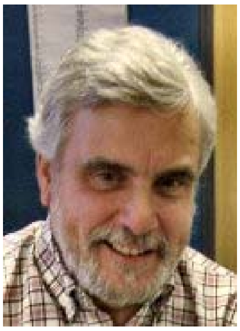
OVERVIEW OF CRANE DESIGN

By Eric S. Long – Chartered Consulting Engineer & Risk Management Consultant Associate to PM Safety Consultants, Coventry



Dr, Eur-Ing Eric S. Long is a graduate of the Universities of Manchester and Salford, majoring in Mechanical Engineering and Advanced Manufacturing Technology and Management. He undertook his initial training at Metropolitan-Vickers in Trafford Park, Manchester, followed by extensive experience in research, consultancy and at one of the foremost inspecting authorities in Europe. Eric is a Chartered Engineer, an independent Consulting Engineer specialising on the Development and Auditing of Safety and Reliability Management Systems, and a Visiting Professor of Safety Law

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Section 1.0 Introduction

This short paper has been compiled to provide the reader with an overview of the designs and operating parameters of various types of crane, predominantly in use for critical lifting operations in the marine and nuclear environments. Whilst the paper covers the generic aspects of a range of crane designs, with the emphasis placed upon heavy lifting marine and nuclear cranes, the range chosen will predominantly provide the reader with an insight into all examples of crane motion design, and includes:

- Floating Marine Cranes
- Container Terminal Cranes

- Bulk Handling Grab Cranes
- Dockside Level Luffing Cranes
- Cantilevered Shipbuilding Cranes
- Overhead Travelling Cranes or Goliath Cranes

Section 2.0 Crane Definitions

There are a number of conventional terms used in the geometry of crane operational configurations, which are referred to in the text, and for convenience they are defined here:

- Traversing – the movement of the whole crane structure along rails, such as at the dockside
- Slewing – the movement of the jib (and hook) in a circular path, in relation to its supporting structure
- Luffing – the variable operating angle of the jib (and variable radius of the hook), as the jib moved inwards or outwards, in relation to its supporting structure
- Level Luffing – the design of jib is articulated, and the luffing rope configuration is such that, as the operating jib radius is varied (ie moving inwards or outwards) in relation to its supporting structure, the hook remains at the same height
- Jib Extension – the jib length may comprise three sections nesting within each other, and extension of which is achieved hydraulically, so increasing the operating radius of the hook
- Fly Jib – sometimes for extended lifting operations, a fixed lattice structured jib is attached to the hydraulically actuated jib, in order to provide extra operating radius of the hook
- Racking – the movement of the crab along the rails of a horizontal jib, so varying the radius of the hook and lifting operation
- Hoisting (and lowering) – the raising and lowering of the hook and the load

In most cases the above crane operations can be duplicated, in order to speed up the positioning of the hook (and the load) within the geometrical boundary or profile of the crane operating parameters

Section 3.0 Generic Configuration of Cranes

Whatever the crane type or design of crane, it will generally comprise of the following major component configuration, commencing at the lifting point:

- Hook, sometime fitted with spring loaded 'keep' to retain the lifting sling within the intrados of the hook
- Return pulley block assembly to accommodate the falls of hoisting rope
- Falls of hoist rope
- Jib head pulley arrangement on a luffing jib, or pulley arrangement on the crab of a fixed (in the luffing sense) horizontal jib, to accommodate the falls of hoist rope
- Luffing or fixed horizontal jib

