THE MEASUREMENT OF VERTICAL AND LATERAL FORCES ON ELECTRIC OVERHEAD CRANES DURING OPERATION

By S.W.H. ENGELBRECHT

A dissertation submitted to the Faculty of Engineering, University of the Witwatersrand, Johannesburg, in fulfilment of the requirements for the degree of Master of Science in Engineering.

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DECLARATION.

I, SCHALK WILLEM HENDRIK ENGELBRECHT, declare that this is my own unaided work, and is being submitted for the degree of Master of Science in Engineering at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any other degree or examination at any other university.

S.W.H. Engelbrecht

S.W.H. ENGELBRECHT

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ABSTRACT

This dissertation is a practical investigation into the magnitude of the vertical and lateral forces exerted, by electric overhead travelling cranes, on their supporting structures during operation.

The method of measuring the forces and the equipment used for the actual measurements are discussed, as well as the equipment used for the processing of the recorded data.

The forces measured during the experiments, executed in two stages namely controlled conditions and normal operation, are discussed under the headings of vertical forces due to the weight of the crane and load handled, and the lateral forces due to cross travel movement, skewing of the crane and acceleration/deceleration of the crane.

It is shown that the vertical misalignment of the rails, together with the stiffness of the crane structure, has a large influence on the magnitude of the vertical forces.

Drive wheel slip, tested under controlled conditions on two E-type cranes, proved to cause high lateral forces.

Comparisons are made with the existing Codes of Practice as well as with the theoretical models of crane behaviour.

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1 INTRODUCTION

With the development of manufacturing equipment with increasing capacities, the material handling problem has become a major consideration, as the production schedule is often dependent on the material handling equipment. Electrical overhead travelling cranes (EOT cranes) are important units in material handling and are depended on to bring about increased production, lower shop costs and better working conditions.<Ref.1>

Cyclic operation, comprising frequent stopping, reversing and starting are characteristic of many types of machines, including EOT cranes. The operation of such machines is very different from those operating continuously and leads to a variety of dynamic loading conditions. This makes their design, production and operation difficult, and introduces special requirements for the design of their supporting structures.

The principle of indestructibility until recently formed part of the basis of design for machine parts. It was assumed that safety and indestructibility could be ensured by selecting a sufficiently large safety factor, this being the ratio of the limiting load (stress) to the actual value. Design and operating experience with such supporting structures and machines has shown however that it is practically impossible, and often unnecessary, to strive for indestructibility. Thus in recent years the fundamental approach to design has changed. The present requirement is that optimum reliability must be ensured.

A crane designer has two methods for solving problems - a theoretical and an experimental one. The method of testing is simpler and cheaper in many cases where one is considering large numbers of crane parts whose design and operating conditions vary only gradually in the course of time. Other parts and components of the crane, which are produced in small quantities and are redesigned frequently, necessitate theoretical analysis. However, even a theoretical analysis must be based on test results. <Ref. 2>

Through the years several codes of practice were developed, using theoretical analysis as well as experimental values. A comparative study done previously by Hunter <Ref. 3>, with the emphasis on lateral design loads on cranes, came to the conclusion that the assessment of the lateral loads is not consistent, and that the actions producing the forces are not agreed upon and in some cases not even identified.

It is therefore important that experiments be carried out to improve the existing codes and contribute to more uniform and accurate design criteria.

As Hunter's study of the codes of practice indicated <Ref. 3>, a great deal of uncertainty exists regarding the magnitude and cause of horizontal wheel loads on EOT cranes. Considering that several of the maintenance problems on cranes stem from these horizontal loads, and that a good knowledge of these loads is required for the economical and reliable design of cranes and crane buildings, a study was conducted to measure these forces.

The purpose of this study is to experimentally determine the size and importance of the forces acting on EOT cranes and their supporting gantries, as well as the influence of certain external factors on these forces.

The study was conducted at the Vanderbijlpark Works of ISCOR, a major iron and steel manufacturing Corporation, which, with its great variety of cranes, provided excellent opportunities for testing. Measurements could thus be taken on cranes working under normal conditions in an industrial environment. Certain measurements under controlled conditions were also possible.

This presentation is divided into four main categories, namely :

1) Discussion of the methods and equipment used.

2) Detailed evaluation of two cranes to determine the accuracy of the measurements and the two methods used for the presentation of the results.

3) Measurements taken on a further four cranes in summarised form.

4) Comparison of the measured forces with the forces predicted by Hunter <Ref. 3> and the various design codes.

As the dissertation is a discussion on the measurement of forces, the graphs are not grouped together in an appendix, but rather shown together with its relevant discussion to ensure that all reference to graphs could be followed with greater ease.

Measurements were conducted on a total of six different cranes, with either four or eight wheels, and capacities ranging from 15 tons to 72 tons. Comparison of these measured forces with various code requirements showed that the predicted forces, especially for the low capacity cranes, are much lower than those measured, but it compares well with earlier theoretical analysis.

2 IDENTIFICATION OF FORCES

A detailed study of the different forces present in cranes and crane structures was done by Hunter <Ref. 3>. In short the forces are:

2.1 Static Forces

2.1.1 Vertical
2.1.2 Horizontal

2.2 Dynamic Forces

2.2.1 Vertical forces due to the following :

Acceleration and retardation of lifting hoist
Unevenness of rail in level
Rail joints during travelling

2.2.2 Horizontal forces due to the following :

Elastic shortening of inside of crane columns
Lateral travel of crab and load
Misalignment of rails
Dynamic asymmetry - Rotational force during braking or accelerating
Skew travel of crane
Drive wheel slip on one rail

A series of measurements, described subsequently, has been carried out on a variety of cranes, and most of these forces were observed during the testing of the cranes under normal working conditions. Skew travel of the crane as well as drive wheel slip, were simulated by disconnecting the one drive motor of the crane. This was done on two four wheel cranes. The drive wheels of the 8-wheel cranes are mechanically coupled and as these cranes are used in the production process they could not be taken off-line for the period required to remove the mechanical coupling, with the result no simulation could be done on the 8-wheel cranes.

3 MEASURING EQUIPMENT

For the measurement of the forces on the wheels the following equipment was used:

A) SE 3000 Tape recorder.
B) Two - Six channel Bridge Conditioning Units.
C) Type KFC-5-C1-16 Strain gauges
D) KD 2300 Series Displacement Measuring System.
E) Transformers.
F) 220V Generator (For cranes without 220V supply).

The arrangement of the equipment is illustrated schematically in fig. 3.1

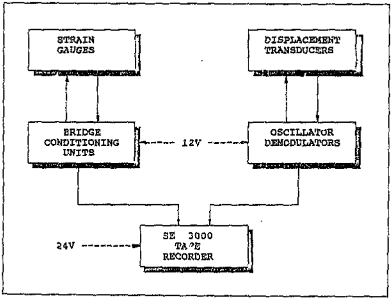


Figure 3.1 Arrangement of Testing Equipment

3.1 Recording Of Data

3.1.1 Tape recorder

Recording of the data was done by means of the SE 3000 14-channel, portable tape recorder. The data was stored in analogue form to maximize data storage and to reduce bulk of the equipment which had to be used on the cranes.

The tape recorder is suitable for both rack and bench mounting as well as for field use. The conditions under which the recorder can operate are:

Temperature	:	10°C to 40°C
Humidity	:	25% to 90% non-condensing
Vibration	:	Stationary and mobile environments,

and hence suitable for the harsh conditions found on the industrial cranes.

The recorder consists of three main assemblies:

Tape Transport
Power supply unit
Data Electronic Unit

The tape transport can operate at eight standard switch selected speeds from 15/32 inch/sec. to 60 inch/sec. The tapes used are 8 inch diameter 0,5 inch tapes.

Throughout the tests a tape speed of 1 7/8 inch/sec. was used, giving a recording time of four hours.

The power requirement of the recorder is a DC Power unit, 11V to 30V used together with a transformer where 220V AC is available. On the cranes which were not equipped with 220V supply, a 220V portable power generator was used.

3.1.2 Bridge conditioning units

Signal conditioning was achieved by means of two 6-channel SE 994 conditioner units. These supplied the excitation for the strain gauges as well as the amplification of the output signals.

The power supply to the amplifiers is 220V AC. They provide an accurately regulated excitation supply of 5V to 15V (DC) to the transducers and the output is ±1V rms (nominal).

3.1.3 Strain gauges

The gauges used are standard gauges with one measuring grid and are temperature compensated for steel. The gauge resistance is 120 Ohms (±0,3) and has a grid length of 5mm.

3.1.4 Displacement measuring system

The system used is a non-contacting linear proximity measuring system for use in static as well as dynamic applications.

The output voltage of the system is proportional to the distance between the face of the sensor and the metallic (conductive) target.

The system uses a principal of impedance variation which is caused by eddy currents induced in a conductive metal target. The coupling between a coil in a sensor and a target is dependent upon their displacement (gap).

The electronics consist of an oscillator, linearization network, amplifiers and a demodulator which provides an analogue voltage directly proportional to displacement.

The range of the KD-2300-12CU transducers which were used, is a 0,2 inch offset gap plus an additional 2,00 inch linear range.

Conditions under which the system can work are:

Temperature

Sensor -55°C to 150°C
Electronics 0°C to 55°C

Environment

For use in oil, water and dirt.

The system was therefore suitable for the conditions on the cranes.

4 EXECUTION OF TESTS

4.1 Principle Of Measurement

With the 8-wheel, bogie type cranes, the forces developed in the crane structure are transmitted through the four pivot bogie pins to the bogie and onto the rails and structure. The forces on each bogie could thus be measured at these points by means of strain gauges attached in such a way that either the effect of vertical wheel loads is eliminated, and only the bending due to horizontal loads is recorded, or the effect of horizontal loads is eliminated and vertical loads are recorded.

Forces on the 4-wheel, fixed wheel type are transmitted directly from the crane structure onto the wheels and rails. The strain gauges therefore had to be attached near the wheel axle in such a position that the elastic strain of the crane structure due to the forces were as big as possible.

The displacement transducers were attached to the four corners of the crane, as near as possible to the wheels, to get an accurate positioning of the crane wheels relative to the rails. It should be noted that the displacement recorded were the displacements between the wheels and the rails. Some consideration was given to measuring the absolute position of the crane or rails, but this would have been difficult and probably not very significant. Hunter <Ref. 3> found that rail alignment was not very important provided it was within the tolerances allowed by the wheel flange spacing.

The tests were done in three stages:

Attaching of strain gauges and displacement transducers.
Calibration.
Tests.

4.1.1 Attachment of strain gauges

For both the vertical force measurement and the horizontal forces, the strain gauges were attached to the structure in the form of a Four arm Wheatstone bridge configuration, in order to eliminate temperature and cable length effects.

Connection for horizontal loads

The strain gauge configuration for horizontal loads is shown in Fig. 4.1

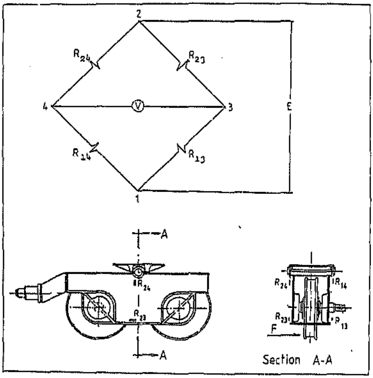


Figure 4.1 Strain gauge configuration and position on bogie for horizontal forces

When a force is applied to the side of the bogie as shown in Fig. 4.1, R_{24} will lengthen, thereby increasing its resistance and then correspondingly R_{14} will shorten and thus decreasing its resistance. Assuming that, due to the symmetry of the bogie, the deformation of the material of the bogie is equal in both sides, then the change in resistance of the two gauges is equal. When R_{24} increases by δR, then R_{14} decreases by the same amount. If R_{23} and R_{13} are *considered constant*, the net effect of the force will be a potential difference measured between points 3 and 4.

$$I_{241} = E / [(R + \delta R) + (R - \delta R)]$$
$$= E / 2R \quad \text{------------------------}1$$

$$I_{231} = E / 2R \quad \text{------------------------}2$$

$$V_{24} = I_{241} * R_{24}$$
$$= E(R + \delta R) / 2R$$
$$= (ER + E\delta R) / 2R \quad \text{------------------------}3$$

$$V_{23} = I_{231} * R_{23}$$
$$= E / 2 \quad \text{------------------------}4$$

$$V = \text{Equation 3} - \text{Equation 4}$$
$$= ER / 2R + E\delta R / 2R - E/2$$
$$= E\delta R / 2R \quad \text{------------------------}5$$

If R_{13} and R_{23} change due to a vertical force, the change in resistance for both gauges are the same ($\delta_1 R$), and equations 2 and 4 become :

Eq 2 : $I_{231} = E / [\,2\,(R + \delta_1 R)\,]$

Eq 4 : $V_{23} = I_{231} * R_{23}$

$$= [E(R + \delta_1 R)] / [2(R + \delta_1 R)]$$

$$= E / 2$$

The net effect therefore stays $V = E\delta R / 2R$

During testing the potential difference due to the force is amplified and continuously stored on the tape in analogue form.

Connection for vertical forces

The strain gauges are connected as shown in *Fig. 4.2*, with the position on the bogie shown as well.

