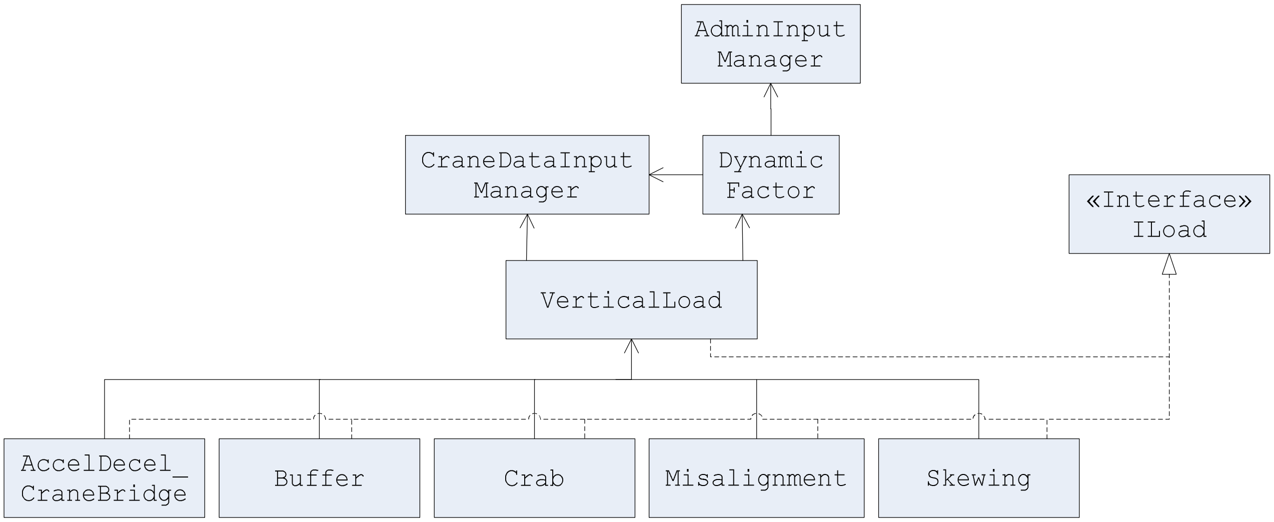


Figure 0.12 Association of algorithm classes

Consider Class `AccelDecel_CraneBridge`. In order to calculate the horizontal loads as a result of the acceleration or deceleration of the crane, certain input parameters are obtained from the `CraneDataInputManager`. This is done via the reference of the `VerticalLoad` object instance which in turn holds a reference on the `CraneDataInputManager` object instance. Certain vertical loads are required to calculate the horizontal loads due to the acceleration or deceleration of the crane. These vertical loads are obtained with the reference the `AccelDecel_CraneBridge` object holds on the `VerticalLoad` object instance. Figure 0.13 refers to the class structure of `VerticalLoad`.

```
VerticalLoad
-----------------------------------------------------------------
df: DynamicFactor
im: CraneDataInputManager
qrmax: Hashtable<Integer,String>
qrmax: Hashtable<Integer,String>
-----------------------------------------------------------------
VerticalLoad(im:CraneDataInputManager,df:DynamicFactor)
maxStaticWheelLoad(): double
maxAccomStaticWheelLoad(): double
minStaticWheelLoad(): double
minAccomStaticWheelLoad(): double
maxLoadPerWheel(gol: int): double
_maxLoadPerWheel(): double
accomLdPerWheel(): double
_accompMaxLoadPerWheel(): double
print(): double
show(): double
```

Figure 0.13 Class VerticalLoad

Table 0.1 summarises the parameters required as well as where they are obtained, in order for an AccelDecel_CraneBridge objects to calculate the necessary loads.

Table 0.1 Summary of the parameters required for the loads calculated by AccelDecel_CraneBridge class

AccelDecel_CraneBridge Class				
Parameter Calculated	**Method Called**	**Parameters Required**	**Obtained From**	**Method or Variable Called**
Drive force - K	K()	$Q_{r,min}$	VerticalLoad object	minSaticWheelLoad()
		m_w	CraneDataInputManager object	singleWheelDrives
		μ	Default value = 0.2	
Horizontal longitudinal load - H_L	HL()	φ5	DynamicFactor object	phi_5()
		K	K()	K()
		n_r	CraneDataInputManager object	numberOfRails
Horizontal transverse load - H_T	HT(...)	φ5	DynamicFactor object	phi_5()
		ξ_1 & ξ_2	calculated inside method HT(...)	HT(...)
		a	CraneDataInputManager object	Calculated from the ei values for i = 1 to 8

A similar referencing procedure as discussed above is followed by the `Buffer`, `Misalignment`, `Crab` and `Skewing` classes to calculate their respective loads.

Annex B

B Further Examples

B.1 Four Wheel Crane

The information regarding the 40t overhead travelling crane is shown in Table B.1.

Table B.1 Crane Information from the crane manufacturer

Weights		
Weight of crane bridge	kN	298
Weight of crab	kN	98
Maximum hoist load	kN	400
Maximum vertical wheel load	kN	306
Minimum vertical wheel load	kN	78
Geometry of crane		
Span of crane bridge	mm	23800
Minimum distance between hoist and rail	mm	1650
Rail type		DIN A100
Width of top of rail	mm	100
Height of rail	mm	95
Speeds		
Steady hoisting speed	m/min	10
Long travel speed	m/min	50
Cross travel speed	m/min	40
Guide means		
Guide rollers present		no
Crane classification		
Class of crane		3
Type of hoist		hook
Hoist load free to swing		yes
Buffers		
Buffer type		hydraulic
Buffer characteristic		0.9
Wheels and wheel drives		
Type of wheel drive		single
Number of single wheel drives		2
Behaviour of drive		smooth
Combination of wheel pairs		IFF (1)
Clearance between rail and wheel flange	mm	25
Number of wheel pairs		2
Wheel spacing	mm	4400
Coefficient of friction		0.20
(1) IFF : *Independent, Fixed/Fixed*		

B.1.1 ***Classification of crane:***

SANS 10160-6:2010, Annex 6A

Hoisting class C4

B.1.2 ***Groups of actions***

The following groups of actions will be calculated:

SANS 10160-6:2010, Table 2

Loading combination 1

φ_1(self-weight of crane) + φ_2(hoist load) + φ_5(acceleration of crane bridge)

Loading combination 3

(self-weight of crane) + φ_5(acceleration of crane bridge)

Loading combination 4

φ_4(self-weight of crane) + φ_4(hoist load) + φ_5(acceleration of crane bridge)

Loading combination 5

φ_4(self-weight of crane) + φ_4(hoist load) + (skewing of crane bridge)

Loading combination 6

φ_4(self-weight of crane) + φ_4(hoist load) + (acceleration or braking of crab)

Loading combination 7

φ_4(self-weight of crane) + φ_4(hoist load) + (misalignment of rails or crane wheels)

Loading combination 9

φ_1(self-weight of crane) + φ_6(test load) + φ_5(acceleration of crane bridge)

Loading combination 10 (accidental)

(self-weight of crane) + (hoist load) + φ_7(buffer force)

B.1.3 *Static Wheel loads*

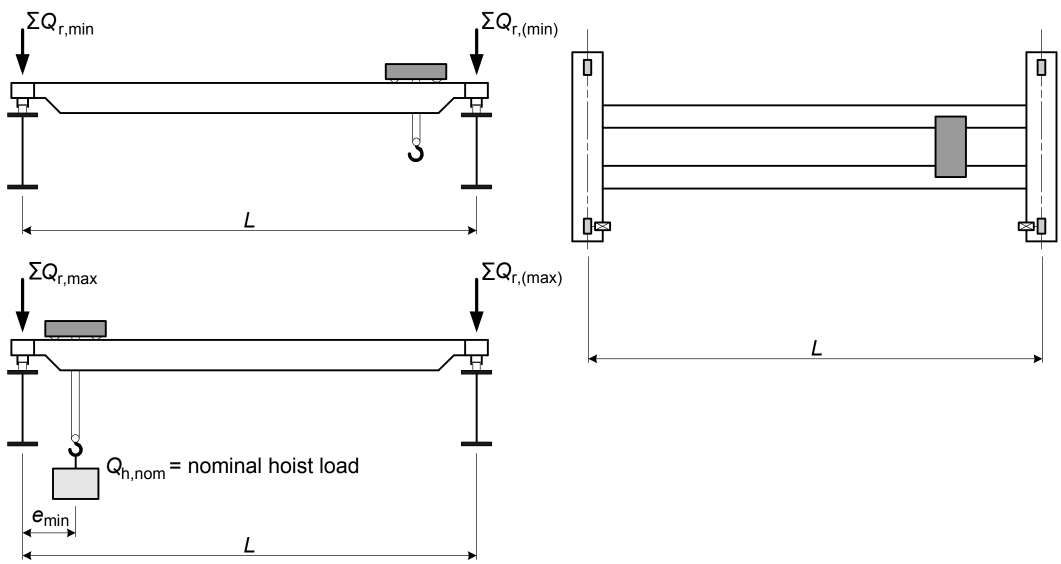


Figure B.1Static wheel loads for a 4 wheel crane

L = 23.8 m

e_{min} = 1.65 m

Weight of crane bridge (Q_{br}) = 298 kN

Crab (Q_{cr}) = 98kN

Hoist Load (Q_h) = 400 kN

Equilibrium:

Maximum vertical wheel load $= \frac{1}{2}\left[\frac{Q_{br}}{2} + \frac{l-e_{min}}{l}(Q_{cr}+Q_h)\right]$

$$Q_{r,max} = \frac{1}{2}\left[\frac{298}{2} + \frac{23800-1650}{23800}(98+400)\right] = 306 \text{ kN}$$

Maximum accompanying vertical wheel load $= \frac{1}{2}\left[\frac{Q_{br}}{2} + \frac{e_{min}}{l}(Q_{cr}+Q_h)\right]$

$$Q_{r,(max)} = \frac{1}{2}\left[\frac{298}{2} + \frac{1650}{23800}(98+400)\right] = 91.8 \text{ kN}$$

Minimum vertical wheel load $= \frac{1}{2}\left[\frac{Q_{br}}{2} + \frac{e_{min}}{l}(Q_{cr})\right]$

$$Q_{r,min} = \frac{1}{2}\left[\frac{298}{2} + \frac{2850}{11700}(98)\right] = 77.9 \text{ kN}$$

Minimum accompanying vertical wheel load $= \frac{1}{2}\left[\frac{Q_{br}}{2} + \frac{l\text{-}e_{min}}{l}(Q_{cr})\right]$

$$Q_{r,(min)} = \frac{1}{2}\left[\frac{298}{2} + \frac{23800\text{-}1650}{23800}(98)\right] = 120 \text{ kN}$$

B.1.4 *Dynamic factors*

φ_1 - vibrational excitation of the crane due to lifting of the hoist load off the ground, applied to the self-weight of the crane

Clause 4.6.3, Table 4, SANS 10160-6:2010

$\varphi_1 = 1.10$

φ_2 - dynamic effects of transferring the hoist load from the ground to the crane, applied to the hoist load

Clause 4.6.3, Table 4, SANS 10160-6:2010

$\varphi_2 = \varphi_{2,min} + \beta_2 V_h$

Hoisting class C3

$\varphi_{2,min} = 1.15$

$\beta_2 = 0.51$

$v = \frac{10}{60}$ steady hoisting speed in m/minute

$$\varphi_2 = 1.15 + (0.51)\left[\frac{10}{60}\right] = 1.235$$

φ_4 - dynamic effect induced when travelling on rail tracks or runways applied to the self-weight of the crane and the hoist load

Clause 4.6.3, Table 4, SANS 10160-6:2010

$\varphi_4 = 1.0$, assume tolerances for rail tracks specified in SANS 2001 CSI are observed.