- Electro-mechanical hoist winding gear assembly in the machinery housing – note that there are normally at least three turns of rope left on the hoist drum when the hook etc is at its lowest point, in order that the ‘wrapping’ effect takes the load off the rope anchorage
- Crane structure in the case of container cranes and conventional shipyard cranes, or a chassis and ‘A’ frame in the case of mobile cranes (including bulk handling cranes)
- Mobility of the vertical crane structure on rails with compensating wheeled bogies, and electro-mechanical drive arrangement
- Mobile cranes comprise a chassis with tyres, wheels, axles and suspension assembly etc in a fairly conventional electro-mechanical drive arrangement, suitable for transportation by road – note that mobile cranes comprise outriggers at the four corners of the chassis, which are extended horizontally by hydraulic actuation, with hydraulically actuated pads with extend vertically downwards from the outriggers, making contact with the ground, in order to take the load off the wheels and maintain stability of the crane during the lifting operation
- Alternatively the mobile crane chassis may be mounted on crawler tracks to facilitate mobility on the site of operations
- Slewing ring mounted on top of the vertical crane structure, or on the mobile crane chassis, complete with the electro-mechanical slew drive, for the purposes of rotating the fixed horizontal jib or luffing jib (complete with the crane operators cab and machinery housing)
- Racking ropes anchored to the crab on the horizontal jib and the electro-mechanical racking gear in the machinery housing
- Luffing ropes anchored to the jib of a mobile crane, complete with compensating pulley arrangement with the electro-mechanical luff winding gear in the machinery housing
- Load compensating system to ensure equal tension on multi-rope systems
- Operator’s cab with the various modes of operational controls and braking system
- Safe load indicator. On mobile cranes, for example, this can vary from: (1) a simple vertically orientating pendulum on the jib, and a notice in the operator’s cab, giving an indication of the safe load to be raised at the particular radius of the jib, to (2) a dynamometer arrangement incorporating a load cell on the jib and readout instrumentation displayed in the cab, through to (3) automatic safe load indicators, incorporating microprocessors which continuously indicate the safe working load and incorporate an series of visual and audible overload alarm systems

Section 4.0 Law of the Lifting Machine

Taking a simplistic viewpoint, from a space diagram of loading criteria on the crane jib, including the load on the hook and the distributed load along the jib from the mass of the structure and rope systems etc, the moments of force can be calculated, taking the fulcrum point as the central vertical axis of the slew ring. The total moments of force on the jib will be a combined function of the inherent distributed loads and the mean distance from the slew ring, together with the point load(s) and distance from the slew ring. These combined moments of force, from the distributed and point loads, require to be balanced and a reactive moment of force is applied on the opposite side of the slew ring. This reactive moment of force is equal to, but in the opposite sense (conventionally), to the moments of force on the jib and applied by a counterbalancing mass. Thus these equal and opposite moments of force about the fulcrum point create an evenly distributed downward load on opposing sides of the slewing ring

In the case of an overhead travelling crane, a similar convention is applied, with the moments of force from the distributed load of the bridge structure and the point loads from the crab and load on the hook, reacted by the upward forces from the end carriage and structural supports

In both cases the moments of force in the clockwise and anticlockwise directions must be in equilibrium, with the reactive forces on either the jib or overhead travelling cranes being capable of sustaining the inherent distributed load of the crane and the load on the crane hook in any operating position

From the space diagram, bending moment diagram and shear force diagram, the bending stresses, along with tensile and shear stresses, can be calculated, within the elasticity range of the stress-strain diagram for the specific material under consideration

On the principle that a body in space must be in equilibrium, when under the action of forces in one plane (ie concurrent, coplanar forces), then from a vector diagram showing the direction and magnitude of the forces applied to individual members of a crane's lattice frame structure, for example, resultant forces can be determined and the tensile or compressive stresses can be calculated for ties and struts, respectively

In order to assist in keeping some of the direct forces down as low as possible in certain elements of the crane structure, the effort required by machinery to raise the load must be reduced so far as practicable. This reduced effort is evident in the reduced size of the winding gear machinery required and in the dynamic effect of raising the load, and is demonstrated by the 'law of the machine'. The simple machine comprises, for example, the principle of the lever, the gear train, and the lifting pulley block – all of which are inherent in the crane's design