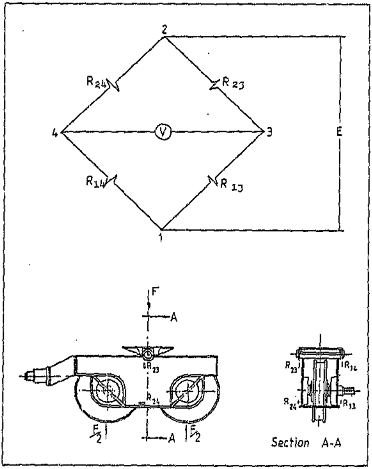


Figure 4.2 Strain gauge configuration and position on bogie for vertical forces

When a vertical force is exerted on the bogie, both R_{24} and R_{13} will lengthen and thus increase their resistance, and R_{23} and R_{14} will shorten. The shortening of R_{23} and R_{14} is proportional to the lengthening of R_{13} and R_{24}. If the resistance of R_{13} and R_{24} increase by δR, the resistance of R_{23} and R_{14} will decrease by $x\,\delta R$. The potential difference recorded will be:

$$I_{241} = E / [(R - x\delta R) + (R + \delta R)]$$

$$= E / A \text{, where } A = 2R + (1 - x)\delta R \qquad \text{----------6}$$

$$I_{231} = E / [(R - x\delta R) + (R + \delta R)]$$

$$= E / A \qquad \text{----------7}$$

$$V24 = E(R_{24}) / A$$

$$= [E(R + \delta R)] / A \qquad \text{----------8}$$

$$V_{23} = E(R_{23}) / A$$

$$= [E(R - x\delta R)] / A \qquad \text{----------9}$$

$$V = \text{Equation 8} - \text{Equation 9}$$

$$= [(ER / A) + (E\delta R / A)] - [(ER / A) - (xE\delta R/A)]$$

$$= [E\delta R(1 + x)] / [2R + (1 - x)\delta R] \qquad \text{----------10}$$

If a horizontal force acts on the bogie simultaneously, the resistance of R_{23} decreases / increases by $y\,\delta R$ and R_{14} increases / decreases by $y\,\delta R$. Then:

$$R_{24} = R + \delta R$$

$$R_{14} = R - x\,\delta R + y\,\delta R$$

$$R_{23} = R - x\,\delta R - y\,\delta R$$

$$R_{13} = R + \delta R$$

$$I_{241} = E / (R_{24} + R_{14})$$
$$= E / B, \text{ where } B = 2R + \delta R(1 - x + y) \qquad \text{-----11}$$

$$I_{231} = E / (R_{23} + R_{13})$$
$$= E / C, \text{ where } C = 2R + \delta R(1 - x - y) \qquad \text{-----12}$$

$$V_{24} = [\,E\,(R_{24})\,] / B$$
$$= (ER + E\delta R) / B \qquad \text{------13}$$

$$V_{23} = [\,E\,(R_{23})\,] / C$$
$$= (ER - xE\delta R - yE\delta R) / C \qquad \text{------14}$$

$$V = \text{Equation 13} - \text{Equation 14}$$
$$= [(ER + E\delta R) / B] - [(ER - xE\delta R - yE\delta R) / C]$$
$$= [ER\,\delta R(2 + 2x) + E\,\delta R^2\,(1 - x^2 + y^2)] / [4R^2 + R\,\delta R(4 - 4x) + \delta R^2\,(1 - 2x + x^2 - y^2)] \qquad \text{-------------16}$$

Assuming that $(\delta R)^2\,y^2$ can be neglected, equation 16 becomes

$$V = [ER\,\delta R(2 + 2x) + E\,\delta R^2\,(1 - x^2)] / [4R^2 + R\,\delta R(4 - 4x) + \delta R^2\,(1 - 2x + x^2)] \qquad \text{-------------17}$$

With an excitation of 5V, an amplification of 100 and the design criterion of horizontal load = 0,2 x Vertical load <Ref. 5>, the difference between equations 16 and 17 is 0,02%, therefore the effect of the horizontal loads on the vertical readings is negligible.

Cross sensitivity of the two configurations

The above calculations were based on the assumption that the strain gauge positions were such that perfect signal separation was obtained. In order to verify the signal separation in the actual experiments, an additional test was done on the South bogie of Crane 535. The crane bogie was lifted and different forces were applied to the side of the bogie. The result is shown in Fig. 4.3.

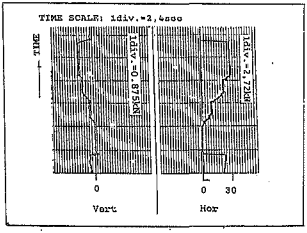


Figure 4.3 Cross sensitivity test : Horizontal forces applied to the bogie

Using Fig. 4.3, three points are plotted on Fig.4.4, showing a linear relation between the horizontal force on the bogie and the vertical force induced through this action.

On this graph the maximum horizontal force of 40 kN, measured on the crane during the experiments (chapter 8 Table T8-11, is shown to cause a vertical load indication of approximately 6,5kN due to the cross sensitivity.

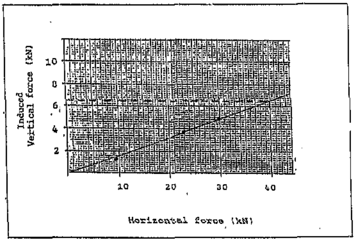


Figure 4.4 Relation between horizontal force and vertical deviation

Thus no more than approximately 6,5kN of the variation in vertical forces are due to the horizontal force on the bogie.

No clear indication of the influence of the vertical forces on the horizontal forces could be determined from this particular experiment. The calculations and measurements of Table T8-06, p78, are used for the determination of the relationship.

The calculations and measurements on the crane were done with the crane standing. During lifting of the load, the horizontal force generated on the bogie can only be due to the elastic deformation of the bridge. The difference between the calculated and measured values are therefore caused by the vertical force, due to the cross sensitivity of the measuring method, inducing an apparent horizontal force.

Using the values of Table T8-08 and the vertical forces on the SW bogie due to lifting of the load, a linear relation is again seen, as shown in Fig. 4.5.

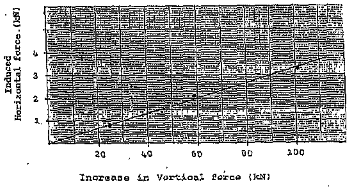


Figure 4.5 Cross sensitivity: Influence of vertical force on horizontal force

From the above graphs and measurements it can be accepted that the influence of the cross sensitivity is sufficiently low not to detrimentally affect the accuracy and usefulness of the results obtained.

The construction of the crane structures in the vicinity where the forces were measured is symmetrical and the straingauges were attached in similar positions on the cranes, which indicates that the results obtained on the other cranes will have a similar degree of accuracy.

Attachment to the crane

Because of the limited time available to do the experiments, it was found that it was not possible to do the wiring connecting the strain gauges after they had been attached on the crane. On the first crane it was found that the wiring of two bogies took about six hours. With the limited space and poor lighting, it was difficult to be assured of good connections.

For the experiments on the other cranes, the wiring was done beforehand in the workshop laboratory, where the connections could be checked and the circuits tested before attaching the strain gauges to the cranes. This procedure worked very well. The time it took to attach the strain gauges to the cranes was approx. 1 3/4 hours for all four bogies.

Displacement transducers

The position of the crane relative to the rails was measured by attaching the transducers to the crane and having the reflectors run against the rails. Equipment was built for this purpose as shown in Fig. 4.6. The mechanisms were adjustable to fit different cranes. The wheel running against the rail moves the reflector, thereby changing the gap between the transducer and the reflector.

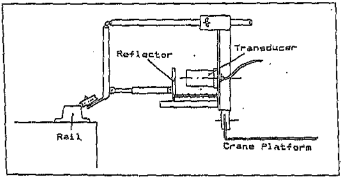


Figure 4.6 Equipment used to utilise the displacement transducers

4.1.2 Calibration

Strain gauges

Vertical loads. The signal from the strain gauges was recorded with the crane standing on the rails. This gave the weight of the crane. Each bogie in turn was then lifted off the rail using a hydraulic jack and the strain gauge signal was again recorded. This gave the zero load value for each bogie.

Horizontal loads. With the bogie lifted from the rail, the horizontal load was zero. A force was applied to the side of the bogie with a hydraulic jack equipped with a pressure gauge. By applying a certain pressure to the bogie, a signal was obtained for a known force. By multiplying this force by the ratio of the distances from the bogie pin to the wheel surface and to the point of application of the force, a calibration force was obtained.

Displa. .nt transducers. The transducers were calibrated beforehand in the workshop by adjusting the oscillator-demodulators. They were adjusted to give an output of 0,5V/10mm movement.

4.1.3 Tests

The tests on each crane were done in two parts:

Controlled tests

During this part of testing the cranes were run under controlled conditions. These consisted mainly of:

Moving the crab from one side of the crane to the other and back.

Running the crane with the crab at one end at slow speed, at medium speed, and at maximum speed. The crab was then moved to the other end and the procedure repeated.

Running the crane at different speeds while the crab was moving. These tests were done without a load suspended from the cranes.

In the case of the 4-wheel cranes, the one drive was disconnected so that the crane was driven by one wheel.

Picking up of a load at a predetermined angle.

Running the crab against the endstops.

Recording during normal operation

The crane was then brought back into operation and normal work was carried out for 1½ to 2 hours, while measurements were continued.

5 PRESENTATION OF FORCES

Two methods of evaluation were used. Analogue to digital conversion was accomplished by means of a DEC KW11-A, 16 channel, analogue-to-digital converter, connected to a PDP 11/23 computer. *Three programmes* which were previously written for similar types of recordings <*Ref 4*> *were used* to sample the data on the different channels at a rate of 20 samples per sec. and *store the* results on disks, to retrieve the unformatted data and adjust it for zero values and scale, and to print the values in graphical form.

The second method was with the use of a Graphtec Linear recorder Mark V11, *a 6-channel plotter*, using heat sensitive paper. It has an accuracy of 0,5% over the *full scale*. The analogue data was plotted directly in graphical form, which gave a better overall picture of the forces during operation.

5.1 Presentation *Using The* PDP 11/23

The processing of the recorded data was done using the three programmes previously developed :

5.1.1 Init

This program is used for the determination of the zero *and* scale values by sampling the calibration data recorded for each channel. The analogue values recorded are converted to digital values as follows :

-5V	:	*0*
0V	:	2048
+5V	:	4096

From these values the zero and scale values are determined, as shown in the example:

1	2	3	4	5	6	7	8
1471	2018	1991	2003	2345	1890	2312	2088
1469	2005	2000	2002	2331	516	2262	2085
1466	2020	1989	2008	2296	1217	2270	2086
1465	2000	1963	2003	2298	1171	2298	2085
1478	2014	1994	2001	2340	1188	2305	2084
1466	2011	2000	2008	2301	1994	2318	2084
1466	2009	1995	2011	2305	907	2269	2085
1439	2093	2230	2023	2037	2036	1993	2036
1467	2022	1997	1980	2298	1049	2172	2175
1467	2014	1999	1984	2338	1768	2164	2190
1470	2023	1982	1982	2341	1533	2154	2169
1473	2025	1998	1983	2300	1156	2157	2172
1466	2015	1990	1982	2334	527	2176	2191
1469	2028	1994	1978	2308	534	2155	2178
1467	2009	1939	1983	2304	1908	2174	2191
1471	2012	1967	1977	2301	1055	2154	2178

Channel 6 which was measuring the South East horizontal force was found to be defective.

Channel 8 recorded the horizontal force of 42,5 kN on the South-west bogie of Crane 439.

Force	Value
0	2084
42,5	2178

Zero value : 2084
Scale value : (2178-2084)/42,5
= <u>2,353</u>

5.1.2 SAMPLER

Using this program, selected pieces of the tape are sampled for a specified time. Analogue to digital conversion is done and the data is stored in files. With this program specific periods of the tests can be evaluated, for example when the crab strikes the buffers.

5.1.3 CALIB

Digital to real value conversion is done by this program. The zero and scale values obtained in INIT are used to convert the values in the SAMPLER file to forces.

5.1.4 CRANPL

The final program plots the force values from CALIB on paper. See Fig. 5.1 for a typical graph obtained.

5.2 Using The GRAPHTEC Plotter

This method prints the analogue values directly. Comparison with the previous shows that the two methods correspond.

A disatvantage of the plotter is the limited vertical scale adjustments. It would have been difficult and time consuming to get the vertical scales the same and it would not have influence the results.

See Fig. 5.2a and Fig 5.2b for a comparison of the two methods.