φ_5 - effects caused by drive forces, applied to the drive force

Clause 4.7.2 (b), Table 6, SANS 10160

Forces change smoothly : $\varphi_5 = 1.5$

φ_6 - when a test load is moved by the drives in the way the crane is used, applied to the test load

Clause 4.10 4, SANS 10160-6:2010

$\varphi_6 = 0.5\left(1+\varphi_2\right) = 0.5(1+1.235) = 1.118$

φ_6 - for the static test, applied to the static test load, Clause 4.10.4b), SANS 10160-6:2010

$\varphi_6 = 1.0$

φ_7 - elastic effects of impact on buffers

Clause 4.12.1.2, Table 9, SANS 10160-6:2010

$\varphi_7 = 1.25+0.70(\xi-0.50) = 1.25+0.70(0.9-0.50)$

$\varphi_7 = 1.53$

B.1.5 *Vertical loads from overhead travelling crane*

Clause 4.5.3, SANS 10160-6:2010

Group of loads 1: φ_1 (self-weight)+φ_2 (hoist load)

Maximum wheel load = $\frac{1}{2}\left[\varphi_1\frac{Q_{br}}{2}+\frac{l-e_{min}}{l}\left(\varphi_1 Q_{cr}+\varphi_2 Q_h\right)\right]$

$$Q_{r,max} = \frac{1}{2}\left[(1.1)\frac{205}{2}+\frac{23800-1650}{23800}(1.1\times98 + 1.235\times400)\right] = 362 \text{ kN}$$

Minimum wheel load = $\frac{1}{2}\left[\varphi_1\frac{Q_{br}}{2}+\frac{e_{min}}{l}\left(\varphi_1 Q_{cr}+\varphi_2 Q_h\right)\right]$

$$Q_{r,(max)} = \frac{1}{2}\left[(1.1)\frac{205}{2}+\frac{1650}{23800}(1.1\times205 + 1.235\times400)\right] = 103 \text{ kN}$$

Group of loads 3: self-weight

Maximum wheel load = $\frac{1}{2}\left[\frac{Q_{br}}{2}+\frac{l-e_{min}}{l}(Q_{cr})\right]$

$$Q_{r,(min)} = \frac{1}{2}\left[\frac{298}{2}+\frac{23800\text{-}1650}{23800}(98)\right] = 120\ \text{kN}$$

$$\text{Minimum wheel load} = \frac{1}{2}\left[\frac{Q_{br}}{2}+\frac{e_{min}}{l}(Q_{cr})\right]$$

$$Q_{r,min} = \frac{1}{2}\left[\frac{298}{2}+\frac{1650}{23800}(98)\right] = 78\ \text{kN}$$

Group of loads 4, 5, 6 and 7: φ_4 (self-weight) + φ_4 (hoist load)

$$\text{Maximum wheel load} = \frac{\varphi_4}{2}\left[\frac{Q_{br}}{2}+\frac{l\text{-}e_{min}}{l}(Q_{cr}+Q_h)\right]$$

$$Q_{r,max} = \frac{1}{2}\left[\frac{298}{2}+\frac{23800\text{-}1650}{23800}(98+400)\right] = 306\ \text{kN}$$

$$\text{Minimum wheel load} = \frac{\varphi_4}{2}\left[\frac{Q_{br}}{2}+\frac{e_{min}}{l}(Q_{cr}+Q_h)\right]$$

$$Q_{r,(max)} = \frac{1}{2}\left[\frac{298}{2}+\frac{1650}{23800}(98+400)\right] = 92\ \text{kN}$$

Group of loads 9: φ_1 (self-weight) + φ_6 (test load)

Dynamic Test Load = 110% of hoist load

$$\text{Maximum wheel load} = \frac{1}{2}\left[\varphi_1\frac{Q_{br}}{2}+\frac{l\text{-}e_{min}}{l}\left[\varphi_1 Q_{cr}+\varphi_6 Q_t\right]\right]$$

$$Q_t = 1.1\times 400 = 440\ \text{kN}$$

$$\varphi_6 = 1.118$$

$$Q_{r,max} = \frac{1}{2}\left[(1.1)\frac{298}{2}+\frac{23800\text{-}1650}{23800}(1.1\times 98 + 1.118\times 440)\right] = 361\ \text{kN}$$

$$\text{Minimum wheel load} = \frac{1}{2}\left[\varphi_1\frac{Q_{br}}{2}+\frac{e_{min}}{l}\left[\varphi_1 Q_{cr}+\varphi_6 Q_t\right]\right]$$

$$Q_{r,(max)} = \frac{1}{2}\left[(1.1)\frac{298}{2}+\frac{1650}{23800}(1.1\times 98 + 1.118\times 440)\right] = 103\ \text{kN}$$

Static Test Load = 125% of hoist load

$$Q_t = 1.25\times 400 = 500\ \text{kN}$$

$\varphi_6 = 1.0$

$$Q_{r,max} = \frac{1}{2}\left[(1.1)\frac{298}{2} + \frac{23800\text{-}1650}{23800}(1.1\times98 + 1.0\times500)\right] = 365 \text{ kN}$$

$$Q_{r,(max)} = \frac{1}{2}\left[(1.1)\frac{298}{2} + \frac{1650}{23800}(1.1\times98 + 1.0\times500)\right] = 103 \text{ kN}$$

Group of loads 10: (self-weight) + (hoist load)

Maximum wheel load $= \frac{1}{2}\left[\frac{Q_{br}}{2} + \frac{l\text{-}e_{min}}{l}(Q_{cr} + Q_h)\right]$

$$Q_{r,max} = \frac{1}{2}\left[\frac{298}{2} + \frac{23800\text{-}1650}{23800}(98 + 400)\right] = 306 \text{ kN}$$

Minimum wheel load $= \frac{1}{4}\left[\frac{Q_{br}}{2} + \frac{e_{min}}{l}(Q_{cr} + Q_h)\right]$

$$Q_{r,(max)} = \frac{1}{2}\left[\frac{298}{2} + \frac{1650}{23800}(98+400)\right] = 92 \text{ kN}$$

B.1.6 *Longitudinal and transverse loads caused by acceleration and deceleration of crane*

Clause 4.7.2 SANS 10160-6:2010

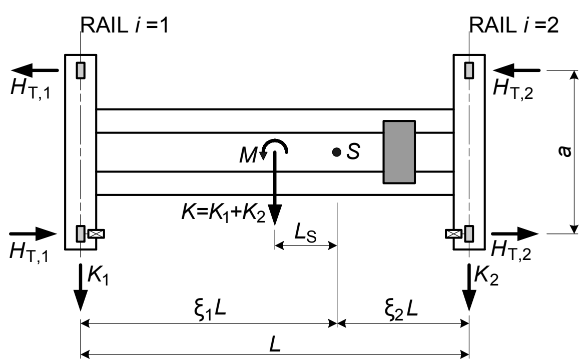


Figure B.2 Load configuration for the acceleration or deceleration of an 4 wheel crane

$$H_L = \varphi_5 K \frac{1}{n_r} = K_1 = K_2$$

n_r = number of rails

Drive force K :

$K = \mu\Sigma Q^*_{r,min} = \mu m_w Q_{r,min} = 0.2\times2\times77.9 = 31.2$ kN where m_w = number of single wheel drives

$$H_L = 1.5(31.2)\frac{1}{2} = 23.4 \text{ kN}$$

$$H_{T,1} = \varphi_5 \xi_2 \frac{M}{a}$$

$$H_{T,2} = \varphi_5 \xi_1 \frac{M}{a}$$

Group of loads 1:

$$\xi_1 = \frac{\Sigma Q_{r,max}}{\Sigma Q_r} = \frac{2 \times 306}{298+98+400} = 0.769$$

$$\xi_2 = 1 - \xi_1 = 0.231$$

$$M = K(\xi_1 - 0.5)L = 31.2(0.769-0.5)23.8 = 199.8 \text{ kNm}$$

$$H_{T,1} = (1.5)(0.231)\frac{199.8}{4.4} = 15.7 \text{ kN}$$

$$H_{T,2} = (1.5)(0.769)\frac{199.8}{4.4} = 52.4 \text{ kN}$$

Group of loads 3:

$$\xi_1 = \frac{\Sigma Q_{r,max}}{\Sigma Q_r} = \frac{2 \times 120}{298+98} = 0.606$$

$$\xi_2 = 1 - \xi_1 = 0.394$$

$$M = K(\xi_1 - 0.5)L = 31.2(0.606-0.5)23.8 = 78.8 \text{ kNm}$$

$$H_{T,1} = (1.5)(0.394)\frac{78.8}{4.4} = 10.6 \text{ kN}$$

$$H_{T,2} = (1.5)(0.606)\frac{78.8}{4.4} = 16.3 \text{ kN}$$

Group of loads 4:

$$\xi_1 = \frac{\Sigma Q_{r,max}}{\Sigma Q_r} = \frac{2 \times 306}{298+98+400} = 0.769$$

$\xi_2 = 1 - \xi_1 = 0.231$

$M = K(\xi_1 - 0.5)L = 31.2(0.769-0.5)23.8 = 199.8$ kNm

$$H_{T,1} = (1.5)(0.231)\frac{199.8}{4.4} = 15.7 \text{ kN}$$

$$H_{T,2} = (1.5)(0.769)\frac{199.8}{4.4} = 52.4 \text{ kN}$$

B.1.7 *Horizontal loads and guide force caused by skewing*

Clause 4.7.4 SANS 10160-6:2010

Guide force $S = f\lambda_{s,j}\sum Q_r$

Horizontal longitudinal forces: $H_{s,i,j,L} = f\lambda_{s,i,j,L}\sum Q_r$

Transverse forces: $H_{s,i,j,T} = f\lambda_{s,i,j,T}\sum Q_r$

Factor $f = 0.3\left(1 - e^{(-250\alpha)}\right) \leq 0.30$

Skewing angle $\alpha = \alpha_F + \alpha_V + \alpha_0 \leq 0.15$

$$\alpha_F = \frac{0.75x}{a} = \frac{0.75(25)}{4400} = 4.26\times10^{-3}$$

where x = clearance between rail and wheel flange

$$\alpha_V = \frac{y}{a} = \frac{7.5}{4400} = 2.27\times10^{-3}$$

where y = wear of rail and guide means $\geq 0.10b = 0.10(100) = 10$ mm

$\alpha_0 = 0.001$

$\alpha = 7.53\times10^{-3}$rad

$f = 0.30\left(1 - e^{(-250\times5.52\times10^{-3})}\right) = 0.254 \leq 0.30$

Combination of wheel pairs: independent, fixed/fixed (IFF)

Distance to instantaneous slide pole:

$$h = \frac{\Sigma e_j^2}{\Sigma e_j} = \frac{4400^2}{4400} = 4400 \text{ mm}$$

$$\lambda_{s,\,j} = 1 - \frac{\Sigma e_j}{nh} = 1 - \frac{4400}{2 \times 4400} = 0.5 \text{ mm}$$

$\lambda_{s,1,j,L} = 0$ for IFF

$$\lambda_{s,1,1,T} = \frac{\xi_2}{n}\left(1 - \frac{e_j}{h}\right) = \frac{0.231}{2}\left(1 - \frac{4400}{4400}\right) = 0.115$$

$\lambda_{s,2,j,L} = 0$ for IFF

$$\lambda_{s,2,1,T} = \frac{\xi_1}{n}\left(1 - \frac{e_j}{h}\right) = \frac{0.769}{2} = 0.385$$

$\lambda_{s,i,2,T} = 0$

Guide force : $S = f\lambda_{s,j}\sum Q_r = (0.245)(0.50\ )(298+98+400) = 101.1$ kN

Transverse forces

$H_{s,1,1,T} = f\lambda_{s,1,1,T}\sum Q_r = (0.254)(0.115)(796) = 23.25$ kN

$H_{s,2,1,T} = f\lambda_{s,2,1,T}\sum Q_r = (0.254)(0.385)(796) = 77.84$ kN

B.1.8 *Horizontal forces caused acceleration or deceleration of crab*

Clause 4.7.5 SANS 10160-6:2010

$$H_{T,3} = \frac{0.10(Q_{cr}+Q_h)}{n_w} = \frac{0.10(98+400)}{4} = 12.5 \text{ kN}$$

Buffer forces related to movements of the crab

Clause 4.12.2 SANS 10160-6:2010

Hoist load is free to swing

$H_{B,2} = H_{T,3}$

B.1.9 ***Test loads***

(Dynamic – Acceleration & deceleration of crane bridge)
Clause 4.10 SANS 10160-6:2010

Dynamic test load : $\varphi_{6,dyn}(1.1Q_h) = 1.118(1.1\times400) = 492$ kN

Static test load : $\varphi_{6,stat}(1.25Q_h) = 1.0(1.25\times400) = 500$ kN

<u>Group of loads 9</u>: φ_1(self-weight) + φ_6(test load)

$$\text{Maximum wheel load} = \frac{1}{2}\left(\frac{Q_{br}}{2} + \frac{L\text{-}e_{min}}{L}(Q_{cr}+Q_T)\right)$$

$$Q_{r,max} = \frac{1}{2}\left(\frac{298}{2} + \frac{23800\text{-}1650}{23800}(98+440)\right) = 324.9 \text{ kN}$$

$$\text{Minimum wheel load} = Q_{r,max} = \frac{1}{2}\left(\frac{Q_{br}}{2} + \frac{L\text{-}e_{min}}{L}(Q_{cr}+Q_T)\right)$$

$$Q_{r,min} = \frac{1}{4}\left(\frac{298}{2} + \frac{1650}{23800}(98+440)\right) = 93.1 \text{ kN}$$

$$K = \mu m_w Q_{r,min} = 0.2\times2\times77.9 = 31.2 \text{ kN}$$

$$H_L = 1.5(31.2)\frac{1}{2} = 23.4 \text{ kN}$$

$$H_{T,1} = \varphi_5 \xi_2 \frac{M}{a}$$

$$H_{T,2} = \varphi_5 \xi_1 \frac{M}{a}$$

$$\xi_1 = \frac{\Sigma Q_{r,max}}{\Sigma Q_r} = \frac{2\times324.9}{98+298+440} = 0.777$$

$$\xi_2 = 1\text{-}\xi_1 = 0.223$$

$$M = KL_s = K\left(\xi_1 - 0.50\right)L = 31.2(0.777 - 0.5)23.8 = 205.7 \text{ kNm}$$

$$H_{T,1} = (1.5)(0.223)\left(\frac{205.7}{4.4}\right) = 15.6 \text{ kN}$$

$$H_{T,2} = (1.5)(0.777)\left(\frac{205.7}{4.4}\right) = 54.5 \text{ kN}$$

B.1.10 *Misalignment of crane wheels*

Clause 4.7.6, SANS 10160-6:2010

$$H_{M,i}=\frac{\mu_m(Q_{cr}+Q_{br+}Q_h)}{n_w}=\frac{0.15(98+298+400)}{4} = 29.9\text{ kN}$$

B.1.11 *Buffer forces related to the crane movement*

Clause 4.12.1, SANS 10160-6:2010

$$H_{B,1}=\varphi_7 v_1 \sqrt{m_c S_B}$$

$$H_{B,1}=1.53\times0.7\times\frac{10}{60}\sqrt{\left(\frac{(98+298+400)\times1000}{9.81}\right)\times100\times10^6}$$

$$H_{B,1}=508464\text{ N}$$

Therefore buffer force per end stop =254 kN

B.2 Eight Wheel Crane

The information regarding the 110t overhead travelling crane is shown in Table B.2.