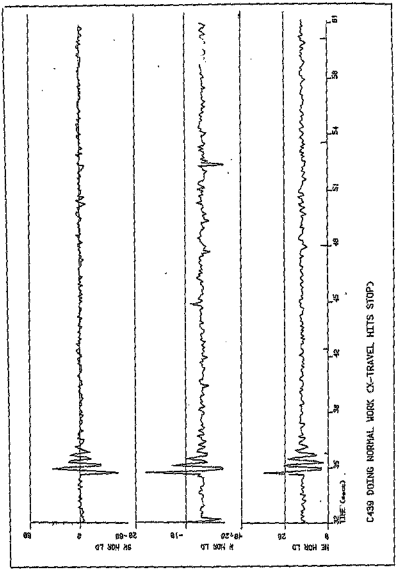


Figure 5.1 Typical graph obtained using CRANPL

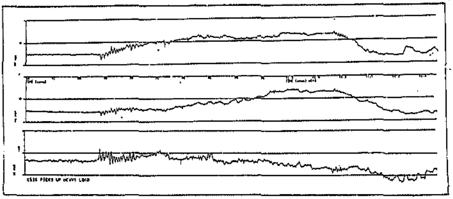


Figure 5.2a Forces using CRANPL

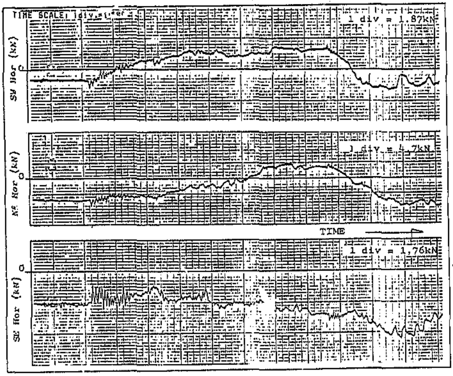


Figure 5.2b Forces using the GRAPHTEC plotter

6 CRANES TESTED

Tests were conducted on the following cranes :

6.1 Crane 439

Capacity		: 72 tons
Span		: 30,48 m
Wheel centres		: 7,16 m
Type		: W-type
Duty Class		: 4 <Ref 5>
Wheels		: 8 wheels, 4 driven
Weight		: 116,9 tons
Speed	Long Travel (LT)	: 60,9m/min
	Cross Travel (XT)	: 30,5m/min
	Hoist	: 4,57m/min

6.2 Crane 501

Capacity		: 50 tons
Span		: 45 m
Wheel centres		: 6,55 m
Type		: W-type
Duty Class		: 4 <Ref 5>
Wheels		: 8 wheels, 4 driven
Weight		: 236,58 tons
Speed	Long Travel	: 150m/min
	Cross Travel	: 66,8m/min
	Hoist	: 17,9m/min

6.3 Crane 535

Capacity		: 50 tons
Span		: 25 m
Wheel centres		: 5,48 m
Type		: W-type
Duty Class		: 4 <Ref 5>
Wheels		: 8 wheels, 4 driven
Weight		: 249,11 tons
Speed	Long Travel	: 63,4m/min
	Cross Travel	: 30,5m/min
	Hoist	: 5m/min

6.4 Crane 563

Capacity		: 15 tons
Span		: 37 m
Wheel centres		: 6,15 m
Type		: E-type
Duty Class		: 2 <Ref 5>
Wheels		: 4 wheels, 2 driven
Weight		: 47,68 tons
Speed	Long Travel	: 45m/min
	Cross Travel	: 24,96m/min
	Hoist	: 0,96m/min

6.5 Crane 701

Capacity		: 16 tons
Span		: 12 m
Wheel centres		: 4,32 m
Type		: E-type
Duty Class		: 2 <Ref 5>
Wheels		: 4 wheels, 2 driven
Weight		: 9,8 tons
Speed	Long Travel	: 11,6m/min
	Cross Travel	: 7,8m/min
	Hoist	: 3,54m/min

6.6 Crane 270

Capacity		: 22,7 tons
Span		: 28,95 m
Wheel centres		: 5,48 m
Type		: W-type
Duty Class		: 4 <ref 5>
Wheels		: 8 wheels, 4 driven
Weight		: 110,8 tons
Speed	Long Travel	: 121,9m/min
	Cross Travel	: 63,1m/min
	Hoist	: 10,0m/min

An E-type drive system is one where the wheels are independently driven and are not electrically or mechanically coupled.

A W-type drive system is one where the wheels are electrically or mechanically coupled.

Crane 270 was the first crane tested and only two bogies were wired up and measured. The purpose of this trial run was to find the best way to do the connections and to determine if such measurements of the forces could be done. With this test several problems were identified, for example the time it took to do the connecting up of the gauges and wires, and the need for special equipment for the displacement transducers.

It was not possible to take readings on high capacity cranes, due to the construction of these cranes (12 wheels) and the fact that the cranes are used in the Iron manufacturing process, and can therefore not be taken out of production for long periods.

7 DETAIL EVALUATION OF CRANE 439

The graphs obtained through the PDP 11/23 Computer, as well as with the Graphtec plotter were evaluated in detail to determine the efficiency and accuracy of the tests.

The following values were obtained from the crane files and drawings :

Mass of bridge	:	130 327 kg
Mass of cross travel	:	35 744 kg
Mass of cabin	:	2 109 kg
Total mass	:	168 180 kg
=> Total weight	:	1 648 kN

Weight distribution with cross travel at extreme north:

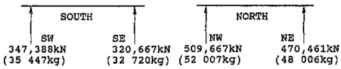


Figure 7.1 Crane 439 : Weight distribution

Loads handled :

Light load (magnet + plates)	:	7 620 kg (74,67 kN)
Heavy load (beam + plates)	:	41 060 kg (402,38 kN)

Orientation of crane :

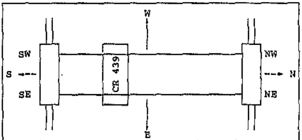


Figure 7.2 Crane 439 : Orientation.

7.1 Vertical Forces Without Load

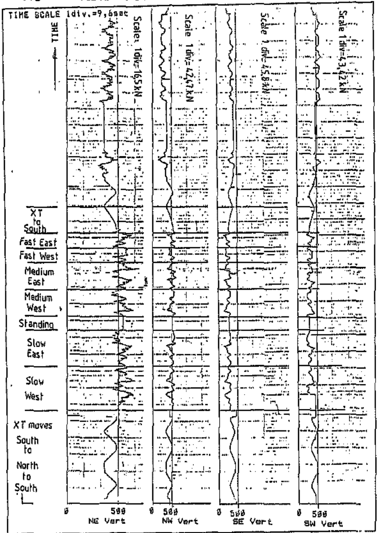


Figure 7.3 Crane 439 : Vertical forces during movement under controlled conditions

Fig 7.3 represents 23 minutes of recording, consisting of :

Crane standing with cross travel moving north to south and back.

Crane moving at slow, medium and fast speed (0,5m/s to 1,2 m/s) with the cross travel at the north side.

Cross travel moves to the south.

Crane moving with varying speed with the cross travel at the south side.

During long travel a certain pattern in the variation of the vertical forces was observed. The forces on the NW and SE bogies increased together while the forces on the NE and SW bogies decreased at the same time. These variations appear to account for most of the dynamic portion of the forces and probably arise due to the torsional stiffness of the crane and small vertical misalignments of the rails.

Transfer of vertical load from one bogie to the other occurs when the slope of the rails change. A crane with a very high torsional stiffness will transfer the total load of the one bogie to the other should the rails be vertically misaligned. A crane with a very low tow torsional stiffness will transfer very little load from the one b gie to the other as the bogie carriage will stay parallel to the rails. It is not possible to comment on this from a measurement point of view as the rail alignment was not measured.

7.1.1 Crane standing with cross travel moving north to south.

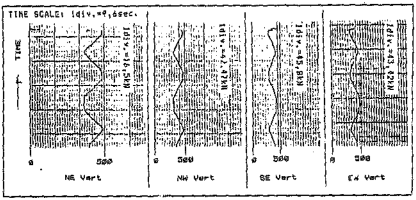


Figure 7.4 Crane 439 : Vertical forces with cross travel moving

Values from Fig. 7.4

	Cross Travel North	Cross Travel South
North-east bogie (NE)	478,7 kN	354,8 kN
North-west bogie (NW)	488,4 kN	331,3 kN
South-east bogie (SE)	302,3 kN	430,5 kN
South-west bogie (SW)	330,0 kN	477,7 kN
Total weight :	1599,4 kN	1594,3 kN

The calculated weight of the crane is 1648,18 kN. The difference between the calculated and measured values is 3,2%.

7.1.2 Crane running with cross travel at north.

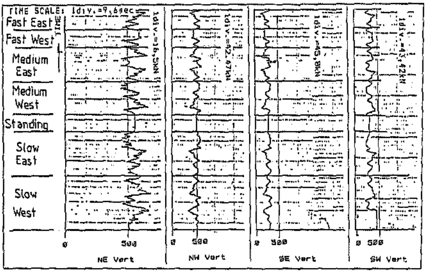


Figure 7.5 Crane 439 : Vertical forces during movement with cross travel north

Fig 7.5 shows the recording done with the crane running at different speeds, varying from 0,5 to 1,2 m/s.

Tables T7-01 to T7-04 give a summary of the maximum and minimum forces measured during these movements.

	DYNAMIC (kN)		STATIC (kN)	%INCREASE	
	MAX	MIN		MAX	MIN
NE	645,2	445,5	478,71	34,77	- 6,93
NW	562,7	331,3	488,41	15,22	-32,2
SE	348,1	160,3	302,28	15,2	-46,9
SW	399,5	212,7	329,99	21,1	-35,5

Table T7-01 : XT at North ; Slow speed West

	DYNAMIC (kN)		STATIC (kN)	%INCREASE	
	MAX	MIN		MAX	MIN
NE	630,3	437,25	478,71	31,67	- 8,67
NW	577,6	339,7	488,41	18,26	-30,4
SE	343,5	146,6	302,28	13,63	-51,5
SW	434,2	221,4	329,99	31,58	-32,9

Table T7-02 : XT at North ; Slow speed East

	DYNAMIC (kN)		STATIC (kN)	%INCREASE	
	MAX	MIN		MAX	MIN
NE	645,0	437,2	478,71	34,73	- 8,6
NW	569,1	352,5	488,41	16,5	-27,8
SE	334,34	160,3	302,28	10,6	-46,9
SW	416,8	238,8	329,99	26,3	-27,6

Table T7-03 : XT at North ; Medium speed West

	DYNAMIC (kN)		STATIC (kN)	%INCREASE	
	MAX	MIN		MAX	MIN
NE	645,2	445,5	478,71	34,77	- 6,9
NW	560,6	360,9	488,41	14,78	-26,1
SE	329,7	164,9	302,28	9,09	-45,4
SW	434,2	247,49	329,99	31,58	-25,0

Table T7-04 : XT at North ; High speed West

7.1.3 Crane running with the cross travel at the south.

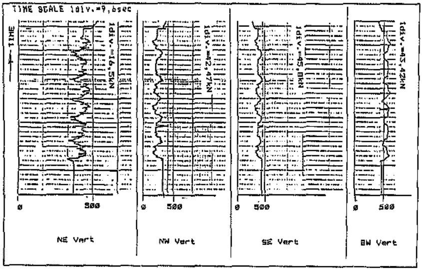


Figure 7.6 Crane 439 : Vertical forces during movement with cross travel south

In Fig 7.6 the recording of the forces with the crane moving with varying speeds and with the cross travel at the south is shown.

Table T7-05 gives a summary of the forces measured during this operation.

	DYNAMIC (kN)		STATIC (kN)	%INCREASE	
	MAX	MIN		MAX	MIN
NE	478,0	338,2	354,75	34,7	- 4,66
NW	335,5	161,4	331,27	1,28	-51,3
SE	439,7	320,6	425,94	3,22	-24,7
SW	607,8	464,6	477,67	27,25	- 2,7

Table T7-05 : XT at South ; Varying speed

It was found that there were no significant increase in the dynamic forces measured during the different speeds up to 1,2 m/s.

7.2 Crane Doing Normal Work

Fig 7.7 show the measurements taken with the crane picking up the magnet, the cross travel moving south and then normal work commencing with the crane picking up two plates (960kg each) and placing them on the floor.

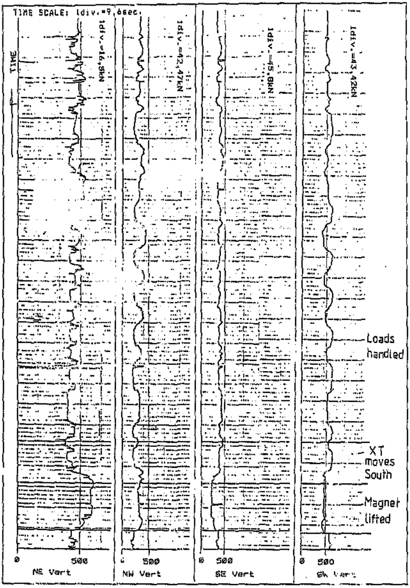


Figure 7.7 Crane 439 : Vertical forces during execution of routine work

7.2.1 Crane picking up the magnet (5800 kg)

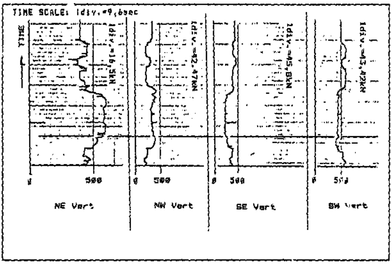


Figure 7.8 Crane 439 : Vertical forces when magnet was lifted (weight 5800 kg)

Fig 7.8 shows the lifting of the magnet.

The forces measured are :

NE	597,3 kN
NW	352,5 kN
SE	233,6 kN
SW	464,6 kN

Total 1648,0 kN

The measured value for the weight of the crane is 1597 kN. The difference is 51 kN, which gives a mass for the magnet of 5200 kg. (The calculated value is 5800 kg).

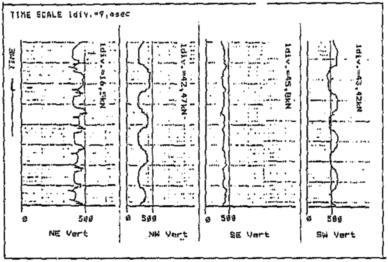


Figure 7.9 Crane 439 : Vertical loads when the light loads were handled

Fig. 7.9 shows the plates being handled. The maximum forces measured *are shown* in Table T7-06 :

	DYNAMIC		STATIC	%INCREASE
	MAX	*MIN*		
NE	531,3 kN	363,0 kN	478,7 kN	*10*,9
NW	496,5 kN	354,8 kN	488,4 kN	1,6
SE	464,6 kN	320,6 kN	425,94 *kN*	9,09
SW	*607*,8 kN	390,78 kN	477,67 kN	27,25

Table T7-06 Crane 439 : Dynamic vertical forces during handling of light loads.

7.2.2 Crane handling a heavy load

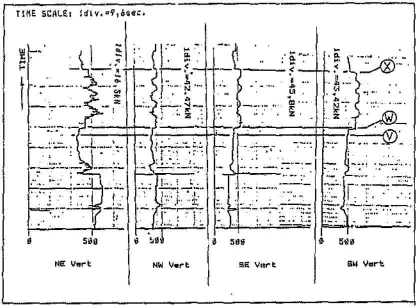


Figure 7.10 Crane 439 : Vertical forces when the heavy load was lifted (41 060kg)

Fig 7.10 shows the recording of the forces when the heavy load (41 060kg) was handled.

Point V on Fig 7.10 shows the beams and hooks being lifted. The total force measured is 1 669,7 kN, which gives a weight for the beam of 72,67 kN, or 7 400kg. The calculated mass is 8 060kg, a 8,9% difference.

Point W on Fig 7.10 shows the loading lifted. The total force is 2 041,5 kN, which is a mass of 45 300kg. The actual mass is 41 060kg, a 9,36% difference.

Point X on Fig. 7.10 shows the load lowered.

The dynamic forces when the crane was moving during the period W and X (Fig. 7.10) were :

	DYNAMIC		STATIC	%INCREASE
	MAX	MIN		
NE	552,75 kN	445,5 kN	445,5 kN	24,1
NW	437,4 kN	382,2 kN	416,2 kN	5,1
SE	595,4 kN	503,8 kN	558,78 kN	6,5
SW	694,7 kN	607,9 kN	629,6 kN	10,3

Table T7-07 Crane 439 : Dynamic vertical forces during handling of the heavy load

7.3 *Horizontal Forces Without Load*

The only channel which did not record any readings was the South-East horizontal force channel.

Fig 7.11 shows the horizontal forces for the same 23 min recording as Fig 7.3 (Page 41).

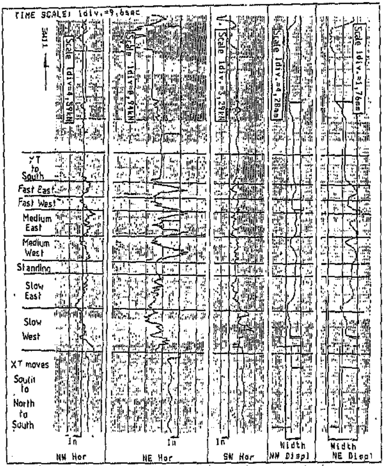


Figure 7.11 Crane 439 : *Horizontal forces during movement under controlled conditions*

7.3.1 Crane standing and cross travel moving.

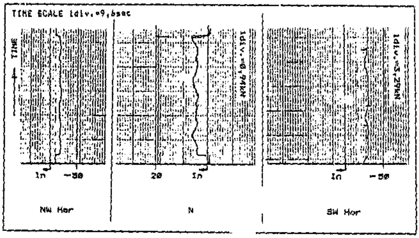


Figure 7.12 Crane 439 : Horizontal forces with the cross travel moving

In Fig 7.12 the horizontal forces on the bogies are shown. The forces recorded are the forces which acted on the bogies as the crane stopped in that position.

The variation in the forces as the cross travel moved is low, as shown :

NW Hor : 4,14 kN
NE Hor : 1,78 kN
SW Hor : 6,58 kN

7.3.2 Crane running slowly with the XT North

The forces exerted by the bogies on the rails while the crane was running at slow speed are shown in Fig 7.13.

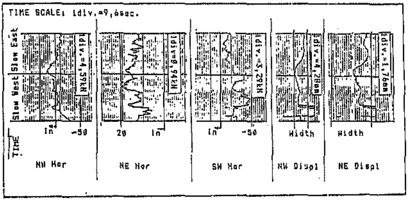


Figure 7.13 Crane 439 : Horizontal forces with the crane moving slowly

The maximum forces recorded during the slow run were:

	East - west	West - east
NW Hor :	-32,14 kN	19,7 kN
NE Hor :	19,74 kN	15,9 kN
SW Hor :	-47,70 kN	-19,2 kN

where the negative (-) sign shows an outward force.

During the first run of the crane, moving slowly East-west, exceptional high forces were measured on the West side bogies. As seen in Fig 7.11, this does not fit into the pattern for the rest of the controlled speed runs.

This first slow run was done directly after the crane was lifted for calibration purposes. The crane was pushed out of its normal running position. The crane then had to drive itself out of this skew position into its normal more stable running position, hence the more regular pattern during the rest of the controlled speed runs.

This corresponds with Hunter's <Ref. 3> observations during his experiment with his scale model where high forces were measured with the drive wheel slipping and the crane driving itself into a severe skew before straightening out.

7.3.3 Crane moving at medium speed

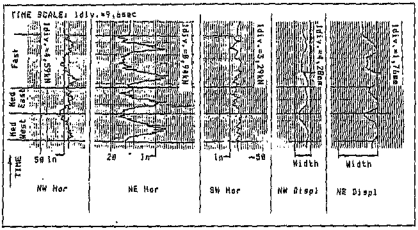


Figure 7.14 Crane 439 : Horizontal *forces* with the crane moving at medium speed.

In Fig 7.14 the *forces* are shown as the crane moved at medium speed. *With* tho crane moving westwards, *the* forces recorded varied :

NW Hor	:	Between -19,74 and 10,10 kN
NE Hor	:	Between -4,7 and 15,98 kN
SW Hor	:	Betweon -18,95 and -8,55 kN

The forces decreased on *the* North side bogies as the crane accelerated *and increased* again as the crane decelerated. *This* is due to the fact that the crane tends to *centralise* itself while running. *With* the cross travel at the north side, the *bigger inertia* at that *side* causes the crane to move *relative* to the *rails* during deceleration and the *forces* to increase.

On the South side the *forces did not* vary as much mainly due to the *cross travel* being at the North side.

7.3.4 *Crane moving at high speed*

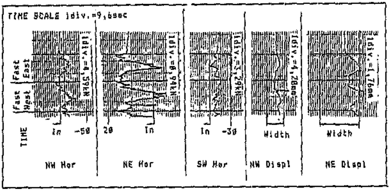


Figure 7.15 *Crane* 439 : Horizontal forces with the crane moving at high speed

The forces on the bogies were slighcly higher than during the *medium* speed run :

NW	Hor	:	Between -32,14 and 9,18 kN
NE	Hor	:	Between -5,64 and 16,64 kN
SW	Hor	:	Between 0 and -18,75 kN

When the crane was travelling at maximum speed with the XT at the south side, the *forces* on all the bogies were high (Fig 7.16).

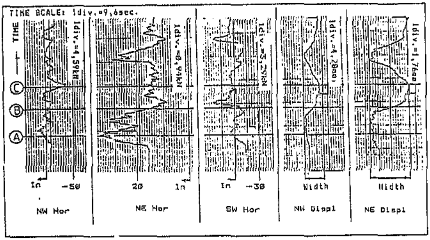


Figure 7.16 Crane 439 : Maximum forces measured under controlled conditions

NW Hor	:	-37,65 kN
NE Hor	:	33,84 kN
SW Hor	:	27,96 kN

As shown in Fig 7.16 the North side bogies were running against the rail when these forces occurred. (Point A).

The crane then started moving mor: to the South side and this sideways movement caused the high force on the South bogie. (point B).

The highest force on the North-west bogie occurred when the outside flange ran against the rail. (Point C).

Fig 7.17 is a graph showing the influence of the crane speed on the magnitude of the horizontal forces, without the values for the first East-west run. The increase is negligible except for the NW bogie, where rail/flange contact caused one high peak force.

Hunter <Ref 3> has also concluded that dynamic factors such as dynamic assymetry only becomes significant in cranes with speeds of >1m/s and that skewing and subsequent rail/flange contact produce the largest lateral forces in cranes with speeds up to 1m/s.

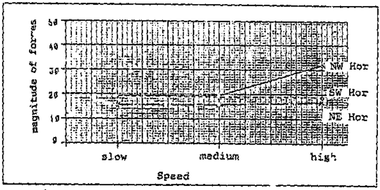


Figure 7.17 Crane 439 : Influence of speed on the magnitude of the horizontal forces

7.4 Crane Doing Normal Work

During these cycles of work, which consisted of handling plates with the cross travel mostly at the South side of the crane, the highest forces occurred on the South bogie each time the wheel flange ran against the rail. (Fig 7.18)

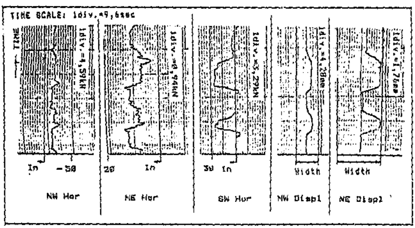


Figure 7.18 Crane 439 : Horizontal forces while executing normal work

The forces were :

NW	Hor	:	Between -33,05 and 18,36 kN
NE	Hor	:	Between 15,42 and 11,28 kN
SW	Hor	:	Between 28,62 and -3,29 kN

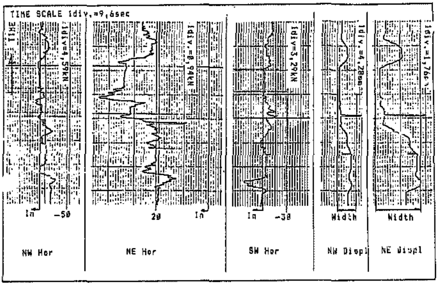


Figure 7.19 Crane 439 : Horizontal forces while executing normal work. Cross travel north

Fig 7.19 shows a period where the crane worked with the cross travel at the North side. The forces changed from predominantly outward to inward forces on the North-west bogie. On the North-east bogie the forces increased as the flange touched the rails. The forces on the South-east bogie changed from inward to outward forces. This is again due to the bigger inertia causing a tendency for the crane to move sideways during braking.

7.4.1 Crane handling heavy load

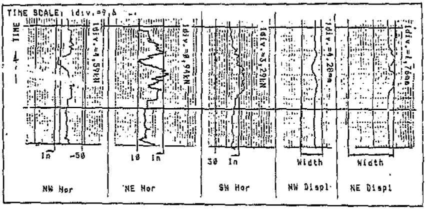


Figure 7.20 Crane 439 : Horizontal forces while handling the heavy load

With the handling of the heavy load the crane appeared to centralise itself on the rails and the forces recorded were smaller :

NW Hor	:	Between -2,75 and 34,89 kN
NE Hor	:	Between 10,24 and 2,16 kN
SW Hor	:	Between -6,58 and 6,58 kN

This observation can possibly be attributed to two main factors :

The crane bridge is 1,5 m higher than the rails and the neutral axis of the crane is high above the rail level. Any lateral movement will therefore be magnified. Carrying the load, the centre of gravity of the system is much lower, which causes a more stable movement.

Due to the higher vertical forces when the loads were carried, the higher friction forces limited lat movement and flange contact, resulting in smalle forces.

7.4.2 Cross travel hits buffers

When the XT hit the South buffers during the handling of the loads, exceptionally high peak forces, specially on the south bogie, were generated as shown in Fig 7.21. The size of these forces were :

NW	Hor	:	-19 to 18 kN
NE	Hor	:	2 to 29 kN
SW	Hor	:	-50 to 34 kN

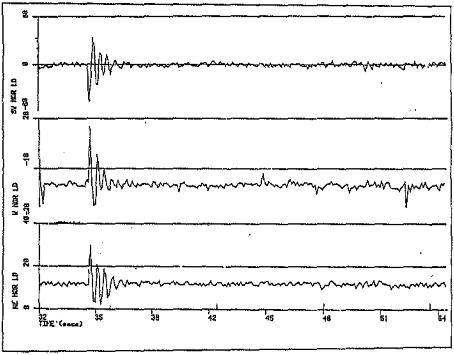


Figure 7.21 Crane 439 : Crane hitting South side buffers

7.5 Conclusions

Vertical forces

No increase in the magnitude of the forces were measured during the different speeds up to 1,2 m/s.

The increase/decrease in the forces measured on the NE and SW bogies and the simultaneous decrease/increase in the forces on the NW and SE bogies, show that small vertical misalignment of the rails can lead to increased maintenance due to high forces on the crane and gantry.

With the low loads the accuracy of the measurements is more than 96%, but decreases to 91% with the heavy loads.

Dynamic forces up to 34,7% higher than the static loads were measured.

Horizontal forces

No significant increase in forces was measured while the cross travel was moving with the crane stationary. The cross travel speed was low : 0,508 m/s max.

The highest forces were measured when the wheel flanges were in contact with the rails. The wheel flange/rail contact is a very important factor in the magnitude of the lateral forces.

The higher load produced lower forces than the light load, due to a centralising effect on the crane.

Fig 7.17 shows that with the exception of the NW bogie, which shows a peak force of 32,14 kN, the increase in force with the increase in speed (up to 1 m/s) is negligible.