Table B.2 Crane supplier information

Weights		
Weight of crane bridge	kN	159
Weight of crab	kN	205
Maximum hoist load	kN	1100
Maximum vertical wheel load	kN	267
Minimum vertical wheel load	kN	32
Geometry of crane		
Span of crane bridge	mm	11700
Minimum distance between hoist and rail	mm	2850
Rail type		A75 DIN 536
Width of top of rail	mm	75
Height of rail	mm	85
Speeds		
Steady hoisting speed	m/min	3
Long travel speed	m/min	32
Cross travel speed	m/min	20
Guide means		
Guide rollers present		no
Crane classification		
Class of crane		3
Type of hoist		hook
Hoist load free to swing		yes
Buffers		
Buffer type		hydraulic
Buffer characteristic		0.9
Wheels and wheel drives		
Type of wheel drive		single
Number of single wheel drives		2
Behaviour of drive		smooth
Combination of wheel pairs		IFF [1]
Clearance between rail and wheel flange	mm	25
Number of wheel pairs		4
Wheel spacing :		
e_1	mm	0
e_2	mm	1000
e_3	mm	4800
e_4	mm	5800
Coefficient of friction		0.20
[1] IFF : *Independent, Fixed/Fixed*		

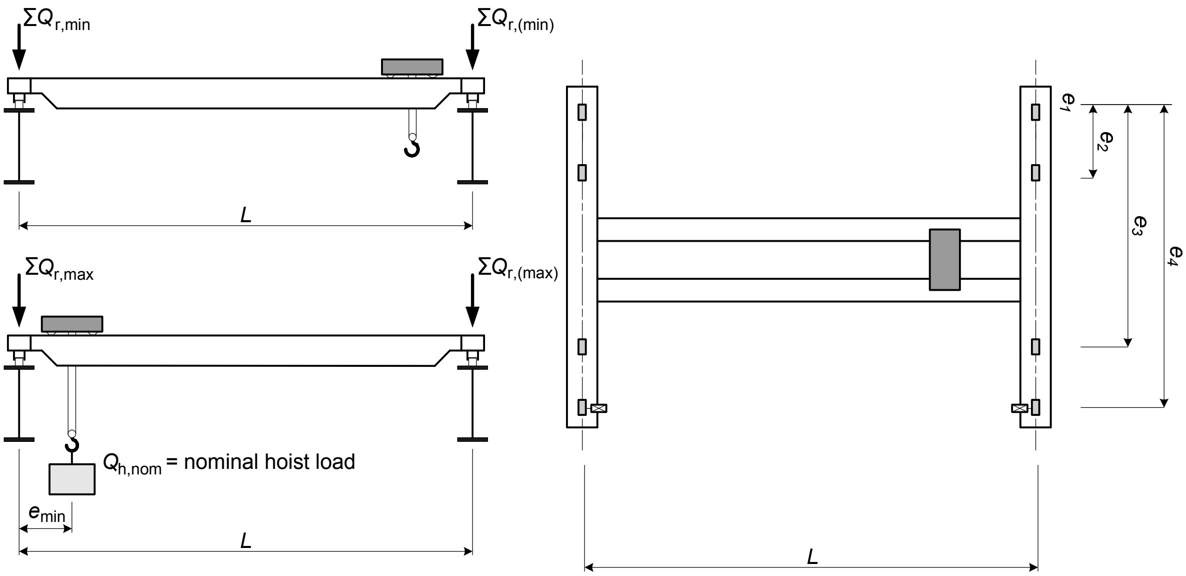


Figure B.3 Proposed wheel configuration of an 8 wheel crane

B.2.1 *Classification of crane*

SANS 10160-6:2010, Annex 6A

Hoisting class C3

B.2.2 *Groups of actions*

The following groups of actions (load combinations of crane induced actions) will be calculated:

Loading combination 1

φ_1(self-weight of crane) + φ_2(hoist load) + φ_5(acceleration of crane bridge)

Loading combination 3

(self-weight of crane) + φ_5(acceleration of crane bridge)

Loading combination 4

φ_4(self-weight of crane) + φ_4(hoist load) + φ_5(acceleration of crane bridge)

Loading combination 5

φ_4(self-weight of crane) + φ_4(hoist load) + (skewing of crane bridge)

Loading combination 6

φ_4(self-weight of crane) + φ_4(hoist load) + (acceleration or braking of crab)

Loading combination 7

φ_4(self-weight of crane) + φ_4(hoist load) + (misalignment of rails or crane wheels)

Loading combination 9

φ_1(self-weight of crane) + φ_6(test load) + φ_5(acceleration of crane bridge)

Loading combination 10 (accidental)

(self-weight of crane) + (hoist load) + φ_7(buffer force)

B.2.3 *Static Wheel Loads*

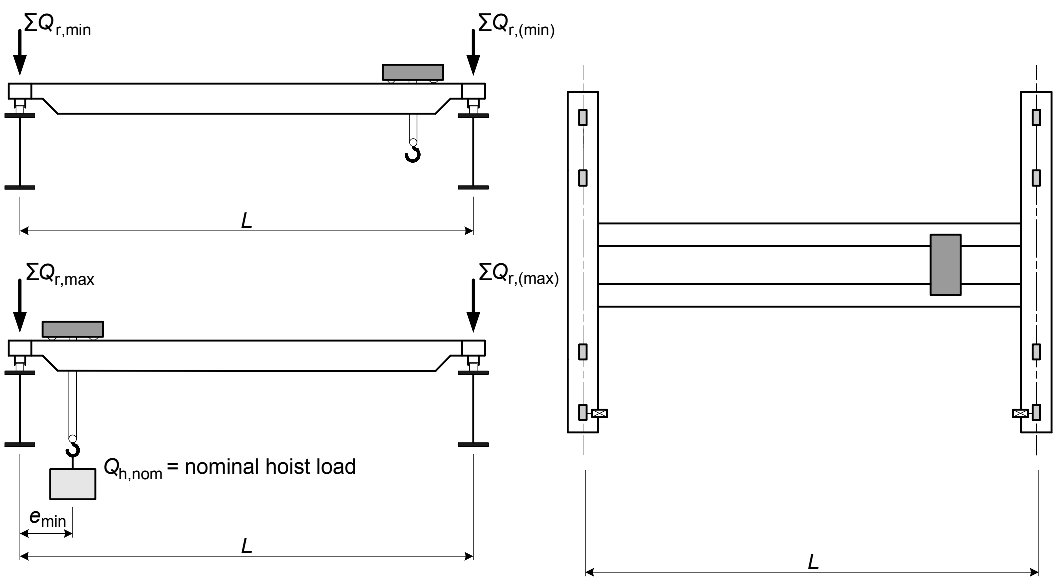


Figure B.4 Static wheel loads for an 8 wheel crane

L = 11.7 m

e_{min} = 2.85 m

Weight of crane bridge (Q_{br}) = 158.86 kN

Crab (Q_{cr}) = 205 kN

Hoist Load (Q_h) = 1100 kN

Equilibrium:

Maximum vertical wheel load = $\frac{1}{4}\left(\frac{Q_{br}}{2}+\frac{l-e_{min}}{l}(Q_{cr}+Q_h)\right)$

$$Q_{r,max} = \frac{1}{4}\left[\frac{159}{2}+\frac{11700-2850}{11700}(205+1100)\right]= 266.7 \text{ kN}$$

Maximum accompanying vertical wheel load $= \frac{1}{4}\left[\frac{Q_{br}}{2}+\frac{e_{min}}{l}(Q_{cr}+Q_h)\right]$

$$Q_{r,(max)} = \frac{1}{4}\left[\frac{159}{2}+\frac{2850}{11700}(205+1100)\right] = 99.3 \text{ kN}$$

Minimum vertical wheel load $= \frac{1}{4}\left[\frac{Q_{br}}{2}+\frac{e_{min}}{l}(Q_{cr})\right]$

$$Q_{r,min} = \frac{1}{4}\left[\frac{159}{2}+\frac{2850}{11700}(205)\right] = 32.4 \text{ kN}$$

Minimum accompanying vertical wheel load $= \frac{1}{4}\left[\frac{Q_{br}}{2}+\frac{l-e_{min}}{l}(Q_{cr})\right]$

$$Q_{r,(min)} = \frac{1}{4}\left[\frac{159}{2}+\frac{11700-2850}{11700}(205)\right]= 58.6 \text{ kN}$$

B.2.4 *Dynamic factors*

φ_1 - vibrational excitation of the crane due to lifting of the hoist load off the ground, applied to the self-weight of the crane

Clause 4.6.3, Table 4, SANS 10160-6:2010

$\varphi_1 = 1.10$

φ_2 - dynamic effects of transferring the hoist load from the ground to the crane, applied to the hoist load

Clause 4.6.3, Table 4, SANS 10160-6:2010

$\varphi_2 = \varphi_{2,min}+\beta_2 V_h$

Hoisting class C3

$\varphi_{2,min}=1.15$

$\beta_2=0.51$

$v=\frac{3}{60}$ steady hoisting speed in m/minute

$\varphi_2 = 1.15+(0.51)\left(\frac{3}{60}\right)=1.176$

φ_4 - dynamic effect induced when travelling on rail tracks or runways applied to the self-weight of the crane and the hoist load

Clause 4.6.3, Table 4, SANS 10160-6:2010

$\varphi_4 = 1.0$, assume tolerances for rail tracks specified in SANS 2001 CSI are observed.

φ_5 - effects caused by drive forces, applied to the drive force

Clause 4.7.2 (b), Table 6, SANS 10160

Forces change smoothly : $\varphi_5 = 1.5$

φ_6 - when a test load is moved by the drives in the way the crane is used, applied to the test load

Clause 4.10 4, SANS 10160-6:2010

$\varphi_6 = 0.5(1+\varphi_2) = 0.5(1+1.176) = 1.088$

φ_6 - for the static test, applied to the static test load, Clause 4.10.4b), SANS 10160-6:2010

$\varphi_6 = 1.0$

φ_7 - elastic effects of impact on buffers

Clause 4.12.1.2, Table 9, SANS 10160-6:2010

$\varphi_7 = 1.25+0.70(\xi-0.50) = 1.25+0.70(0.9-0.50)$

$\varphi_7 = 1.53$

B.2.5 *Vertical loads from overhead travelling crane*

Clause 4.5.3, SANS 10160-6:2010

Group of loads 1: φ_1 (self-weight)+φ_2 (hoist load)

Maximum wheel load = $\frac{1}{4}\left[\varphi_1 \frac{Q_{br}}{2} + \frac{l-e_{min}}{l}\left(\varphi_1 Q_{cr} + \varphi_2 Q_h\right)\right]$

$$Q_{r,max} = \frac{1}{4}\left[(1.1)\frac{159}{2} + \frac{11700\text{-}2850}{11700}(1.1 \times 205 + 1.176 \times 1100)\right] = 309.1 \text{ kN}$$

$$\text{Minimum wheel load} = \frac{1}{4}\left[\varphi_1 \frac{Q_{br}}{2} + \frac{e_{min}}{l}\left(\varphi_1 Q_{cr} + \varphi_2 Q_h\right)\right]$$

$$Q_{r,(max)} = \frac{1}{4}\left[(1.1)\frac{159}{2} + \frac{2850}{11700}(1.1 \times 205 + 1.176 \times 1100)\right] = 114.4 \text{ kN}$$

Group of loads 3: self-weight

$$\text{Maximum wheel load} = \frac{1}{4}\left[\frac{Q_{br}}{2} + \frac{l\text{-}e_{min}}{l}(Q_{cr})\right]$$

$$Q_{r,(min)} = \frac{1}{4}\left[\frac{159}{2} + \frac{11700\text{-}2850}{11700}(205)\right] = 58.6 \text{ kN}$$

$$\text{Minimum wheel load} = \frac{1}{4}\left[\frac{Q_{br}}{2} + \frac{e_{min}}{l}(Q_{cr})\right]$$

$$Q_{r,min} = \frac{1}{4}\left[\frac{159}{2} + \frac{2850}{11700}(205)\right] = 32.4 \text{ kN}$$