The max forces measured during the handling of the loads were:

NW	Hor	:	7,7% of cross travel + load
NE	Hor	:	6,7% of cross travel + load
SW	Hor	:	3,6% of cross travel + load

The method of measuring the forces gives detail data showing the forces and factors which influence the magnitude of both the vertical and horizontal forces.

Where certain tests were repeated, during the experiment, the results obtained were similar as can be seen from Fig 7.4, Fig 7.7 and Fig 7.12.

8 EVALUATION OF CRANE 535 USING THE PDP 11/23 COMPUTER

Crane 535 is a Class 4 crane with a capacity of 50 tons, being used for handling of coils as well as for maintenance work on the Mills.

Values from the crane's files and drawings are :

Mass of bridge	:	85 426 kg
Mass of cross travel	:	25 923 kg
Mass of cabin	:	1 958 kg
Total mass	:	113 307 kg
=>Total weight	:	1 110,41 kN

Weight distribution of crane with cross travel at extreme west :

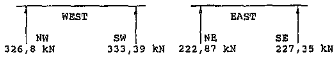


Figure 8.1 Crane 535 : Weight distribution.

Loads handled :

Light load (C-Hook)	:	85,54 kN
Medium load (Mill roll)	:	194,884 kN
Heavy load (Mill roll + bearings)	:	338,58 kN

Orientation of Crane 535 :

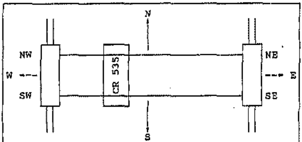


Figure 8.2 Crane 535 : Orientation.

8.1 Vertical Forces

8.1.1 The difference in vertical loads as the crane remained static and the cross travel moved were :

SW Vert : 320 to 350 kN
SE Vert : 250 to 280 kN
NW Vert : 330 to 365 kN
NE Vert : No data recorded

8.1.2 With the cross travel at the west side and the crane running slowly, the forces recorded were :

	DYNAMIC (kN)		STATIC (kN)	%INCREASE	
	MAX	MIN		MAX	MIN
SW	360	300	350	2,85	-14,28
SE	260	220	250	4,0	-12,0
NW	398	350	365	9,04	- 4,1

Table T8-01 Crane 535 : Vertical loads with crane running slowly

With the crane running at high speed, the forces were:

	DYNAMIC (kN)		STATIC (kN)	%INCREASE	
	MAX	MIN		MAX	MIN
SW	360	330	350	2,85	- 5,71
SE	270	250	250	8,0	0,0
NW	385	340	365	5,48	- 6,80

Table T8-02 Crane 535 : Vertical loads with crane running at high speed

8.1.3 Handling of light load

Fig 8.3 shows the light load being picked up at the west side of the bay.

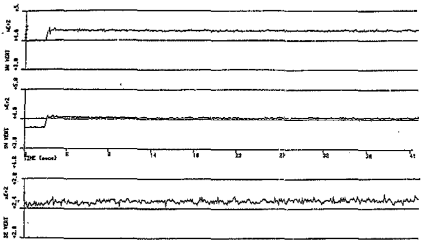


Figure 8.3 Crane 535 : Light load picked up

The increase in forces were :

NW	:	From 400 to 435 kN => 35 kN
SW	:	From 370 to 410 kN => 40 kN
SE	:	From 243 to 250 kN => 7 kN

Table T8-03 Crane 535 : *Increase* in vertical forces due to the light load lifted

Assuming that the increase at the NE bogie was 7 kN as well, the measured increase in the weight was 89 kN, while the calculated weight is 85,54 kN. The difference is 4,04%.

When the load was swinging, the forces showed a wave pattern, oscillating as shown in Fig 8.4 :

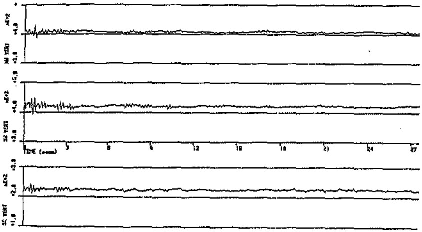


Figure 8.4 Crane 535 : Light load swinging

The variation in vertical forces were :

NW : Between 380 and 420 kN
SW : Between 390 and 450 kN
SE : Between 210 and 240 kN

The lowering of the load caused a decrease in the forces (Fig 8.5) :

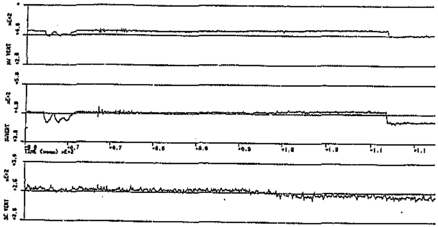


Figure 8.5 Crane 535 : Vertical forces when the light load was lowered

NW	:	From 435 to 400 kN => 35 kN
SW	:	From 410 to 37[illegible] kN => 35 kN
SE	:	From 240 to [illegible] kN => 10 kN

Table T8-04 Crane 535 : Decrease in vertical forces when the light load was lowered

Assuming that the force on the NE bogie was also 10 kN, the decrease measured value was 90 kN, a 5,2% difference with the calculated weight of [illegible]5,54 kN.

8.1.4 Handling of medium load

Hoisting of the medium *load* produced an increase in forces as shown in *Fig* 8.6 :

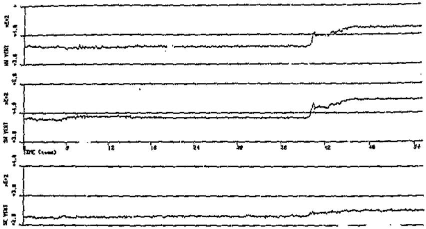


Figure 8.6 Crane 535 : Medium load lifted

N	:	From 360 to 425 kN => 65 kN
SW	:	From 375 to 450 kN => 75 kN
SE	:	From 225 to 255 kN => 30 kN

Table T8-05 Crane 535 : Increase in vertical forces when the medium load was lifted

Assuming that the *force on* the NE bo[illegible] was also 30 kN, the difference *between* this measured increase *and* the calculated value was 2,62%.

Movement of the crane with the medium load showed a variation in the forces as shown in Fi 8.7

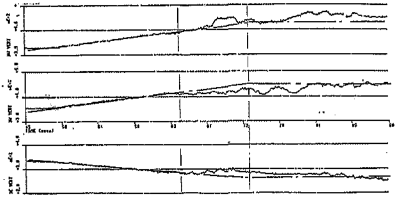


Figure 8.7 Crane 535 : Crane moving with medium load

The variation in forces was due to the cross travel moving west. At 64 seconds the crane started moving, while the cross travel was still moving west.

	DYNAMIC (kN)		% DEVIATION FROM STATIC LINE	
	MAX	MIN	MAX	MIN
SW	455	405	1,1	-10,0
SE	301	245	13,5	- 3,9
NW	475	420	11,7	- 1,2

Table T8-06 Crane 535 : Increase in vertical forces during crane movement

The dynamic forces were up to 13,5% higher than the static weight on the wheels.

Lowering of the load is shown in Fig 8.8

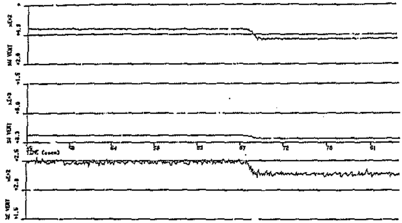


Figure 8.8 Crane 535 : Medium load lowered

8.1.5 Handling of heavy load

Lowering of the load shows a decrease in vertical *force* (Fig 8.9) :

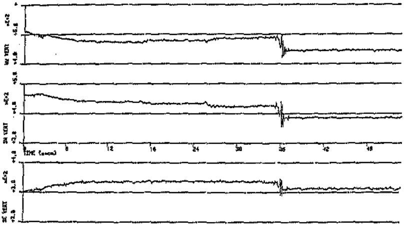


Figure 8.9 Crane 535 : Heavy *load* lowered

NW	:	From 510 to 440 kN =>	70 kN
SW	:	From 470 to 380 kN =>	90 kN
SE	:	From 345 to 305 kN =>	40 kN

Table T8-07 Crane 535 : Decrease in vertical *forces* when the heavy load was lowered.

Assuming that the force on the NE bogie was 40 kN, the decrease was 240 kN, while the load put down (the roll + bearings) weighed 253,08 kN. The difference is 5,45%. *In Fig 8.9* it can be seen that dynamic forces were generated when the load touched the floor. These forces were due to the elastic deformation of the bridge under the weight of the load carried.

Increase in the forces due to the movement of the crane with the heavy load was 20% on the SW bogie and 13,2% on the NW bogie. (Fig 8.10)

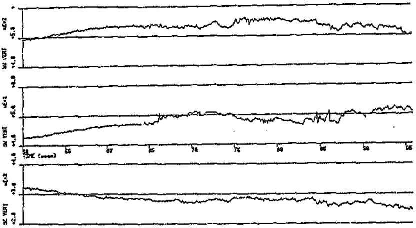


Figure 8.10 Crane 535 : Crane moves with heavy load

As the PDP 11/23 COMPUTER only evaluates short periods of recordings, a 20 minute period of recording, plotted with the GRAPHTEC plotter, is shown in Fig 8.11, giving a better overall indication of the variation in forces during the travelling of the crane.

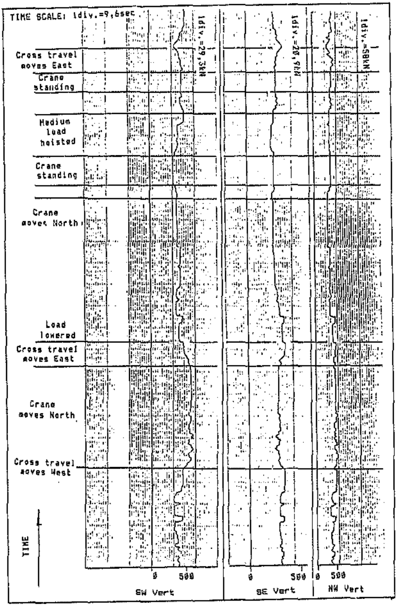


Figure 6.11 Crane 535 : Vertical forces during operation

8.2 Horizontal Forces

No data was recorded on the NW bogie.

8.2.1 The forces generated with the crane stationary and the cross travel moving, were a maximum of 2 kN.

8.2.2 With the crane moving slowly north to south and the cross travel west, the forces on the bogies varied :

SW	:	Between 18 and -10 kN
NE	:	Between 8 and -10 kN
SE	:	Between -25 and -35 kN, the (-) indicates an outward force

With the crane moving at high speed, the forces varied:

SW	:	Between 6 and -15 kN
NE	:	Between -28 and -40 kN
SE	:	Between -40 and -18 kN

When the crane was moving south and the cross travel moving as well, the forces on the SW and NE bogies were outward and on the SE bogie mostly inwards (Fig 8.12)

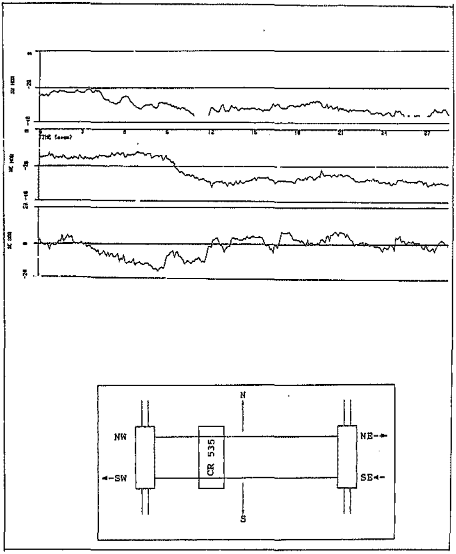


Figure 8.12 Crane 535 : Horizontal forces -
Magnitude and direction with
the crane moving south

With the crane moving in the *opposite* direction, the direction of the forces on the bogies changed as shown in Fig 8.13.

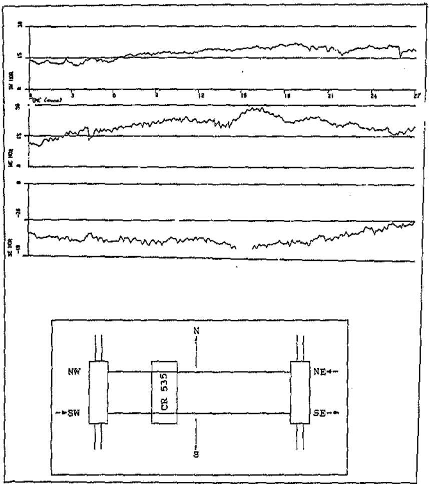


Figure 8.13 Crane 535 : Horizontal forces - Magnitude and direction with the *crane* moving north

Although the displacement transducers were not connected, the direction of the forces indicates that the crane was skewing during this time. High forces were measured :

SW	:	Between	-40 and	20 kN
NE	:	Between	-37 and	10 kN
SE	:	Between	-40 and	8 kN

8.2.3 Loads lifted

Elastic deformation of the bridge occurred with the handling of the load. This deflection of the bridge caused rotation of the bogies, and induced a horizontal component to the vertical force, as illustrated in Fig 8.14. The flexural stiffness of the structure plays a role in the magnitude of these induced forces, as well as the position of the wheels relative to the neutral axis. Should the neutral axis be much higher than the wheel surface , a larger displacement of the wheel surface will occur, which can cause flange/rail contact and high induced forces.