Group of loads 4, 5, 6 and 7: φ_4 (self-weight) + φ_4 (hoist load)

$$\text{Maximum wheel load} = \frac{\varphi_4}{4}\left[\frac{Q_{br}}{2} + \frac{l\text{-}e_{min}}{l}(Q_{cr} + Q_h)\right]$$

$$Q_{r,max} = \frac{1}{4}\left[\frac{159}{2} + \frac{11700\text{-}2850}{11700}(205 + 1100)\right] = 266.7 \text{ kN}$$

$$\text{Minimum wheel load} = \frac{\varphi_4}{4}\left[\frac{Q_{br}}{2} + \frac{e_{min}}{l}(Q_{cr} + Q_h)\right]$$

$$Q_{r,(max)} = \frac{1}{4}\left[\frac{159}{2} + \frac{2850}{11700}(205+1100)\right] = 99.3 \text{ kN}$$

Group of loads 9: φ_1 (self-weight) + φ_6 (test load)

Dynamic Test Load = 110% of hoist load

$$\text{Maximum wheel load} = \frac{1}{4}\left[\varphi_1 \frac{Q_{br}}{2} + \frac{l\text{-}e_{min}}{l}\left(\varphi_1 Q_{cr} + \varphi_6 Q_t\right)\right]$$

$Q_t = 1.1 \times 1100 = 1210$ kN

$\varphi_6 = 1.088$

$$Q_{r,max} = \frac{1}{4}\left[(1.1)\frac{159}{2} + \frac{11700-2850}{11700}(1.1\times205 + 1.088\times1210)\right] = 313.5 \text{ kN}$$

Minimum wheel load = $\frac{1}{4}\left[\varphi_1 \frac{Q_{br}}{2} + \frac{e_{min}}{l}\left(\varphi_1 Q_{cr} + \varphi_6 Q_t\right)\right]$

$$Q_{r,(max)} = \frac{1}{4}\left[(1.1)\frac{159}{2} + \frac{2850}{11700}(1.1\times205 + 1.088\times1210)\right] = 115.8 \text{ kN}$$

Static Test Load = 125% of hoist load

$Q_t = 1.25\times1100 = 1375$ kN

$\varphi_6 = 1.0$

$$Q_{r,max} = \frac{1}{4}\left[(1.1)\frac{159}{2} + \frac{11700-2850}{11700}(1.1\times205 + 1.0\times1375)\right] = 324.5 \text{ kN}$$

$$Q_{r,(max)} = \frac{1}{4}\left[(1.1)\frac{159}{2} + \frac{2850}{11700}(1.1\times205 + 1.0\times1375)\right] = 119.3 \text{ kN}$$

Group of loads 10: (self-weight) + (hoist load)

Maximum wheel load = $\frac{1}{4}\left[\frac{Q_{br}}{2} + \frac{l-e_{min}}{l}(Q_{cr} + Q_h)\right]$

$$Q_{r,max} = \frac{1}{4}\left[\frac{159}{2} + \frac{11700-2850}{11700}(205 + 1100)\right] = 266.7 \text{ kN}$$

Minimum wheel load = $\frac{1}{4}\left[\frac{Q_{br}}{2} + \frac{e_{min}}{l}(Q_{cr} + Q_h)\right]$

$$Q_{r,(max)} = \frac{1}{4}\left[\frac{159}{2} + \frac{2850}{11700}(205+1100)\right] = 99.3 \text{ kN}$$

B.2.6 *Longitudinal and transverse loads caused by acceleration and deceleration of crane*

Clause 4.7.2 SANS 10160-6:2010

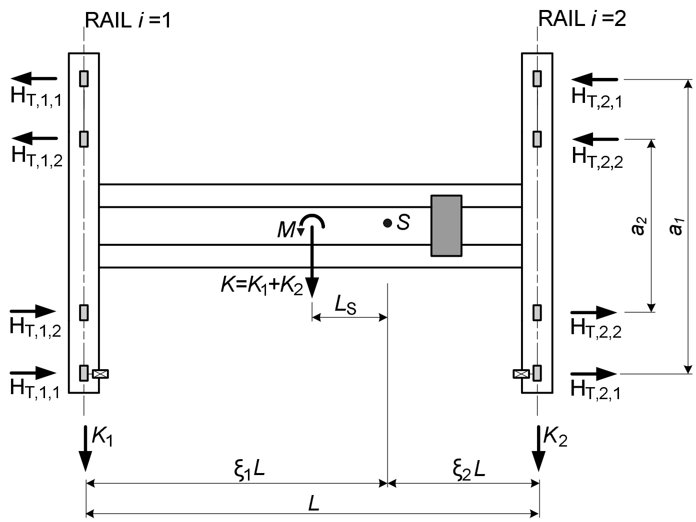


Figure B.5 Load configuration for the acceleration or deceleration of an 8 wheel crane

$$H_L = \varphi_5 K \frac{1}{n_r} = K_1 = K_2$$

n_r = number of rails

Drive force K :

$$K = \mu \Sigma Q^*_{r,min} = \mu m_w Q_{r,min} = 0.2 \times 2 \times 32.4 = 12.96 \text{ kN}$$

where m_w = number of single wheel drives

$$H_L = 1.5(12.96)\frac{1}{2} = 9.72 \text{ kN}$$

Couple force set 1:

$$H_{T,1,1} = \varphi_5 \xi_2 M \frac{a_1}{a_1^2 + a_2^2}$$

$$H_{T,2,1} = \varphi_5 \xi_1 M \frac{a_1}{a_1^2 + a_2^2}$$

Couple force set 2:

$$H_{T,1,2} = \varphi_5 \xi_2 M \frac{a_2}{a_1^2 + a_2^2}$$

$$H_{T,2,2} = \varphi_5 \xi_1 M \frac{a_2}{a_1^2 + a_2^2}$$

Group of loads 1:

$$\xi_1 = \frac{\Sigma Q_{r,max}}{\Sigma Q_r} = \frac{4 \times 266.7}{159+205+1100} = 0.729$$

$$\xi_2 = 1 - \xi_1 = 0.271$$

$$M = K(\xi_1 - 0.5)L = 12.96(0.729-0.5)11.7 = 34.7 \text{ kNm}$$

Couple force set 1:

$$H_{T,1,1} = (1.5)(0.271)(34.7)\left(\frac{5.8}{5.8^2+3.8^2}\right) = 1.70 \text{ kN}$$

$$H_{T,2,1} = (1.5)(0.729)(34.7)\left(\frac{5.8}{5.8^2+3.8^2}\right) = 4.58 \text{ kN}$$

Couple force set 2 :

$$H_{T,1,2} = (1.5)(0.271)(34.7)\left(\frac{3.8}{5.8^2+3.8^2}\right) = 1.11 \text{ kN}$$

$$H_{T,2,2} = (1.5)(0.729)(34.7)\left(\frac{3.8}{5.8^2+3.8^2}\right) = 3.0 \text{ kN}$$

Group of loads 3:

$$\xi_1 = \frac{\Sigma Q_{r,(min)}}{\Sigma Q_r} = \frac{4 \times 58.6}{159+205} = 0.644$$

$$\xi_2 = 1 - \xi_1 = 0.356$$

$$M = KL_s = K(\xi_1 - 0.50)L = 12.96(0.644 - 0.5)11.7 = 21.84 \text{ kNm}$$

Couple force set 1:

$$H_{T,1,1} = (1.5)(0.356)(21.84)\left(\frac{5.8}{5.8^2+3.8^2}\right) = 1.41 \text{ kN}$$

$$H_{T,2,1} = (1.5)(0.644)(21.84)\left(\frac{5.8}{5.8^2+3.8^2}\right) = 2.55 \text{ kN}$$

Couple force set 2:

$$H_{T,1,2} = (1.5)(0.356)(21.84)\left(\frac{3.8}{5.8^2+3.8^2}\right) = 0.92 \text{ kN}$$

$$H_{T,2,2} = (1.5)(0.644)(21.84)\left(\frac{3.8}{5.8^2+3.8^2}\right) = 1.67 \text{ kN}$$

Group of loads 4:

$$\xi_1 = \frac{\Sigma Q_{r,max}}{\Sigma Q_r} = \frac{4 \times 266.7}{159+205+1100} = 0.729$$

$$\xi_2 = 1 - \xi_1 = 0.271$$

$$M = KL_s = K\left(\xi_1 - 0.50\right)L = 12.96(0.729 - 0.5)11.7 = 34.72 \text{ kNm}$$

Couple force set 1 :

$$H_{T,1,1} = (1.5)(0.271)(34.72)\left(\frac{5.8}{5.8^2+3.8^2}\right) = 1.70 \text{ kN}$$

$$H_{T,2,1} = (1.5)(0.729)(34.72)\left(\frac{5.8}{5.8^2+3.8^2}\right) = 4.58 \text{ kN}$$

Couple force set 2:

$$H_{T,1,2} = (1.5)(0.271)(34.72)\left(\frac{3.8}{5.8^2+3.8^2}\right) = 1.12 \text{ kN}$$

$$H_{T,2,2} = (1.5)(0.729)(34.72)\left(\frac{3.8}{5.8^2+3.8^2}\right) = 3.00 \text{ kN}$$

B.2.7 *Horizontal loads and guide force caused by skewing*

Clause 4.7.4 SANS 10160-6:2010

Guide force $S = f\lambda_{s,j}\sum Q_r$

Horizontal longitudinal forces: $H_{s,i,j,L} = f\lambda_{s,i,j,L}\sum Q_r$

Transverse forces: $H_{s,i,j,T} = f\lambda_{s,i,j,T}\sum Q_r$

Factor $f = 0.3\left(1 - e^{(-250\alpha)}\right) \leq 0.30$

Skewing angle $\alpha = \alpha_F+\alpha_V+\alpha_0 \leq 0.15$

$$\alpha_F = \frac{0.75x}{a} = \frac{0.75(25)}{5800} = 3.23\times10^{-3}$$

where x = clearance between rail and wheel flange

$$\alpha_V = \frac{y}{a} = \frac{7.5}{5800} = 1.29\times10^{-3}$$

where y = wear of rail and guide means ≥ 0.10b = 0.10(75) = 7.5 mm

$\alpha_0 = 0.001$

$\alpha = 5.52\times10^{-3}\text{rad}$

$f = 0.30\left(1 - e^{(-250\times5.52\times10^{-3})}\right) = 0.225 \leq 0.30$

Combination of wheel pairs: independent, fixed/fixed (IFF)

Distance to instantaneous slide pole:

$$h = \frac{\Sigma e_j^2}{\Sigma e_j} = \frac{1000^2+4800^2+5800^2}{1000+4800+5800} = 4972.4 \text{ mm}$$

$$\lambda_{s,j} = 1-\frac{\Sigma e_j}{nh} = 1-\frac{1000+4800+5800}{4\times4972} = 0.417 \text{ mm}$$

$\lambda_{s,1,j,L} = 0$ for IFF

$\xi_1 = 0.729$

$\xi_2 = 1 - \xi_1 = 0.271$

$\lambda_{s,1,j,L} = 0$ for IFF

$$\lambda_{s,1,2,T} = \frac{\xi_2}{n}\left(1-\frac{e_j}{h}\right) = \frac{0.271}{4}\left(1-\frac{1000}{4972.4}\right) = 0.0541$$

$$\lambda_{s,1,3,T} = \frac{\xi_2}{n}\left(1-\frac{e_j}{h}\right) = \frac{0.271}{4}\left(1-\frac{4800}{4972.4}\right) = 0.0023$$

$$\lambda_{s,1,4,T} = \frac{\xi_2}{n}\left(1-\frac{e_j}{h}\right) = \frac{0.271}{4}\left(1-\frac{5800}{4972.4}\right) = -0.0113$$

$\lambda_{s,2,j,L} = 0$ for IFF

$$\lambda_{s,2,1,T} = \frac{\xi_1}{n}\left(1-\frac{e_j}{h}\right) = \frac{0.729}{4} = 0.1823$$

$$\lambda_{s,2,2,T} = \frac{\xi_1}{n}\left(1-\frac{e_j}{h}\right) = \frac{0.729}{4}\left(1-\frac{1000}{4972.4}\right) = 0.1456$$

$$\lambda_{s,2,3,T} = \frac{\xi_1}{n}\left(1-\frac{e_j}{h}\right) = \frac{0.729}{4}\left(1-\frac{4800}{4972.4}\right) = 0.0063$$

$$\lambda_{s,2,4,T} = \frac{\xi_1}{n}\left(1-\frac{e_j}{h}\right) = \frac{0.729}{4}\left(1-\frac{5800}{4972.4}\right) = -0.0303$$

Guide force : $S = f\lambda_{s,j}\sum Q_r=(0.225)(0.417\ )(159+205+1100) = 137.4$ kN

Transverse forces

$H_{s,1,1,T} = f\lambda_{s,1,1,T}\sum Q_r = (0.225)(0.0678)(1464) = 22.3$ kN

$H_{s,1,2,T} = f\lambda_{s,1,2,T}\sum Q_r = (0.225)(0.0541)(1464) = 17.8$ kN

$H_{s,1,3,T} = f\lambda_{s,1,3,T}\sum Q_r = (0.225)(0.0023)(1464) = 0.76$ kN

$H_{s,1,4,T} = f\lambda_{s,1,4,T}\sum Q_r = (0.225)(-0.0113)(1464) = -3.72$ kN

$H_{s,2,1,T} = f\lambda_{s,2,1,T}\sum Q_r = (0.225)(0.1823)(1464) = 60.0$ kN

$H_{s,2,2,T} = f\lambda_{s,2,2,T}\sum Q_r = (0.225)(0.1456)(1464) = 47.96$ kN

$H_{s,2,3,T} = f\lambda_{s,2,3,T}\sum Q_r = (0.225)(0.0063)(1464) = 2.08$ kN

$H_{s,2,4,T} = f\lambda_{s,2,4,T}\sum Q_r = (0.225)(-0.0303)(1464) = -9.98$ kN

B.2.8 *Horizontal forces caused acceleration or deceleration of crab*

Clause 4.7.5 SANS 10160-6:2010

$$H_{T,3} = \frac{0.10(Q_{cr}+Q_h)}{n_w} = \frac{0.10(205+1100)}{8} = 16.3 \text{ kN}$$

Buffer forces related to movements of the crab

Clause 4.12.2 SANS 10160-6:2010

Hoist load is free to swing

$H_{B,2} = H_{T,3}$

B.2.9 *Test loads*

(Dynamic – Acceleration & deceleration of crane bridge)
Clause 4.10 SANS 10160-6:2010

Dynamic test load : $\varphi_{6,dyn}(1.1Q_h) = 1.117(1.1\times1100) = 1351.6$ kN

Static test load : $\varphi_{6,stat}(1.25Q_h) = 1.0(1.25\times1100) = 1375$ kN

<u>Group of loads 9</u>: φ_1(self-weight) + φ_6(test load)

$$\text{Maximum wheel load} = \frac{1}{4}\left[\frac{Q_{br}}{2} + \frac{L-e_{min}}{L}(Q_{cr}+Q_T)\right]$$

$$Q_{r,max} = \frac{1}{4}\left[\frac{205}{2} + \frac{11700-2850}{11700}(159+1210)\right] = 285 \text{ kN}$$

$$\text{Minimum wheel load} = Q_{r,max} = \frac{1}{4}\left[\frac{Q_{br}}{2} + \frac{L-e_{min}}{L}(Q_{cr}+Q_T)\right]$$

$$Q_{r,min} = \frac{1}{4}\left[\frac{205}{2} + \frac{2850}{11700}(159+1210)\right] = 109 \text{ kN}$$

$K = \mu m_w Q_{r,min} = 0.2\times2\times32.4 = 12.96$ kN

$$H_L = 1.5(12.96)\frac{1}{2} = 9.72 \text{ kN}$$

$$\xi_1 = \frac{\Sigma Q_{r,max}}{\Sigma Q_r} = \frac{4 \times 285}{159+205+1210} = 0.724$$

$$\xi_2 = 1-\xi_1 = 0.276$$

$$M = KL_s = K\left(\xi_1 - 0.50\right)L = 12.96(0.724 - 0.5)11.7 = 34 \text{ kNm}$$

Couple force set 1:

$$H_{T,1,1} = \varphi_5 \xi_2 M \frac{a_1}{a_1^2 + a_2^2}$$

$$H_{T,2,1} = \varphi_5 \xi_1 M \frac{a_1}{a_1^2 + a_2^2}$$

Couple force set 2:

$$H_{T,1,2} = \varphi_5 \xi_2 M \frac{a_2}{a_1^2 + a_2^2}$$

$$H_{T,2,2} = \varphi_5 \xi_1 M \frac{a_2}{a_1^2 + a_2^2}$$

Couple force set 1:

$$H_{T,1,1} = (1.5)(0.276)(34)\left(\frac{5.8}{5.8^2+3.8^2}\right) = 1.7 \text{ kN}$$

$$H_{T,2,1} = (1.5)(0.724)(34)\left(\frac{5.8}{5.8^2+3.8^2}\right) = 4.5 \text{ kN}$$

Couple force set 2:

$$H_{T,1,2} = (1.5)(0.276)(34)\left(\frac{3.8}{5.8^2+3.8^2}\right) = 1.1 \text{ kN}$$

$$H_{T,2,2} = (1.5)(0.724)(34)\left(\frac{3.8}{5.8^2+3.8^2}\right) = 2.9 \text{ kN}$$

B.2.10 *Misalignment of crane wheels*

Clause 4.7.6, SANS 10160-6:2010

$$H_{M,i}=\frac{\mu_m(Q_{cr}+Q_{br+}Q_h)}{n_w}=\frac{0.15(205+159+1100)}{8}=27.45\text{ kN}$$

B.2.11 *Buffer forces related to the crane movement*

Clause 4.12.1, SANS 10160-6:2010

$$H_{B,1}=\varphi_7 v_1\sqrt{m_c S_B}$$

$$H_{B,1}=1.53\times0.7\times\frac{3}{60}\sqrt{\left(\frac{(159+205+1100)\times1000}{9.81}\right)\times100\times10^6}$$

$$H_{B,1}=202812.8\text{ N}$$

Therefore buffer force per end stop = 101 kN

B.3 Sixteen Wheel Crane

Calculation of loads imposed by a 150 t overhead travelling crane

Information regarding the 150t overhead travelling crane is shown Table B.3.

Table B.3 Crane supplier information

Weights		
Weight of crane bridge	kN	192.75
Weight of crab	kN	120
Maximum hoist load	kN	1500
Maximum vertical wheel load	kN	533
Minimum vertical wheel load	kN	65
Geometry of crane		
Span of crane bridge	mm	21336
Minimum distance between hoist and rail	mm	3200
Rail type		A100 DIN 536
Width of top of rail	mm	100
Height of rail	mm	85
Speeds		
Steady hoisting speed	m/min	4.5
Long travel speed	m/min	40
Cross travel speed	m/min	20
Guide means		
Guide rollers present		no
Crane classification		
Class of crane		4
Type of hoist		hook
Hoist load free to swing		yes
Buffers		
Buffer type		hydraulic
Buffer characteristic		0.9
Wheels and wheel drives		
Type of wheel drive		single
Number of single wheel drives		2
Behaviour of drive		smooth
Combination of wheel pairs		IFF [(1)]
Clearance between rail and wheel flange	mm	25
Number of wheel pairs		8
Wheel spacing :		
e_1	mm	0
e_2	mm	1000
e_3	mm	2300
e_4	mm	3300
e_5	mm	7500
e_6	mm	8500
e_7	mm	9800
e_8	mm	10800
Coefficient of friction		0.20
[(1)] IFF : *Independent, Fixed/Fixed*		

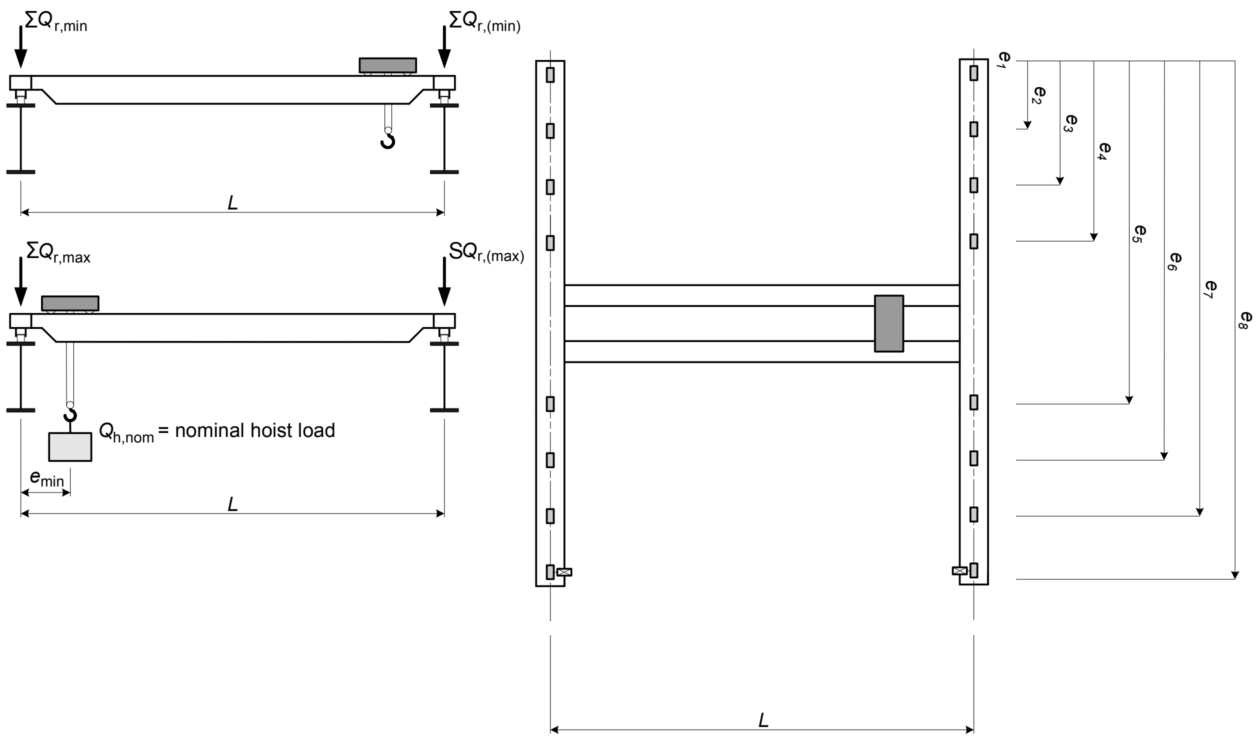


Figure B.6 Proposed wheel configuration of a 16 wheel crane

B.3.1 Classification of crane:

SANS 10160-6:2010, Annex 6A

Hoisting class C4

B.3.2 Groups of actions

The following groups of actions will be calculated:

SANS 10160-6:2010, Table 2

Loading combination 1

φ_1(self-weight of crane) + φ_2(hoist load) + φ_5(acceleration of crane bridge)

Loading combination 3

(self-weight of crane) + φ_5(acceleration of crane bridge)

Loading combination 4

φ_4(self-weight of crane) + φ_4(hoist load) + φ_5(acceleration of crane bridge)

Loading combination 5

φ_4(self-weight of crane) + φ_4(hoist load) + (skewing of crane bridge)

Loading combination 6

φ_4(self-weight of crane) + φ_4(hoist load) + (acceleration or braking of crab)

Loading combination 7

φ_4(self-weight of crane) + φ_4(hoist load) + (misalignment of rails or crane wheels)

Loading combination 9

φ_1(self-weight of crane) + φ_6(test load) + φ_5(acceleration of crane bridge)

Loading combination 10 (accidental)

(self-weight of crane) + (hoist load) + φ_7(buffer force)

B.3.3 Static Wheel Loads

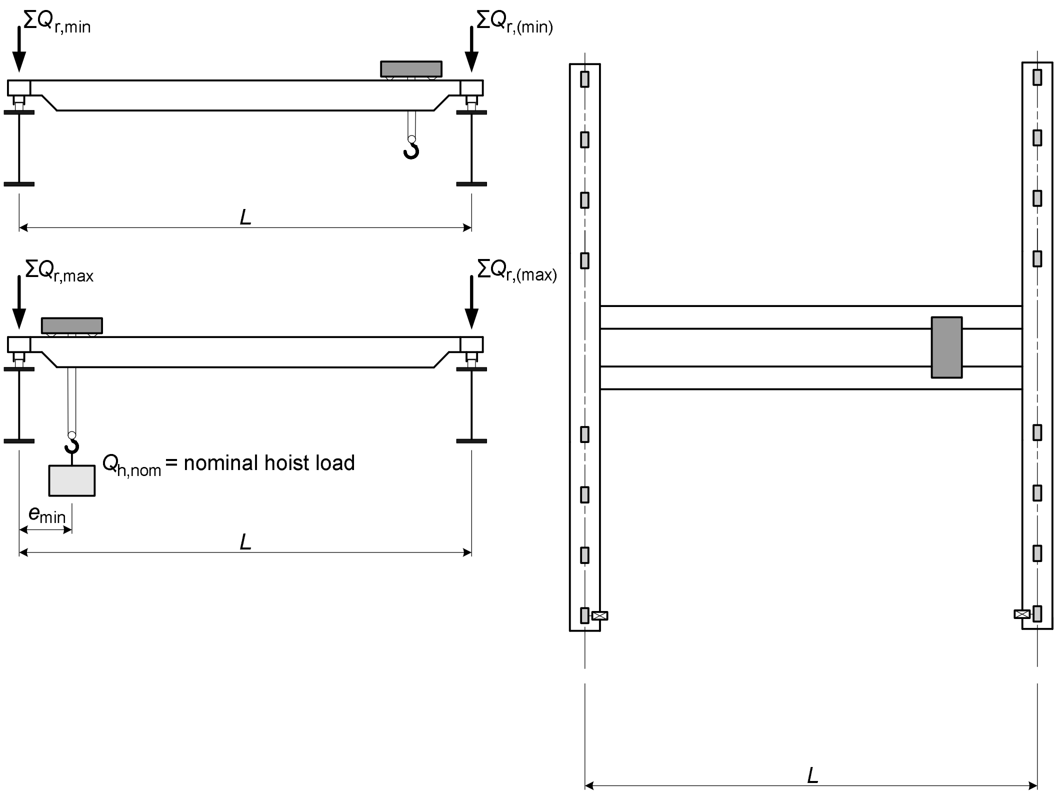


Figure B.7 Static wheel loads for a 16 wheel crane

L = 21.336 m

e_{min} = 3.2 m

Weight of crane bridge (Q_{br}) = 192.75 kN

Weight of Crab (Q_{cr}) = 120 kN

Hoist Load (Q_h) = 1500 kN

Equilibrium:

Maximum vertical wheel loads = $\frac{1}{8}\left[\frac{Q_{br}}{2}+\frac{l\text{-}e_{min}}{l}(Q_{cr}+Q_h)\right]$

$$Q_{r,max} = \frac{1}{8}\left[\frac{192.75}{2}+\frac{21336\text{-}3200}{21336}(120+1500)\right]= 184.2 \text{ kN}$$

Maximum accompanying vertical wheel load = $\frac{1}{8}\left[\frac{Q_{br}}{2}+\frac{e_{min}}{l}(Q_{cr}+Q_h)\right]$

$$Q_{r,(max)} = \frac{1}{8}\left[\frac{192.75}{2}+\frac{3200}{21336}(120+1500)\right]= 42.4 \text{ kN}$$

Minimum accompanying vertical wheel load = $\frac{1}{8}\left[\frac{Q_{br}}{2}+\frac{l\text{-}e_{min}}{l}(Q_{cr})\right]$

$$Q_{r,(min)} = \frac{1}{8}\left[\frac{192.75}{2}+\frac{21336\text{-}3200}{21336}(120)\right]= 24.8 \text{ kN}$$

Minimum vertical wheel load = $\frac{1}{2}\left[\frac{Q_{br}}{2}+\frac{e_{min}}{l}(Q_{cr})\right]$

$$Q_{r,min} = \frac{1}{8}\left[\frac{192.75}{2}+\frac{3200}{21336}(120)\right]= 14.3 \text{ kN}$$

B.3.4 Dynamic factors

φ_1 - vibrational excitation of the crane due to lifting of the hoist load off the ground, applied to the self-weight of the crane

Clause 4.6.3, Table 4, SANS 10160-6:2010

φ_1 = 1.10

φ_2 - dynamic effects of transferring the hoist load from the ground to the crane, applied to the hoist load

Clause 4.6.3, Table 4, SANS 10160-6:2010

$\varphi_2 = \varphi_{2,min}+\beta_2 V_h$

Hoisting class C4

$\varphi_{2,min}$=1.20

β_2=0.68

v=$\frac{4.5}{60}$ steady hoisting speed in m/min

$\varphi_2 = 1.20+(0.68)\left(\frac{4.5}{60}\right)=1.251$

φ_4 - dynamic effect induced when travelling on rail tracks or runways applied to the self-weight of the crane and the hoist load
Clause 4.6.3, Table 4, SANS 10160-6:2010

φ_4 = 1.0, assume tolerances for rail tracks specified in SANS 2001 CSI are observed.

φ_5 - effects caused by drive forces, applied to the drive force
Clause 4.7.2 (b), Table 6, SANS 10160-6:2010

Forces change smoothly: φ_5= 1.5

φ_6 - when a test load is moved by the drives in the way the crane is used, applied to the test load
Clause 4.10 4, SANS 10160-6:2010

$\varphi_6 = 0.5(1+\varphi_2) = 0.5(1+1.251) = 1.126$

φ_6 - for the static test, applied to the static test load, Clause 4.10.4b), SANS 10160-6:2010

φ_6 = 1.0

φ_7 - elastic effects of impact on buffers
Clause 4.12.1.2, Table 9, SANS 10160-6:2010

$\varphi_7 = 1.25+0.70(\xi-0.50) = 1.25+0.70(0.9-0.50)$

φ_7 = 1.53

B.3.5 Vertical loads from overhead travelling crane

Clause 4.5.3, SANS 10160-6:2010

Group of loads 1: φ_1 (self-weight)+φ_2 (hoist load)

Maximum wheel load = $\frac{1}{8}\left(\varphi_1\frac{Q_{br}}{2}+\frac{l-e_{min}}{l}\left(\varphi_1 Q_{cr}+\varphi_2 Q_h\right)\right)$

$$Q_{r,max} = \frac{1}{8}\left[(1.1)\frac{192.75}{2} + \frac{21336\text{-}3200}{21336}(1.1\times120 + 1.251\times1500)\right] = 226.7 \text{ kN}$$

$$\text{Minimum wheel load} = \frac{1}{8}\left[\varphi_1\frac{Q_{br}}{2} + \frac{e_{min}}{l}\left[\varphi_1 Q_{cr} + \varphi_2 Q_h\right]\right]$$

$$Q_{r,(max)} = \frac{1}{8}\left[(1.1)\frac{192.75}{2} + \frac{3200}{21336}(1.1\times120 + 1.251\times1500)\right] = 50.9 \text{ kN}$$

Group of loads 3: self-weight

$$\text{Maximum wheel load} = \frac{1}{8}\left[\frac{Q_{br}}{2} + \frac{l\text{-}e_{min}}{l}(Q_{cr})\right]$$

$$Q_{r,(min)} = \frac{1}{8}\left[\frac{192.75}{2} + \frac{21336\text{-}3200}{21336}(120)\right] = 24.8 \text{ kN}$$

$$\text{Minimum wheel load} = \frac{1}{8}\left[\frac{Q_{br}}{2} + \frac{e_{min}}{l}(Q_{cr})\right]$$

$$Q_{r,min} = \frac{1}{8}\left[\frac{192.75}{2} + \frac{3200}{21336}(120)\right] = 14.3 \text{ kN}$$

Group of loads 4, 5, 6 and 7 : φ_4 (self-weight) + φ_4 (hoist load)

$$\text{Maximum wheel load} = \frac{\varphi_4}{8}\left[\frac{Q_{br}}{2} + \frac{l\text{-}e_{min}}{l}(Q_{cr} + Q_h)\right]$$

$$Q_{r,max} = \frac{1}{8}\left[\frac{192.75}{2} + \frac{21336\text{-}3200}{21336}(120 + 1500)\right] = 184.2 \text{ kN}$$

$$\text{Minimum wheel load} = \frac{\varphi_4}{8}\left[\frac{Q_{br}}{2} + \frac{e_{min}}{l}(Q_{cr} + Q_h)\right]$$

$$Q_{r,(max)} = \frac{1}{8}\left[\frac{192.75}{2} + \frac{3200}{21336}(120+1500)\right] = 42.4 \text{ kN}$$

Group of loads 9: φ_1 (self-weight) + φ_6 (test load)

Dynamic Test Load = 110% of hoist load

$$\text{Maximum wheel load} = \frac{1}{8}\left[\varphi_1\frac{Q_{br}}{2} + \frac{l\text{-}e_{min}}{l}\left[\varphi_1 Q_{cr} + \varphi_6 Q_t\right]\right]$$

Q_t = 1.1×1500 = 1650 kN

φ_6 = 1.126

$$Q_{r,max} = \frac{1}{8}\left[(1.1)\frac{192.75}{2} + \frac{21336\text{-}3200}{21336}(1.1\times120 + 1.126\times1650)\right] = 224.7 \text{ kN}$$

Minimum wheel load = $\frac{1}{8}\left[\varphi_1 \frac{Q_{br}}{2} + \frac{e_{min}}{l}\left(\varphi_1 Q_{cr} + \varphi_6 Q_t\right)\right]$

$$Q_{r,(max)} = \frac{1}{8}\left[(1.1)\frac{192.75}{2} + \frac{3200}{21336}(1.1\times120 + 1.126\times1650)\right] = 50.6 \text{ kN}$$

Static Test Load = 125% of hoist load

$Q_t = 1.25\times1500 = 1875$ kN

$\varphi_6 = 1.0$

$$Q_{r,max} = \frac{1}{8}\left[(1.1)\frac{192.75}{2} + \frac{21336\text{-}3200}{21336}(1.1\times120 + 1.0\times1875)\right] = 226.5 \text{ kN}$$

$$Q_{r,min} = \frac{1}{8}\left[(1.1)\frac{192.75}{2} + \frac{3200}{21336}(1.1\times120 + 1.0\times1875)\right] = 50.9 \text{ kN}$$

Group of loads 10: (self-weight) + (hoist load)

Maximum wheel load = $\frac{1}{8}\left[\frac{Q_{br}}{2} + \frac{l\text{-}e_{min}}{l}(Q_{cr} + Q_h)\right]$

$$Q_{r,max} = \frac{1}{8}\left[\frac{192.75}{2} + \frac{21336\text{-}3200}{21336}(120 + 1500)\right] = 184.2 \text{ kN}$$

Minimum wheel load = $\frac{1}{8}\left[\frac{Q_{br}}{2} + \frac{e_{min}}{l}(Q_{cr} + Q_h)\right]$

$$Q_{r,(max)} = \frac{1}{8}\left[\frac{192.75}{2} + \frac{3200}{21336}(120+1500)\right] = 42.4 \text{ kN}$$

B.3.6 Longitudinal and transverse loads caused by acceleration and deceleration of crane

Clause 4.7.2 SANS 10160-6:2010

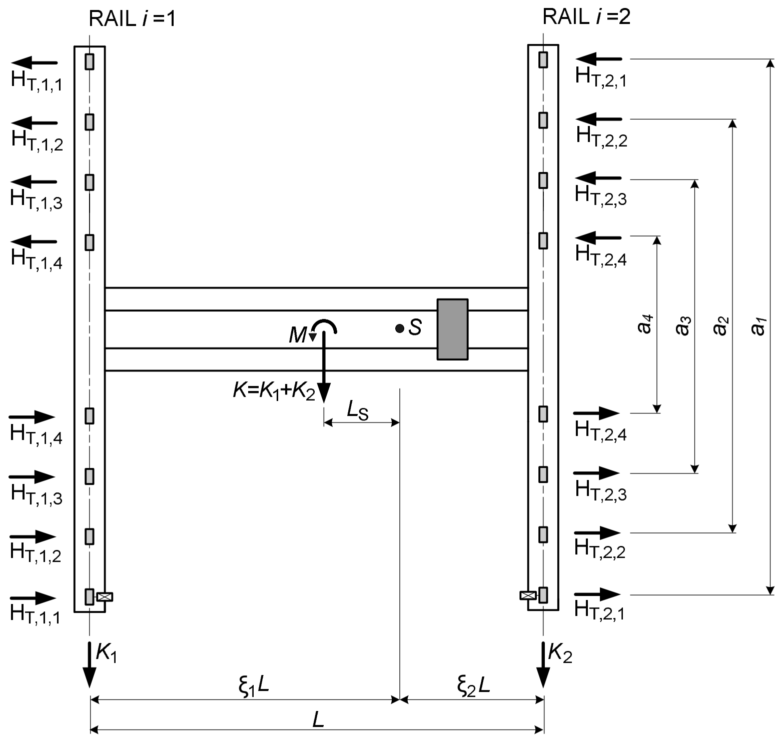


Figure B.8 Load configuration for the acceleration or deceleration of a 16 wheel crane

$$H_L = \varphi_5 K \frac{1}{n_r} = K_1 = K_2$$

n_r = number of rails

Drive force K :

$$K = \mu \Sigma Q^*_{r,min} = \mu m_w Q_{r,min} = 0.2 \times 2 \times 14.3 = 5.72 \text{ kN}$$

where m_w = number of single wheel drives

$$H_L = 1.5(5.72)\frac{1}{2} = 4.29 \text{ kN}$$

Couple force set 1 :

$$H_{T,1,1} = \varphi_5 \xi_2 M \frac{a_1}{a_1^2 + a_2^2 + a_3^2 + a_4^2}$$

$$H_{T,2,1} = \varphi_5 \xi_1 M \frac{a_1}{a_1^2 + a_2^2 + a_3^2 + a_4^2}$$

Couple force set 2 :

$$H_{T,1,2} = \varphi_5 \xi_2 M \frac{a_2}{a_1^2 + a_2^2 + a_3^2 + a_4^2}$$

$$H_{T,2,2} = \varphi_5 \xi_1 M \frac{a_2}{a_1^2 + a_2^2 + a_3^2 + a_4^2}$$

Couple force set 3 :

$$H_{T,1,3} = \varphi_5 \xi_2 M \frac{a_3}{a_1^2 + a_2^2 + a_3^2 + a_4^2}$$

$$H_{T,2,3} = \varphi_5 \xi_1 M \frac{a_3}{a_1^2 + a_2^2 + a_3^2 + a_4^2}$$

Couple force set 4 :

$$H_{T,1,4} = \varphi_5 \xi_2 M \frac{a_4}{a_1^2 + a_2^2 + a_3^2 + a_4^2}$$

$$H_{T,2,4} = \varphi_5 \xi_1 M \frac{a_4}{a_1^2 + a_2^2 + a_3^2 + a_4^2}$$

Group of loads 1:

$$\xi_1 = \frac{\Sigma Q_{r,max}}{\Sigma Q_r} = \frac{8 \times 184.2}{192.75+120+1500} = 0.813$$

$$\xi_2 = 1 - \xi_1 = 0.187$$

$$M = KL_s = K(\xi_1 - 0.50)L = 5.72(0.813 - 0.5)21.336 = 38.2 \text{ kNm}$$

Couple force set 1:

$$H_{T,1,1} = (1.5)(0.187)(38.2)\left(\frac{10.8}{10.8^2+8.8^2+6.2^2+4.2^2}\right) = 0.463 \text{ kN}$$

$$H_{T,2,1} = (1.5)(0.813)(38.2)\left(\frac{10.8}{10.8^2+8.8^2+6.2^2+4.2^2}\right) = 2.01 \text{ kN}$$