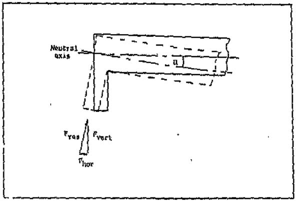


Figure 8.14 Deflection of bogie due to weight lifted

To compare the magnitude of the measured and calculated values of F_{hor} , the flexural stiffness of Crane 535 was determined, as well as the expected deflection of the bridge due to the lifting of the different forces. F_{hor} was then calculated.

Table T8-08 shows the comparison between the calculated and measured forces.

	LIGHT (kN)		MEDIUM (kN)		HEAVY (kN)	
	CALC	MEAS	CALC	MEAS	CALC	MEAS
NE	0,149	1	0,367	2,5	0,716	4
SW	0,156	1	0,380	1,2	0,747	3
SE	0,151	0,5	0,367	1,0	0,716	4

Table T8-08 Comparison between calculated and measured values for F_{hor}

Fig. 8.15 (page 79) shows the distinct change in the lateral forces during the lifting of heavy loads.

The difference between the measured and calculated values is due to the cross sensitivity, as discussed in Chapter 4, section 4.1.1 (p27). Because the crane was standing, no dynamic factors were involved.

For cranes with high flexural stiffness, the forces caused by the static bridge deflection are sufficiently low to be ignored.

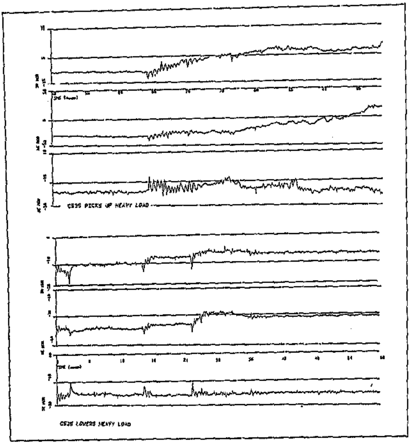


Figure 8.15 Crane 535 : Oscillating horizontal forces when heavy load was hoisted and lowered

It appears that the crane, simultaneously with the elastic deformation of the bridge, was rotating in the horizontal plane as can be observed by the diagonally opposite forces changing concurrently.

8.2.5 Forces during travelling

Light load

In Fig 8.16 it is shown that oscillating forces were generated on the bogies as the load was swinging. The forces varied in magnitude :

SW	:	Between 3 and -3 kN
NE	:	Between -14 and -23 kN
SE	:	Between -11 and -18 kN

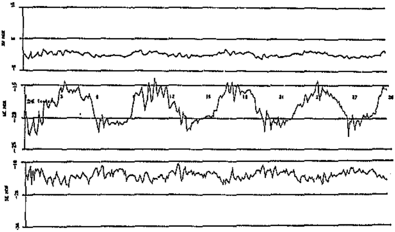


Figure 8.16 Crane 535 : Horizontal forces when load was swinging

During the movement of the crane with the light load, the forces on the bogies varied as shown in Table T8-09.

	DYNAMIC (kN)		LOAD + CROSS TRAVEL	% OF LOAD + XT	
	MAX	MIN		MAX	MIN
SW	9	- 3	339,84	2,6	0,8
SE	-21	-16	339,84	6,17	4,7
NE	-12	- 2	339,84	3,5	0,6

Table 8-09 Crane 535 : Magnitude of horizontal forces when light load was swinging.

The maximum force was 6,17% of the cross travel weight plus load lifted.

Medium load

Fig 8.17 gives an i[illegible]ation of the forces exerted on the wheels while the [illegible]rane was carrying the medium load.

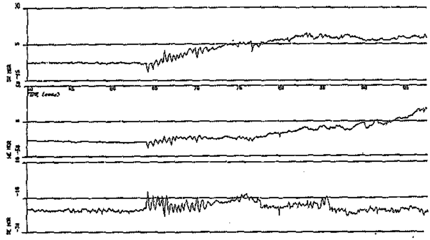


Figure 8.17 Crane 535 : Horizontal forces *when* crane was *moving* with medium load

The magnitude of the forces are shown in Table T8-10

	DYNAMIC (kN)		LOAD + CROSS TRAVEL	% OF LOAD + XT	
	MAX	MIN		MAX	MIN
SW	10	-10	449,18	2,3	2,3
SE	-32	-18	449,18	7,1	4,0
NE	25	-22	449,18	5,6	4,9

Table T8-10 Crane 535 : Magnitude of forces shown in Fig 8.17.

The maximum force recorded was 7,1% of the cross travel weight plus load carried.

Heavy load

While the crane was .arrying the heavy load, the forces as shown in Fig 8.13 was measured. Table T8-11 lists the magnitudes.

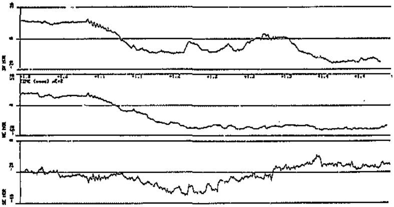


Figure 8.18 Crane 535 : Horizontal forces when the heavy load was lifted and the crane started moving

	DYNAMIC (kN)		LOAD + CROSS TRAVEL	% OF LOAD + XT	
	MAX	MIN		MAX	MIN
SW	-15	12	592,89	2,5	2,0
SE	-35	-16	592,89	5,9	2,7
NE	-40	18	592,89	6,7	3,03

Table T8-11 Crane 535 : Magnitude of forces as shown in Fig 8.18

The maximum force of 40 kN was 6,7% of the cross travel weight plus load handled.

8.3 *Conclusions*

Vertical

With the assumption that the forces on the NE bogie, where the recording did not work, varied with the same magnitude as the SE bogie, the measured values were within 5% of the calculated load values.

Dynamic forces due to the movement of the crane were a maximum of 20% of the static value.

Oscillating forces generated when the load was lowered onto the floor, were due to the elastic deformation of the bridge structure. These forces had a magnitude of up to 9 kN. The deformation of the structure was felt during the execution of the tests.

When the loads were lifted, a greater increase of forces was observed in the bogies closer to the cross travel.

Swinging of the load, observed in Fig 8.4, showed to have a marked influence on the magnitude of the vertical forces.

Horizontal forces

When the cross travel moved while the crane was standing, only small variations in the horizontal forces were observed.

Although the displacement transducers could not be connected, the variation in forces as shown in Fig 8.12 and Fig 8.13, indicated that the crane was skewing. High forces were recorded during this period, confirming that the flange contact with the rails is an important factor in the magnitude of the lateral forces.

Elastic deformation of the bridge induces lateral forces on the bogies, which are influenced by the flexural stiffness of the bridge, the position of the wheel surface relative to the rail and the position of the cross travel.

9 DISCUSSION OF FORCES MEASURED ON CRANES 501, 563, 701 AND 270.

9.1 Crane 501

Crane 501 is a 50 ton capacity crane with the longest span (45 meters) at ISCOR works. The crane is used for the handling of the hot rolled coils.

Crane data :

Mass of bridge	:	171 321 kg
Mass of cross travel	:	60 226 kg
Mass of cabin	:	5 031 kg
Total mass	:	236 578 kg
=>Total weight	:	2318,46 kN

Weight distribution with cross travel in centre of crane :

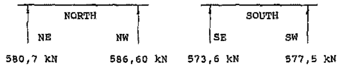


Figure 9.1 Crane 501 : Weight distribution.

Loads handled :

Load A	:	98,0 kN
Load B	:	139,94 kN
Load C	:	242,06 kN
Load D	:	246,57 kN
Load E	:	304,97 kN

Orientation of crane :

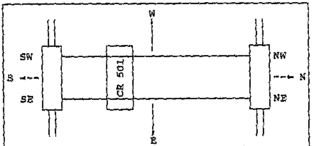


Figure 9.2 Crane 501 : Orientation.

9.1.1 Vertical forces

The forces measured during the travelling of the crane with the cross travel at different positions were :

CROSS TRAVEL	SOUTH kN	CENTRE kN	NORTH kN
SE	656,6	571,8	465,9
SW	697,2	611,6	538,2

Table T9-01 Crane 501 : Vertical forces with the cross travel in different positions

(No readings were registered on north side bogies)

With the crane handling the different loads, the maximum and minimum forces recorded were :

	LOAD A		LOAD B		LOAD C	
	MAX	MIN	MAX	MIN	MAX	MIN
SE	748,5	398,4	597,7	323,4	921,5	37[illegible],6
SW	873,9	280,8	764,79	437,04	1030,1	312,1

	LOAD D		LOAD E	
	MAX	MIN	MAX	MIN
SE	736,01	523,9	748,5	449,05
SW	780,4	310,2	811,6	171,3

Table T9-02 Crane 501 : Vertical forces with different loads

The highest force was measured when the cross travel was maximum south, during the handling of load C. This force was 25,19% higher than the static force on the bogie.

Oscillating forces were observed on the SW Bogie during the handling of the load C, showing that the structure of the crane, due to the long span, deformed elastically.

9.1.2 Horizontal forces

Crane travelling without load

The forces recorded during the travelling of the crane with different speeds and with the cross travel in the centre were :

	EAST	WEST
SE	-50,83 kN	53,79 kN
NW	-52,34 kN	54,69 kN
SW	42,14 kN	-48,38 kN

Table T9-03 Crane 501 : Horizontal forces with the cross travel centre

With the cross travel South :

	EAST	WEST
SE	-58,66 kN	47,31 kN
NW	--	50,88 kN
SW	23,96 kN	46,32 kN

Table T9-04 Crane 501 : Horizontal forces with the cross travel south

With the cross travel North :

	EAST	WEST
SE	-44,57 kN	50,84 kN
NW	--	--
SW	15,17 kN	-38,33 kN

Table T9-05 Crane 501 : Horizontal forces with the cross travel north

Crane handling loads

The maximum forces recorded during the handling of the loads are summarised in *Table T9-06.*

	A	B	C	D	E
SE	54,75	59,05	70,78	50,84	-67,65
NW	-54,79	47,74	79,82	44,72	43,13
SW	-39,93	3,92	43,10	52,45	43,13

Table T9-06 Crane 501 : Horizontal forces witn the crane handling loads

General

High oscillating forces were recorded during the *hoisting* of some of the loads. These were due to the elastic deformation of the bridge and the speed with which the hoisting were done. Fig 9.3 (Page 89) shows these forces.

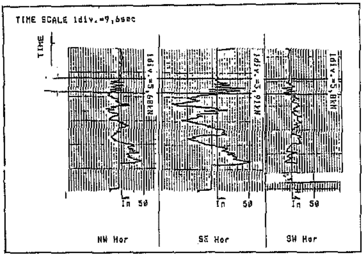


Figure 9.3 Crane 501 : Oscillating horizontal forces during handling of load.

During the test it was observed that the high forces were generated when the bogies were running against the rails. Fig 9.4 (Page 90) shows how the forces changed when the crane moved relative to the rails.

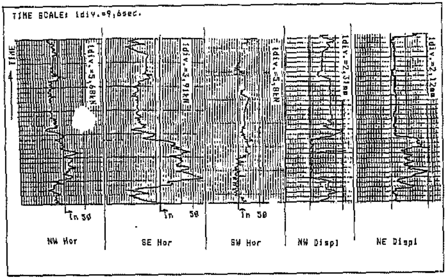


Figure 9.4 Crane 501 : Horizontal forces generated when the crane moved relative to the rails

It was also observed that the crano was skewing as seen in Fig 9.5 (Page 91). The maximum forces were generated during the times the wheels were running, due to the skewing motion, against the rails.

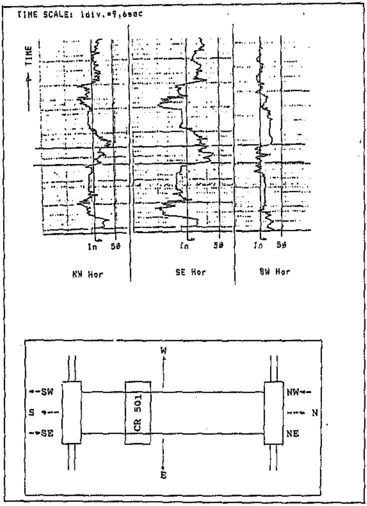


Figure 9.5 Crane 501 : Horizontal forces - Magnitude and direction when crane was skewing

9.2 Crane 563

Crane 563 is a 16 ton capacity, pendant controlled crane with a span of 37 meters. The crane is used for the handling of spares.

Crane data :

Mass of bridge	:	43 420 kg
Mass of cross travel	:	4 260 kg
Total mass	:	47 680 kg
=>Total weight	:	467,264 kN

Weight distribution with cross travel South

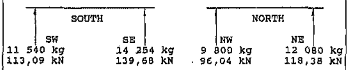


Figure 9.6 Crane 563 : Weight distribution.

Loads handled :

Load A : 7,252 kN
Load B : 14,504 kN

Orientation of crane :

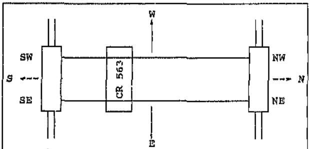


Figure 9.7 Crane 563 : Orientation.