Couple force set 2:

$$H_{T,1,2} = (1.5)(0.187)(38.2)\left(\frac{8.8}{10.8^2+8.8^2+6.2^2+4.2^2}\right) = 0.376 \text{ kN}$$

$$H_{T,2,1} = (1.5)(0.813)(38.2)\left(\frac{8.8}{10.8^2+8.8^2+6.2^2+4.2^2}\right) = 1.64 \text{ kN}$$

Couple force set 3 :

$$H_{T,1,3} = (1.5)(0.187)(38.2)\left(\frac{6.2}{10.8^2+8.8^2+6.2^2+4.2^2}\right) = 0.266 \text{ kN}$$

$$H_{T,2,3} = (1.5)(0.813)(38.2)\left(\frac{6.2}{10.8^2+8.8^2+6.2^2+4.2^2}\right) = 1.15 \text{ kN}$$

Couple force set 4 :

$$H_{T,1,4} = (1.5)(0.187)(38.2)\left(\frac{4.2}{10.8^2+8.8^2+6.2^2+4.2^2}\right) = 0.180 \text{ kN}$$

$$H_{T,2,4} = (1.5)(0.813)(38.2)\left(\frac{4.2}{10.8^2+8.8^2+6.2^2+4.2^2}\right) = 0782 \text{ kN}$$

Group of loads 3:

$$\xi_1 = \frac{\Sigma Q_{r,(min)}}{\Sigma Q_r} = \frac{8 \times 24.8}{192.75+120} = 0.634$$

$$\xi_2 = 1 - \xi_1 = 0.366$$

$$M = KL_s = K(\xi_1 - 0.50)L = 5.72(0.634 - 0.5)21.336 = 16.4 \text{ kNm}$$

Couple force set 1:

$$H_{T,1,1} = (1.5)(0.366)(16.4)\left(\frac{10.8}{10.8^2+8.8^2+6.2^2+4.2^2}\right) = 0.389 \text{ kN}$$

$$H_{T,2,1} = (1.5)(0.634)(16.4)\left(\frac{10.8}{10.8^2+8.8^2+6.2^2+4.2^2}\right) = 0.673 \text{ kN}$$

Couple force set 2 :

$$H_{T,1,2} = (1.5)(0.366)(16.4)\left(\frac{8.8}{10.8^2+8.8^2+6.2^2+4.2^2}\right) = 0.317 \text{ kN}$$

$$H_{T,2,1} = (1.5)(0.634)(16.4)\left(\frac{8.8}{10.8^2+8.8^2+6.2^2+4.2^2}\right) = 0.549 \text{ kN}$$

Couple force set 3 :

$$H_{T,1,3} = (1.5)(0.366)(16.4)\left(\frac{6.2}{10.8^2+8.8^2+6.2^2+4.2^2}\right) = 0.223 \text{ kN}$$

$$H_{T,2,3} = (1.5)(0.634)(16.4)\left(\frac{6.2}{10.8^2+8.8^2+6.2^2+4.2^2}\right) = 0.387 \text{ kN}$$

Couple force set 4 :

$$H_{T,1,4} = (1.5)(0.366)(16.4)\left(\frac{4.2}{10.8^2+8.8^2+6.2^2+4.2^2}\right) = 0.151 \text{ kN}$$

$$H_{T,2,4} = (1.5)(0.634)(16.4)\left(\frac{4.2}{10.8^2+8.8^2+6.2^2+4.2^2}\right) = 0.262 \text{ kN}$$

Load Combination 4:

$$\xi_1 = \frac{\Sigma Q_{r,max}}{\Sigma Q_r} = \frac{8\times184.2}{192.75+120+1500} = 0.813$$

$$\xi_2 = 1 - \xi_1 = 0.187$$

$$M = KL_s = K\left(\xi_1 - 0.50\right)L = 5.72(0.813 - 0.5)21.336 = 38.20 \text{ kNm}$$

Couple force set 1:

$$H_{T,1,1} = (1.5)(0.187)(38.20)\left[\frac{10.8}{10.8^2+8.8^2+6.2^2+4.2^2}\right] = 0.463 \text{ kN}$$

$$H_{T,2,1} = (1.5)(0.813)(38.20)\left[\frac{10.8}{10.8^2+8.8^2+6.2^2+4.2^2}\right] = 2.01 \text{ kN}$$

Couple force set 2:

$$H_{T,1,2} = (1.5)(0.187)(38.20)\left[\frac{8.8}{10.8^2+8.8^2+6.2^2+4.2^2}\right] = 0.377 \text{ kN}$$

$$H_{T,2,1} = (1.5)(0.813)(38.20)\left[\frac{8.8}{10.8^2+8.8^2+6.2^2+4.2^2}\right] = 1.64 \text{ kN}$$

Couple force set 3 :

$$H_{T,1,3} = (1.5)(0.187)(38.20)\left[\frac{6.2}{10.8^2+8.8^2+6.2^2+4.2^2}\right] = 0.266 \text{ kN}$$

$$H_{T,2,3} = (1.5)(0.813)(38.20)\left[\frac{6.2}{10.8^2+8.8^2+6.2^2+4.2^2}\right] = 1.15 \text{ kN}$$

Couple force set 4 :

$$H_{T,1,4} = (1.5)(0.187)(38.20)\left[\frac{4.2}{10.8^2+8.8^2+6.2^2+4.2^2}\right] = 0.180 \text{ kN}$$

$$H_{T,2,4} = (1.5)(0.813)(38.20)\left[\frac{4.2}{10.8^2+8.8^2+6.2^2+4.2^2}\right] = 0.782 \text{ kN}$$

B.3.7 Horizontal loads and guide force caused by skewing

Clause 4.7.4 SANS 10160-6:2010

Guide force $S = f\lambda_{s,j}\sum Q_r$

Horizontal longitudinal forces : $H_{s,i,j,L} = f\lambda_{s,i,j,L}\sum Q_r$

Transverse forces : $H_{s,i,j,T} = f\lambda_{s,i,j,T}\sum Q_r$

Factor $f = 0.3\left(1 - e^{(-250\alpha)}\right) \leq 0.30$

Skewing angle $\alpha = \alpha_F+\alpha_V+\alpha_0 \leq 0.15$

$$\alpha_F = \frac{0.75x}{a} = \frac{0.75(25)}{10800} = 1.74\times10^{-3}$$

where x = clearance between rail and wheel flange

$$\alpha_V = \frac{y}{a} = \frac{10}{10800} = 0.926\times10^{-3}$$

where y = wear of rail and guide means $\geq 0.10b = 0.10(100) = 10$ mm

$\alpha_0 = 0.001$

$\alpha = 3.67\times10^{-3}$rad

$$f = 0.30\left(1 - e^{(-250\times3.67\times10^{-3})}\right) = 0.180 \leq 0.30$$

Combination of wheel pairs: independent, fixed/fixed (IFF)

Distance to instantaneous slide pole :

$$h = \frac{\Sigma e_j^2}{\Sigma e_j} = \frac{1000^2+2300^2+3300^2+7500^2+8500^2+9800^2+10800^2}{1000+2300+3300+7500+8500+9800+10800} = 8295.37\text{mm}$$

$$\lambda_{s,j} = 1-\frac{\Sigma e_j}{nh} = 1-\frac{1000+2300+3300+7500+8500+9800+10800}{8\times8295.37} = 0.349 \text{ mm}$$

$\lambda_{s,i,j,L} = 0$ for IFF

$$\lambda_{s,1,1,T} = \frac{\xi_2}{n}\left(1-\frac{e_j}{h}\right) = \frac{0.187}{8} = 0.0234$$

$$\lambda_{s,1,2,T} = \frac{\xi_2}{n}\left(1-\frac{e_j}{h}\right) = \frac{0.187}{8}\left(1-\frac{1000}{8295.37}\right) = 0.0206$$

$$\lambda_{s,1,3,T} = \frac{\xi_2}{n}\left(1-\frac{e_j}{h}\right) = \frac{0.187}{8}\left(1-\frac{2300}{8295.37}\right) = 0.0169$$

$$\lambda_{s,1,4,T} = \frac{\xi_2}{n}\left(1-\frac{e_j}{h}\right) = \frac{0.187}{8}\left(1-\frac{3300}{8295.37}\right) = 0.0141$$

$$\lambda_{s,1,5,T} = \frac{\xi_2}{n}\left(1-\frac{e_j}{h}\right) = \frac{0.187}{8}\left(1-\frac{7500}{8295.37}\right) = 0.0022$$

$$\lambda_{s,1,6,T} = \frac{\xi_2}{n}\left(1-\frac{e_j}{h}\right) = \frac{0.187}{8}\left(1-\frac{8500}{8295.37}\right) = -0.0006$$

$$\lambda_{s,1,7,T} = \frac{\xi_2}{n}\left(1-\frac{e_j}{h}\right) = \frac{0.187}{8}\left(1-\frac{9800}{8295.37}\right) = -0.0042$$

$$\lambda_{s,1,8,T} = \frac{\xi_2}{n}\left(1-\frac{e_j}{h}\right) = \frac{0.187}{8}\left(1-\frac{10800}{8295.37}\right) = -0.0071$$

$$\lambda_{s,2,1,T} = \frac{\xi_1}{n}\left(1-\frac{e_j}{h}\right) = \frac{0.813}{8} = 0.1016$$

$$\lambda_{s,2,2,T} = \frac{\xi_1}{n}\left(1-\frac{e_j}{h}\right) = \frac{0.813}{8}\left(1-\frac{1000}{8295.37}\right) = 0.0894$$

$$\lambda_{s,2,3,T} = \frac{\xi_1}{n}\left(1-\frac{e_j}{h}\right) = \frac{0.813}{8}\left(1-\frac{2300}{8295.37}\right) = 0.0734$$

$$\lambda_{s,2,4,T} = \frac{\xi_1}{n}\left(1-\frac{e_j}{h}\right) = \frac{0.813}{8}\left(1-\frac{3300}{8295.37}\right) = 0.0612$$

$$\lambda_{s,2,5,T} = \frac{\xi_1}{n}\left(1-\frac{e_j}{h}\right) = \frac{0.813}{8}\left(1-\frac{7500}{8295.37}\right) = 0.0097$$

$$\lambda_{s,2,6,T} = \frac{\xi_1}{n}\left(1-\frac{e_j}{h}\right) = \frac{0.813}{8}\left(1-\frac{8500}{8295.37}\right) = -0.0025$$

$$\lambda_{s,2,7,T} = \frac{\xi_1}{n}\left(1-\frac{e_j}{h}\right) = \frac{0.813}{8}\left(1-\frac{9800}{8295.37}\right) = -0.0184$$

$$\lambda_{s,2,8,T} = \frac{\xi_1}{n}\left(1-\frac{e_j}{h}\right) = \frac{0.813}{8}\left(1-\frac{10800}{8295.37}\right) = -0.0307$$

Guide force : $S = f\lambda_{s,j}\sum Q_r = (0.180)(0.349)(192.75+120+1500) = 113.88$ kN

Transverse forces

$H_{s,1,1,T} = f\lambda_{s,1,1,T}\sum Q_r = (0.180)(0.0234)(1812.75) = 7.64$ kN

$H_{s,1,2,T} = f\lambda_{s,1,2,T}\sum Q_r = (0.180)(0.0206)(1812.75) = 6.72$ kN

$H_{s,1,3,T} = f\lambda_{s,1,3,T}\sum Q_r = (0.180)(0.0169)(1812.75) = 5.51$ kN

$H_{s,1,4,T} = f\lambda_{s,1,4,T}\sum Q_r = (0.180)(0.0141)(1812.75) = 4.60$ kN

$H_{s,1,5,T} = f\lambda_{s,1,5,T}\sum Q_r = (0.180)(0.0022)(1812.75) = 0.72$ kN

$H_{s,1,6,T} = f\lambda_{s,1,6,T}\sum Q_r = (0.180)(-0.0006)(1812.75) = -0.20$ kN

$H_{s,1,7,T} = f\lambda_{s,1,7,T}\sum Q_r = (0.180)(-0.0042)(1812.75) = -1.37$ kN

$H_{s,1,8,T} = f\lambda_{s,1,8,T}\sum Q_r = (0.180)(-0.0071)(1812.75) = -2.32$ kN

$H_{s,2,1,T} = f\lambda_{s,2,1,T}\sum Q_r = (0.180)(0.1016)(1812.75) = 33.15$ kN

$H_{s,2,2,T} = f\lambda_{s,2,2,T}\sum Q_r = (0.180)(0.0894)(1812.75) = 29.17$ kN

$H_{s,2,3,T} = f\lambda_{s,2,3,T}\sum Q_r = (0.180)(0.0734)(1812.75) = 23.95$ kN

$H_{s,2,4,T} = f\lambda_{s,2,4,T}\sum Q_r = (0.180)(0.0612)(1812.75) = 19.97$ kN

$H_{s,2,5,T} = f\lambda_{s,2,5,T}\sum Q_r = (0.180)(0.0097)(1812.75) = 3.17$ kN

$H_{s,2,6,T} = f\lambda_{s,2,6,T}\sum Q_r = (0.180)(-0.0025)(1812.75) = -0.82$ kN

$H_{s,2,7,T} = f\lambda_{s,2,7,T}\sum Q_r = (0.180)(-0.0184)(1812.75) = 6.00$ kN

$H_{s,2,8,T} = f\lambda_{s,2,8,T}\sum Q_r = (0.180)(-0.0307)(1812.75) = -10.02$ kN

B.3.8 Horizontal forces caused acceleration or deceleration of crab

Clause 4.7.5 SANS 10160-6:2010

$$H_{T,3} = \frac{0.10(Q_{cr}+Q_h)}{n_w} = \frac{0.10(120+1500)}{16} = 10.125 \text{ kN}$$

Buffer forces related to movements of the crab

Clause 4.12.2 SANS 10160-6:2010
Hoist load is free to swing

$H_{B,2} = H_{T,3}$

B.3.9 Test loads

(Dynamic – Acceleration & deceleration of crane bridge)
Clause 4.10 SANS 10160

Dynamic test load : $\varphi_{6,dyn}(1.1Q_h) = 1.126(1.1\times1500) = 1857.9$ kN

Static test load : $\varphi_{6,stat}(1.25Q_h) = 1.0(1.25\times1500) = 1875$ kN

Group of loads 9: φ_1(self-weight) + φ_6(test load)

$$\text{Maximum wheel load} = \frac{1}{8}\left[\frac{Q_{br}}{2} + \frac{L-e_{min}}{L}(Q_{cr}+Q_T)\right]$$

$$Q_{r,max} = \frac{1}{8}\left[\frac{192.75}{2} + \frac{21336-3200}{21336}(120+1650)\right] = 200 \text{ kN}$$

$$\text{Minimum wheel load} = Q_{r,max} = \frac{1}{8}\left[\frac{Q_{br}}{2} + \frac{L-e_{min}}{L}(Q_{cr}+Q_T)\right]$$

$$Q_{r,(max)} = \frac{1}{8}\left[\frac{192.75}{2} + \frac{3200}{21336}(120+1650)\right] = 45.2 \text{ kN}$$

$$K = \mu\Sigma Q^{*}_{r,min} = \mu m_w Q_{r,min} = 0.2\times2\times14.3 = 5.72 \text{ kN}$$

$$H_L = 1.5(5.72)\frac{1}{2} = 4.29 \text{ kN}$$

$$\xi_1 = \frac{\Sigma Q_{r,max}}{\Sigma Q_r} = \frac{8\times200}{192.75+120+1650} = 0.815$$

$$\xi_2 = 1-\xi_1 = 0.185$$

$$M = KL_s = K\left(\xi_1 - 0.50\right)L = 5.72(0.815 - 0.5)21.336 = 38.4 \text{ kNm}$$

Couple force set 1 :

$$H_{T,1,1} = (1.5)(\ 0.185)(38.4\ ) \left[\frac{10.8}{10.8^2+8.8^2+6.2^2+4.2^2} \right] = 0.460 \text{ kN}$$

$$H_{T,2,1} = (1.5)(0.815)(38.4\ ) \left[\frac{10.8}{10.8^2+8.8^2+6.2^2+4.2^2} \right] = 2.03 \text{ kN}$$

Couple force set 2 :

$$H_{T,1,2} = (1.5)(\ 0.185)(38.4\ ) \left[\frac{8.8}{10.8^2+8.8^2+6.2^2+4.2^2} \right] = 0.375 \text{ kN}$$

$$H_{T,2,1} = (1.5)(0.815)(38.4\ ) \left[\frac{8.8}{10.8^2+8.8^2+6.2^2+4.2^2} \right] = 1.65 \text{ kN}$$

Couple force set 3 :

$$H_{T,1,3} = (1.5)(\ 0.185)(38.4\ ) \left[\frac{6.2}{10.8^2+8.8^2+6.2^2+4.2^2} \right] = 0.264 \text{ kN}$$

$$H_{T,2,3} = (1.5)(0.815)(38.4\ ) \left[\frac{6.2}{10.8^2+8.8^2+6.2^2+4.2^2} \right] = 1.16 \text{ kN}$$

Couple force set 4 :

$$H_{T,1,4} = (1.5)(\ 0.185)(38.4\ ) \left[\frac{4.2}{10.8^2+8.8^2+6.2^2+4.2^2} \right] = 0.179 \text{ kN}$$

$$H_{T,2,4} = (1.5)(0.815)(38.4\ ) \left[\frac{4.2}{10.8^2+8.8^2+6.2^2+4.2^2} \right] = 0.788 \text{ kN}$$

B.3.10 Misalignment of crane wheels

$$H_{M,i} = \frac{\mu_m (Q_{cr}+Q_{br}+Q_h)}{n_w} = \frac{0.2(120+192.75+1500)}{16} = 22.7 \text{ kN}$$

B.3.11 Buffer forces related to the crane movement

Clause 4.12.1, SANS 10160-6:2010

$$H_{B,1} = \varphi_7 v_1 \sqrt{m_c S_B}$$

$$H_{B,1} = 1.53 \times 0.7 \times \frac{4.5}{60} \sqrt{\left(\frac{(192.75+120+1500) \times 1000}{9.81} \right) \times 100 \times 10^6}$$

$H_{B,1}$=345291 N

Therefore buffer force per end stop = 172.6 kN

Annex C

C Derivation of equations for the transverse horizontal loads as a result of the acceleration or deceleration of a sixteen wheel crane

For the explanation that follows the following notation is adopted.

Horizontal transverse forces, $H_{T,i,j}$

Where:

- T is the horizontal transverse force
- i is the rail, either 1 or 2
- j is the wheel pair

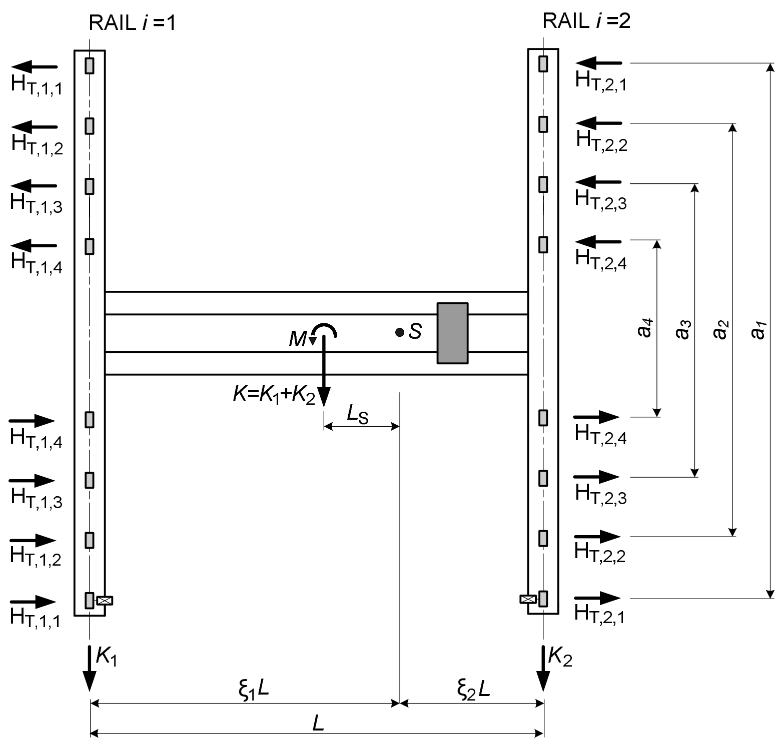


Figure C.1 Horizontal transverse forces as a result of the acceleration or deceleration of the crane

Where:

- K The total drive force
- M $= KL_s$
- K1 The drive force for rail 1
- K2 The drive force for rail 2

C.1 Rail 1

For the load scenario shown in Figure 3.11 and Equation 3.2, Equation C.1 takes precedence for rail 1.

$$H_{T,1,1}(a_1)+H_{T,1,2}(a_2)+H_{T,1,3}(a_3)+H_{T,1,4}(a_4)=\xi_2 M \tag{C.1}$$

Assume a rigid end carriage as seen in plan-view. A linear relation between $H_{T,1,1}$and $H_{T,1.2}$, $H_{T,1,1}$ and $H_{T,1,3}$ and $H_{T,1,1}$ and $H_{T,1,4}$ can be established resulting in the expression in Equations C.2, C.3 and C.4 respectively.

$$H_{T,1,2}=\frac{a_2}{a_1}\left(H_{T,1,1}\right) \tag{C.2}$$

$$H_{T,1,3}=\frac{a_3}{a_1}\left(H_{T,1,1}\right) \tag{C.3}$$

$$H_{T,1,4}=\frac{a_4}{a_1}\left(H_{T,1,1}\right) \tag{C.4}$$

Substituting C.2, C.3, and C.4 into equation C.1 Equation C.5 is obtained. Simplifying C.5 an expression for $H_{T,1,1}$ is obtained as shown in Equation C.6

$$H_{T,1,1}\left(\left(\frac{a_1^2}{a_1}\right)+\left(\frac{a_2^2}{a_1}\right)+\left(\frac{a_3^2}{a_1}\right)+\left(\frac{a_4^2}{a_1}\right)\right)=\xi_2 M H_{T,1,1}=\frac{a_1}{a_1^2+a_2^2+a_3^2+a_4^2}\xi_2 M \tag{C.6}$$

Substituting Equation C.6 into C.2, C.3 and C.4 respectively the expressions for $H_{T,1,2}$, $H_{T,1,3}$ and $H_{T,1,4}$ are obtained as shown in Equations C.7, C8 and C9 respectively.

C.2 Rail 2

The same procedure and reasoning is carried out for rail to determine the horizontal transverse loads that will act on rail 2.

For the load scenario shown in Figure 3.11 and Equation 3.3, Equation C.10 takes precedence for rail 2.

$$H_{T,2,1}(a_1)+H_{T,2,2}(a_2)+H_{T,2,3}(a_3)+H_{T,2,4}(a_4)=\xi_1 M \tag{C.10}$$

Assume a rigid end carriage as seen in plan-view. A linear relation between $H_{T,2,1}$and $H_{T,2.2}$, $H_{T,2,1}$ and $H_{T,2,3}$ and $H_{T,2,1}$ and $H_{T,2,4}$ can be established resulting in the expression in Equations C.11, C.12 and C.13 respectively.

$$H_{T,2,2}=\frac{a_2}{a_1}\left(H_{T,2,1}\right) \tag{C.11}$$

$$H_{T,2,3}=\frac{a_3}{a_1}\left(H_{T,2,1}\right) \tag{C.12}$$

$$H_{T,2,4}=\frac{a_4}{a_1}\left(H_{T,2,1}\right) \qquad \text{(C.13)}$$

Substituting C.11, C.12, and C.13 into equation C.10 Equation C.14 is obtained. Simplifying C.14 an expression for $H_{T,2,1}$ is obtained as shown in Equation C.15

$$H_{T,2,1}\left(\left(\frac{a_1^2}{a_1}\right)+\left(\frac{a_2^2}{a_1}\right)+\left(\frac{a_3^2}{a_1}\right)+\left(\frac{a_4^2}{a_1}\right)\right)=\xi_1 M \qquad \text{(C.14)}$$

$$H_{T,2,1}=\frac{a_1}{a_1^2+a_2^2+a_3^2+a_4^2}\xi_1 M \qquad \text{(C.15)}$$

Substituting Equation C.15 into C.11, C.12 and C.13 respectively the expressions for $H_{T,2,2}$, $H_{T,2,3}$ and $H_{T,2,4}$ are obtained as shown in Equations C.16, C17 and C18 respectively.

$$H_{T,2,2}=\frac{a_2}{a_1^2+a_2^2+a_3^2+a_4^2}\xi_1 M \qquad \text{(C.16)}$$

$$H_{T,2,3}=\frac{a_3}{a_1^2+a_2^2+a_3^2+a_4^2}\xi_1 M \qquad \text{(C.17)}$$

$$H_{T,2,4}=\frac{a_4}{a_1^2+a_2^2+a_3^2+a_4^2}\xi_1 M \qquad \text{(C.18)}$$

Appendix D

D Microsoft Excel Examples

References

De Lange, J. H. (2007). Behaviour of a 5tone electric overhead travelling crane and its supporting structure. *Behaviour of a 5tone electric overhead travelling crane and its supporting structure*. Western Cape, South Africa.

Dunaiski, P. E., & Retief, J. V. (2009). *Basis for structural design and actions for buildings and industrial structures* (First Edition 2009 ed., Vol. 1). (P. E. Dunaiski, & J. V. Retief, Eds.) Stellenbosch, Western Cape, South Africa: Liezel Meintjes.

Dymond, J. S. (2005). Reliability based codification for the design of overhead travelling crane support structures. *Reliability based codification for the design of overhead travelling crane support structures*. Stellenbosch, Western Cape, South Africa: Department of Civil Engineering, University of Stellenbosch.

Haas, T. N. (2007). Numerical (FEA) Evaluation of Crane End Buffer Impact Forces. *Numerical (FEA) Evaluation of Crane End Buffer Impact Forces*. Stellenbosch, Western Cape, South Africa: Department of Civil Engineering, Stellenbosch University.

prEN 1993-3.

SABS 0160:1989.

SANS 10160-6. (2010). Basis of structural design and actions for buildings and industrial structures. *SANS 10160-6:2010 - Actions induced by cranes and machinery*. South Africa: SABS Standards Division.

SANS 2001 CSI.