9.2.1 Vertical forces

The forces measured during the travelling of the crane with the cross travel at different positions are :

CROSS TRAVEL	NORTH		SOUTH	
	STATIC	DYNAMIC	STATIC	DYNAMIC
NW	113,09	118,88	96,04	101,155
NE	139,69	143,01	118,38	122,36
SE	115,38	126,49	139,69	143,75

Table T9-07 Crane 563 : Vertical forces with crane moving without load

(No readings were registered on the south-west bogie)

With the crane handling the different loads, the maximum forces recorded were :

	LOAD A	LOAD B
NW	111,33	113,43
NE	145,47	151,16
SE	131,57	134,61

Table T9-08 Crane 563 : Vertical forces with crane handling loads

The highest vertical force was measured on the NE bogie when the heavy load was picked up. This force was 151,16 kN, which was 12,5% higher than the maximum static force.

Oscillating forces were observed on the bogies during the tests showing that the structure of the crane is much more flexible due to the long span and light construction. The forces are also carried over directly to the structure, as this crane is a fixed wheel type, with the wheels connected directly to the structure.

9.2.3 Horizontal Forces

Crane travelling without load

The forces recorded during the travelling of the crane with different speeds and with the cross travel in different positions were :

	FORCE (kN)	
	XT SOUTH	XT NORTH
NW	13,19	- 6,60
NE	-10,84	+ 3,02
SW	13,45	- 3,45

Table T9-09 Crane 563 : Horizontal forces with the crane moving without loads

(No readings recorded on the south-east bogie)

Crane handling loads

During hoisting of the load the forces generated are shown in Fig 9.8

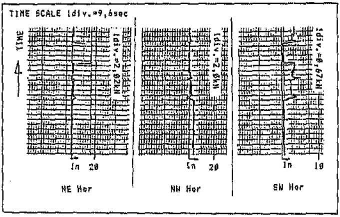


Figure 9.8 Crane 563 : Load lifted

	FORCE (kN)
NW	− 2,62
NE	2,45
SW	5,31

Table T9-10 *Crane* 563 : Horizontal forces with the light load (load A) lifted

The forces generated are transmitted more directly through the structure, as there is no *bogie pin which* can have a reducing effect on the forces.

As there is always play between the bogie pins and its *housing, forces* due to small movements of the bridge relative to the bogies, are absorbed by this play. In the case of the directly coupled wheels, the forces are transmitted directly through the structure.

Fig 9.9 shows the forces during a *period where the* crane was moving with load.

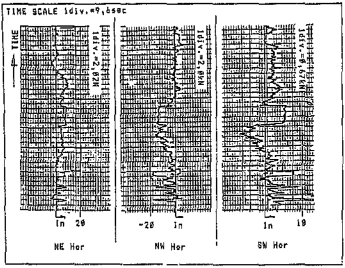


Figure 9.9 Crane 563 : Horizontal forces with crane moving with heavy load

Hitting the end stops

Due to the low velocity of the cross travel, the forces generated during the collision with the end stops were low :

	FORCE (kN)
NW	2,31
NE	2,58
SW	1,20

Table T9-11 Crane 563 : Horizontal forces generated when the cross travel hit the endstops

Off-centre lifting of the load

This action also produced low forces :

	FORCE (kN)
NW	1,10
NE	2,34
SW	1,95

Table T9-12 Crane 563 : Horizontal forces during off centre lifting of the load

Skewing of crane

Slipping of the drive wheel, causing skewing of the crane, was simulated by disconnecting the one drive wheel. The crane was then driven by the NE drive wheel. Fig 9.10 (Page 97) shows the forces recorded during these tests, with the magnitudes summarised in Table T9.13.

CROSS TRAVEL	MOVING EAST (kN)		MOVING WEST (kN)	
NW	16,61	17,23	-23,28	-17,22
NE	- 9,20	- 8,02	10,00	9,49
SW	8,45	9,11	- 8,55	- 9,10

Table T9-13 Crane 563 : Horizontal forces generated during skewing of the crane

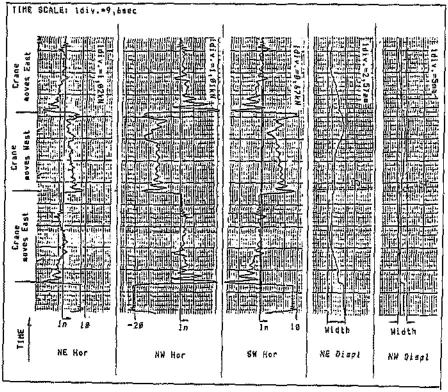


Figure 9.10 Crane 56J : Effect of drive wheel slip, causing skewing

9.3 Crane 701

Crane 701 is a 16 ton capacity, pendant controlled crane with a span of 12 meters. It is a fixed wheel type crane with four wheels, two drive and two non-drive. The crane is used in the servicing of an ore crushing facility.

Crane data :

Mass of bridge	:	7 000 Kg
Mass of cross travel	:	2 800 Kg
Total mass	:	9 800 Kg
=> Total weight	:	96,040 kN

Weight distribution with cross travel East :

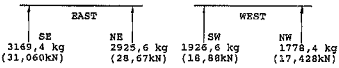


Figure 9.11 Crane 701 : Weight distribution.

Load handled :

Load A : 25,480 kN

Orientation of the crane :

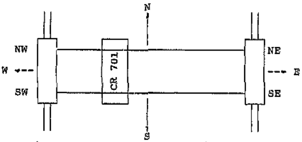


Figure 9.12 Crane 701 : Orientation.

9.3.1 Vertical forces

The vertical forces recorded with the crane travelling without load, but with the cross travel in different positions are shown in *Table* T9-14 :

	MAX (kN)	MIN (kN)
SW	32,27	18,13
NW	33,82	17,34

Table T9-14 Crane 701 : Vertical forces with the crane moving without load.

With the crane handling the load, the forces recorded were :

	MAX (kN)	MIN (kN)
SW	37,35	16,68
NW	40,80	20,60

Table T9-15 Crane 701 : Vertical forces with the crane moving with load.

The highest vertical force measured was 40,8 kN, an increase of 8,25% on the maximum static wheel load.

9.3.2 Horizontal forces

Crane moving without load

The forces recorded when the crane was travelling without the load are shown in Table T9-16 :

	FORCES (kN)
SW	-3,22
NW	6,71
NE	7,16

Table T9-16 Crane 701 : Horizontal forces with the crane moving without load.

Crane handling the load

During the handling of the load the maximum forces recorded on the wheels were :

	FORCES (kN)
SW	-3,866
NW	8,055
NE	8,350

Table T9-17 Crane 701 : Crane moving with load.

Hitting the end stops

Due to the very low velocity of the cross travel (0,127m/s), the forces generated when the cross travel hit the end stops were low, as seen in Table T9-18.

	FORCES (kN)
SW	2,15
NW	0,67
NE	1,55

Table T9-18 Crane 701 : Horizontal forces when the cross travel hits the endstops.

Skewing of crane

For this measurement the East drive motor was disconnected. Fig 9.13 shows the sharp forces generated similar to the forces observed on crane 563. Table T9-19 shows the magnitudes.

	NORTH	SOUTH
SW	2,79	-3,22
NW	-2,68	2,95
NE	3,58	-3,81

Table T9-19 Crane 701 : Horizontal forces with skewing of the crane.

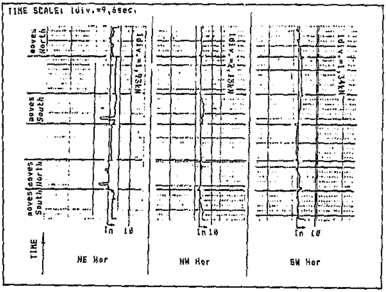


Figure 9.13 Crane 701 : Effect of drive wheel slip, causing skewing

9.4 Crane 270

Crane 270 was the first crane tested and only two bogies were wired up and measured. As the wiring was done on the crane itself, the connections were not good and only one channel, the SW horizontal force, recorded meaningful data.

This crane is a 22,7 ton capacity crane with a span of 28,95 m and is used in the storing of hot rolled coils.

Crane data :

Mass of bridge	:	86 808 kg
Mass of cross travel	:	21 260 kg
Mass of cabin	:	2 740 kg
Total mass	:	110 808 kg
=> Total weight	:	1087,03 kN

Weight distribution with cross travel north

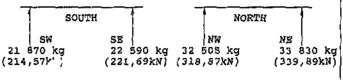


Figure 9.14 Crane 270 : Weight distribution.

Loads handled :

Load A : 32,96 kN
Load B : 53,95 kN

Orientation of the crane :

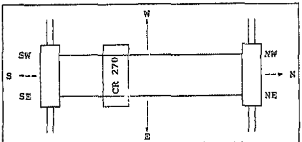


Figure 9.15 Crane 270 : Orientation.

9.4.1 Horizontal forces

With the crane moving east without a load, the maximum force was 16,93 kN outwards.

The highest force recorded when the crane was moving with load A was 24,48 kN, which was the overall highest force recorded.

As the crane moved west with the heavier load B, the maximum force recorded was 15,84 kN.

Although the insufficient data does not give an idea of the actions of the crane i.e. skewing, dynamic asymmetry, etc, the readings do give an indication of the magnitude of the forces exerted on the crane wheels.

9.5 Conclusions

9.5.1 Vertical Forces

Dynamic forces when lifting and lowering loads are more prominent in the cranes with long spans, as were recorded on cranes 501 and 563. The elasticity of the crane structure is an important factor in the magnitude of the vertical forces.

The highest force measured during the operation of the cranes was 25,19% higher than the static force at that point (Crane 501).

9.5.2 Horizontal Forces

The dynamic forces were also observed in the horizontal direction during the lifting of the loads. It was more prominent in the long span cranes.

High forces were recorded when the crane wheels were running against the rails.

The large lateral forces observed by Hunter in his scale model <Ref 3> when the drive wheel slipped, were measured on the two four wheel cranes as well, thereby confirming his observations. These forces were up to 32,18% of the cross travel weight, plus load handled.

Off-vertical lifting of the loads produced only low forces, and can be neglected in the design criteria.

In the low velocity cranes (<0,127m/s), the forces produced when the cross travel hits the end stops, are negligible.

10 CODE COMPARISON

10.1 Vertical loads as a percentage increase of the static wheel loads

CRANE	MEASURED	LIMITING FORCE %			
NO	VALUE %	SABS 0160 <Ref 7>	DIN 4132 <Ref 10>	BS 449 <Ref 6>	AISC <Ref 9>
439	34,77	25	40	25	25
535	20,00	25	40	25	25
501	25,19	25	40	25	25
563	12,50	20	20	25	25
701	8,54	20	20	25	25

Table T10-01 : Vertical forces as predicted by various codes of practice.

10.2 Horizontal Forces

10.2.1 B.S.- 449 <Ref 6>

Forces acting transverse to the rails shall be taken as a percentage of the combined weight of the crab and load as follows :

EOT 10%
Hand Operated 5%

CRANE NO	LOAD	MEASURED (kN)	%	BS 449
439	NO LOAD	47,70	13,60	10
	A	33,05	7,78	10
	B	34,89	4,60	10
535	NO LOAD	40,00	15,50	10
	A	23,00	6,75	10
	B	25,00	5,55	10
	C	40,00	6,70	10
501	NO LOAD	58,66	9,16	10
	A	54,79	7,40	10
	B	59,05	7,56	10
	C	79,82	9,05	10
	D	52,45	5,91	10
	E	67,65	7,16	10
563	NO LOAD	13,45	32,18	10
	A	5,31	10,82	10
	B	16,20	28,77	10
701	NO LOAD	7,16	26,10	10
	A	8,35	15,77	10
270	NO LOAD	16,93	8,11	10
	A	24,48	10,13	10
	B	15,84	6,03	10

Table T10-02 : Horizontal forces as per BS 449.

10.2.2 S.A.B.S. 0160 <Ref 7>

Allowance for accelerating or braking :

Combined weight of crab and load lifted multiplied by :

Class 1 0,05
2 0,10
3 0,15
4 0,20

Divide the forces amongst all the wheels.

According to this standard, cranes 439, 535, 501 and 270 are class 3 cranes.

Skewing of crane in plan :

Apply to each wheel a force of

$P_2 = 1,5 * P_1$

Wh[illegible] $P_1 = XM/N$

X = Class 1 0.05
2 0,12
3 0,15
4 0,20

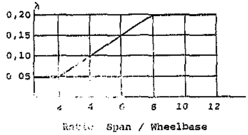
M = [illegible]bined weight of bridge, crab and load
N = [illegible]er of crane wheels.

CRANE NO	LOAD	MEASURED (kN)	PREDICTED (kN)
439	NO LOAD	47,70	46,40
	A	33,05	48,50
	B	34,89	57,72
535	NO LOAD	40,00	3[illegible],26
	A	23,00	[illegible],67
	B	25,00	36,74
	C	40,00	40,28
501	NO LOAD	58,66	65,27
	A	54,79	68,03
	B	59,05	69,20
	C	7[illegible],82	72,08
	D	52,[illegible]	72,21
	E	67,65	73,84
563	NO LOAD	13,45	21,04
	A	5,31	21,37
	B	16,20	21,70
701	NO LOAD	7,16	4,33
	A	8,35	5,47
270	NO LOAD	16,93	30,57
	A	24,48	31,50
	B	15,84	32,09

Table T10-03 : Horizontal forces as per SABS 0160.

10.2.3 B.S.- 2573 <Ref 5>

Skew loads due to travelling :
Multiply the vertical forces on each *wheel or bogie by* Coeff λ



CRANE NO	LOAD	MEASURED (kN)	PREDICTED (kN)
439	NO LOAD	47,70	56,06
	A	33,05	59,35
λ = 0,11	B	4,89	73,77
	NO LOAD	40,00	33,39
535	A	23,00	36,76
	B	25,00	41,13
λ = 0,10	C	40,00	46,88
	NO LOAD	58,56	67,26
	A	54,29	71,50
501	B	59,65	73,30
	C	79,82	84,27
λ = 0,10	D	52,45	83,60
	E	67,65	80,60
563	NO LOAD	13,45	20,95
	A	5,31	21,38
λ = 0,15	B	16,20	21,82
701	NO LOAD	7,16	2,29
λ = 0,08	A	8,35	3,19
370	NO LOAD	16,93	25,74
	A	24,48	28,34
λ = 0,12	B	15,84	29,45

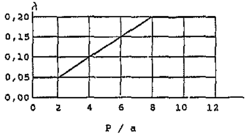
Table T10-04 : Horizontal forces as per BS 2573.

10.2.4 F.E.M. Section 1 <Ref 9>

Transverse reactions due to rolling action

When two wheels (or two bogies) roll along a rail, the couple formed by the horizontal forces normal to the rail shall be taken into consideration. The components of this couple are obtained by multiplying the vertical load exerted on the wheels (or *bogies*) by a *coefficient* λ which depends upon the ratio of the span p to the wheel base a.

As shown in the graph, this coefficient lies between 0,05 and 0,2 for ratios of P/a between 2 and 8.



The values are the same as for *BS 2573* *<Ref 5>*

10.2.5 Models developed by Hunter <Ref 3>

The models developed *by Hunter were* used to predict the forces on three of the cranes tested.

The three cranes evaluated were Crane 701, Crane 563 and Crane 439.

Data for these cranes, used in the evaluation are :

CRANE	701	563	439
TYPE	E	E	W
Building stiffness (kN/m)	7434	3483	2327,5
Mass of bridge (ton)	7,0	43,37	132,13
Mass of cross travel (ton)	2,8	4,26	35,66
Mass of load (ton)	2,15	0,8	6,0
Mass moment of inertia (t.m)	222,32	7438,4	20163,35
Crane span (m)	12,0	37,0	30,48
Wheel centres (m)	4,32	6,15	7,16
Max. cross travel limit (m)	10,0	34,0	27,0
Wheel radius (m)	0,157	0,230	0,419
Flange contact radius (m)	0,169	0,236	0,445
Crane velocity (m/s)	0,193	0,330	1,219
Initial angle of skew (rad)	-0,0032	-0,00296	-0,00397
Time step (sec)	0,001	0,001	0,001
Rail 1 - Vertical reaction (kN)	48,06	234,75	823,19
Rail 2 - Vertical reaction (kN)	48,06	234,75	823,19
Rail 1 - Wheel resistance (kN)	2,90	13,01	54,025
Rail 2 - Wheel resistance (kN)	2,90	13,01	54,025
Rail 1 - Braking force (kN)	9,61	86,95	164,63
Rail 2 - Braking force (kN)	9,61	86,95	164,63
Rail head width (m)	0,06	0,08	0,10
Pendulum length (m)	5,0	13,0	13,5
Buffer stiffness (kN/m)	2000,0	1200,0	1250,0
Bridge mass+portion of building	8,8	48,17	141,28
Log decrement of building	0,3	0,3	0,3
Log decrement of buffer	0,5	0,5	0,5

With these parameters the programs CROSS TRAVEL, CRAB and SKEW were run. Table T10-05 gives a summary of the predicted and measured values. It is clear that the values as predicted by Hunter <Ref 3> compare well with the forces measured.

CRANE	CROSS TRAVEL		CRAB		SKEW	
NO	MEASURED	CT	MEASURED	CRAB	MEASURED	SKEW
701	2,15	5,54	2,10	0,97	8,35	12,86
563	2,58	2,72	2,01	1,46	23,28	26,53
439	50,00	46,23	16,95	12,09	47,70	37,91

Table T10-05 : Comparison of measured forces with the models developed by Hunter <Ref 3>

The skewing forces and cross travel forces are more easily determined than the forces due to the dynamic asymmetry of the crane, as the former can be measured under controlled conditions, where as the latter cannot always be isolated from the other forces.

The values for the forces due to the dynamic asymmetry were taken as the forces recorded just before and after the change of direction of the crane as can be seen in Fig 7.15.

These models were developed assuming that the vertical reactions on all the wheels are equal, which is not the case in practice. The values, however, correlate well.

10.3 General Discussion

The accurate determination of the forces generated during operation is important for both the crane design and the structure. It is therefore very important that design codes of practice include all the possible actions when giving formulae for limiting forces.

10.3.1 Vertical forces

DIN 4132 <Ref 10> is the only code where the measured forces were lower than the limiting force predicted. The limiting force according to SABS 0160 <Ref 7> was, except for Crane 535, lower than the forces measured. Although the limiting forces predicted by BS 449 <Ref 6> and AISC <Ref 9> are lower than those predicted by the other codes, the values measured on the cranes were all still lower except for two exceptions (Table T10-01 Page 105).

The high force on Crane 439 was due to the observation that forces on the bogies diagonally opposite each other increased as the forces on the other two bogies decreased. The weight of the crane was then mostly carried by the two bogies, giving a larger percentage increase in the static wheel loads.

10.3.2 Horizontal forces

Most of the measured forces which were higher than the limiting predicted forces, were measured when the cranes were running without load. This can possibly be attributed to the centre of gravity of the cranes being above rail level, as well as the higher friction forces during the carrying of the loads, which limited lateral movement and flange contact, resulting in lower forces.

Drive wheel slip occurs during normal operation of the cranes, either because of dirt or grease on the rails, or failure of one drive system due to electrical failure of the motor or mechanical failure of the coupling or drive shaft.

The very high forces on Cranes 563 and 701 were measured when the drive wheel slip was simulated. The codes of practice do not take this into consideration, but it was seen to cause very high forces on the wheels.

In the codes of practice where the weight of the crane bridge is taken into consideration, especially on the light structured cranes 563 and 701, the predicted limiting forces were closer to the measured values than BS 449 <Ref 6>, where only the weight of the cross travel (crab) is taken into consideration. This was due to the fact that in a long span, low capacity crane the bridge structure is heavy, but the cross travel weight low, and low forces are therefore predicted.

10.3.3 Factors not taken into consideration in the codes of practice

The torsional stiffness of the crane structure together with the vertical misalignment of rails.

Drive wheel slip.

When the crane is running without load.

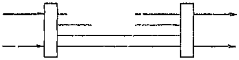
Elastic deformation of the crane structure.

Swinging of the load.

These factors were found to be important factors in the magnitude of the forces generated.

10.3.4 Actions influencing the maximum forces.

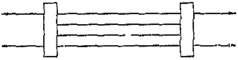
Case 1



These forces are generated by the cross travel movement and/or hitting the end stops. Here the forces due to the different actions can act together and when working in the same direction cause high forces.

It was seen in Fig 7.21 (Page 62) that high forces developed in the same direction when the cross travel hit the end stops.

Case 2

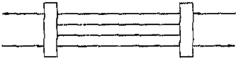


Due to the deformation of the crane bridge and/or the misalignment of the rails, *outward forces* are exerted on both rails. These forces will have an influence on the supporting columns.

These forces will, however, have a *less severe influence* on the supporting columns with structures where the columns also support a roof structure *than* the *forces* in Case 1. Fig 8.15 (Page 79) shows that the forces were mostly outward during handling of the loads. *It appeared* that the crane bridge did not deform uniformly but that the crane rotated in the horizontal *plane*.

Lifting of the *load*, *occurring* simultaneously with the outward forces, will increase the total force on each wheel.

Case 3



These forces are caused by skewing of the crane due to unequal wheel *diameters*, difference in drive motor speeds (for E-type cranes) and drive wheel slip. These forces will primarily *effect* the gantry beams, and also the connection point between two beams, or between the beams and the column, *when the wheels are* on both sides of the joint.

When the cross travel hits the endstops during this action, the worst situation probably *occurs*. It was seen that high forces were measured when the crane was skewing, as well as when the cross travel *hits the endstops*. Should these actions occur simultaneously, the forces on the one *bogie* will add up, giving a very high resultant *force*, while the force on the other *bogie* on the same side will decrease. The oscillations during the lifting *of a load* are, however, of sufficiently short duration that they will not occur *simultaneously* with skewing or drive wheel slip and need not be considered together.

10.3.5 Forces predicted *by Hunter* <Ref 3>

In Fig. 7.16 flange wheel contact occurred. *The forces* predicted, and measured were as *follows :*

	PREDICTED (kN)	MEASURED (*kN*)
NW HOR	37,91	37,65
NE HOR	16,93	14,10
SW HOR	1,65	2,60

In Fig. 9.10 the same correlation was *seen* during wheel/flange contact *:*

	PREDICTED (*kN*)	*MEASURED* (kN)
NW	26,53	20,12
NE	8,12	2,76
SW	0,00	2,02

The programmes *developed* are not only useful in *predicting* the maximum forces, but also give an indication of the forces which will be *exerted* on the other wheels.

10.3.6 General

When we consider the design of the building supporting the crane, the problem is not only to find the maximum forces on the individual wheels, as the combination of certain actions can cause higher resultant forces on the structure.

In all these cases it is clear that the forces are transmitted by the crane rails to the structures and must therefore also be taken into consideration in the design of the rail fasteners.

From this study, as well as the work done by Hunter <Ref 3>, it is clear that all the actions producing the forces are not taken into consideration in the codes of practice.

Lower forces are predicted in the codes where only the cross travel and the load are taken into consideration. In the case of long span , low capacity cranes (Crane 563), the bridge needs to be heavy for strength and higher forces are therefore generated (Table 10-02 Page 106). The codes taking the bridge weight into consideration , predicted higher forces (Table 10-03 Page 107 and Table 10-04 Page 108)

Higher forces for the high capacity cranes are predicted by the codes which take the span of the crane into consideration than those only using the weight of the crane components as a criterion.

The neutral axis of the 8 wheel cranes are higher than the wheels at rail level. This can cause a magnifying effect on the forces generated and higher forces were therefore measured on Cranes 439, 535 and 501. (Table 10-03 Page 107). Relatively high forces were measured on Crane 701, a light structured, low capacity crane.

The codes do take skewing caused by misalignment of wheels, different wheel diameters or difference in rail levels, Hunter <Ref 3>, into consideration but do not consider the case where the crane is driven skew. This driving acoion pruduced much higher forces than the forces predicted by the codes for other forms of skewing. (Fig 9.10 Page 97 and Fig 9.13 Page 101)

11 CONCLUSIONS

i) The method of measuring the forces is practical and gives accurate data of the forces generated during operation. Due to the dirty environment and vibrations experienced on the cranes in the Iron manufacturing Process, problems were experienced with bad connections, leading to channels not working. Cross sensitivity was found to be low.

ii) Processing of the data using the PDP 11/23 computer gives accurate results, as a wide scale range can be used. The Graphtec plotter gives a better overall picture of the whole period of operation, but is limited in the vertical scale range.

iii) Vertical Forces

a) For speeds up to 1 m/s, the dynamic increase in force was independent of crane speed.

b) Small vertical misalignments in the rails lead to high forces on the crane and gantry.

c) Oscillating forces are generated during lifting and lowering of the loads, due to the elastic deformation of the bridge. These forces are higher in the cranes with longer spans.

d) The measured values compare well with the predicted values of the different codes of practice.

iv) Horizontal Forces

a) The low cross travel speeds of the cranes tested, showed that this action caused very low forces and can be neglected in the design of the cranes.

b) Wheel/Flange contact produces high forces on the rails and is one of the primary causes of lateral forces on the crane wheels

c) The increase in lateral forces with the increase in crane speed (up to 1 m/s), is negligible.

d) No correlation was observed between the lateral forces and the loads handled. On Crane 439 the forces decreased with the increase in loads handled. It appears that the load has a stabilising effect on the crane, tending to keep the crane from "wandering" whereby the flange/wheel contact is limited. On Crane 501 higher forces were observed when the crane handled a lighter load than when it was handling a high load. (Table T9-06)

e) Deformation of the bridge generated cyclic forces during hoisting of loads.

f) Off-centre lifting of loads produced low forces. However, it was only tested with the load sliding into position, and not with an obstacle preventing sideways movement of the load.

g) Large lateral forces, observed by Hunter <Ref 3> in his scale model when the drive wheel slipped, were observed on the two four wheel cranes tested for this purpose.

h) The present Codes of Practice are too inconsistent and all the actions generating forces are not always taken into consideration.

i) For the heavier, faster crane the values predicted by Hunter <Ref. 3> compare well. The difference in the measured and predicted forces can be attributed to the fact that in practice the different forces never occur in isolation, but are rather the combination of different forces which then increase or reduce the resultant force on each bogie.

j) Not only the maximum forces, but also the combination of forces are important in the design of cranes and their supporting structures.

12 RECOMMENDATIONS FOR FURTHER WORK

1) The effects of vertical misalignment of the rails on the magnitude of the forces needs to be investigated further.

2) The action of a drive wheel slipping on one side showed the development of large forces. This needs to be investigated.

3) The influence of the position of the centre of the gravity of the crane on the behaviour of the crane and the magnitude of forces need to be assessed.

4) The forces on very light, low capacity cranes, which were found to be higher than predicted.

5) From Hunter's work <Ref. 3> and the correlation found in the measurements between his prediction and forces found in practice, a revision of existing codes can be done.

13 REFERENCES

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