In the case of the crane, in simple terms, the 'effort' is the force applied by the winding machine in order the raise the 'load' (including overcoming any resistance and frictional effects in the lifting machine and at the points of material contact in the load path). Therefore:

- Work input = Effort * Distance moved by the effort
- Work output = Load * Distance moved by the load
- Efficiency of the machine = Work output / Work input
- (Alternatively: Useful work done by machine / Actual work done by machine)

Note that the efficiency will always be less than unity or 100% due to the effects of friction

The essential principle of the machine is that there is a benefit in to be gained in its application. This is referred to as the Mechanical Advantage

- Mechanical advantage = Useful load or Distance overcome / Effort employed

The so-called trade-off, is the fact that there is a reduction in the distance moved by the load towards the distance moved by the effort in the same amount of time (which can work to advantage with the slightly reduced dynamic loading effect on the crane). This is referred to as the Velocity Ratio

- Velocity ratio = Distance moved by effort / Distance moved by load
- (Alternatively: Speed of effort / Speed of load)

It can be shown that the 'Efficiency' of the machine is also equal to the 'Mechanical Advantage / Velocity Ratio'

Graphically: the (1) Effort, (2) Effect of friction, and (3) Efficiency can be represented on the vertical axis and the Load on the horizontal axis, and graphs displayed of: (1) Load v. Effort, (2) Load v. Effect of friction, and (3) Load v. Efficiency. From this, the:

- Law of the machine is the graph of 'load v. effort'

This conforms to the straight line algebraic equation: $y = mx + c$; and is theoretically valid for all loads within the range of the machine. These symbols can be replaced by Effort = m * Load + c (where 'm' is the slope of the graph and c is a constant for the law of the machine [ie where the line crosses the x axis])

From this the:

- Limiting efficiency of machine = Load / (Law of the Machine) * Velocity Ratio

As the load increases the efficiency of the machine tends towards its limiting value. As such the lifting machine must be designed within the range of greatest efficiency by optimising the 'law of the machine', ie the effort provided by the winding gear for the load lifted

Before leaving the 'law of the machine', the concept of 'overhauling' of a machine must be mentioned. A machine is said to be capable of overhauling when the load is able to raise the effort, ie the operation of the machine is reversed. Such a condition is only possible when the effect of friction is less than the load or when the efficiency of the machine is over 50%

Section 5.0 Stresses within the Structural Lifting System

Stress analysis of crane structures is a complex subject, requiring a detailed understanding of the mathematics associated with strength of materials and mechanics of machines, and no attempt has been made in this paper to cover the subject in anything but the briefest of detail

The forces on the structural elements of any crane configuration will vary due to the variations in the working load applied and the position or radius of the load from the central pivot. The magnitude of these forces in the structure may well be highest with the maximum load positioned at the minimum radius of the jib (or minimum position along the jib), or alternatively with the minimum load at the maximum operating radius of the jib (or maximum position along the jib). In addition to the force from the load itself, other forces are inherent in the structural elements due to the mass of the structure itself (including the mass of the hook, return block and roping systems), and wind forces – the effect of which depends upon the 'sail-area' of the structure. The 'sail-area' is the 'shadowed area' that is cast on a vertical plane behind and in parallel with the jib. The degree of 'shadowed area' depends upon the angle at which the wind force is applied to the jib structure

Having decided upon the magnitude of the loads applied, from bending moment diagrams and vector force diagrams referred to above, the loading criteria on the structure and mechanisms are factorised by such duty factors as: (1) the crane group classification, (2) the state of loading, (3) class of utilisation of the crane (ie the cycles of loading), (4) load spectrum (range of loads applied), and (5) impact factors, providing a safety margin on the static and dynamic loading that the crane elements are subjected to in the course of a predicted lifetime of operation. It will be appreciated that in addition to the static loads applied, the dynamics of vertical load movement and braking, and load swing during slewing, together with such impact factors due to partially dropped load (from above a ledge), and snagging of the load when hoisting (from below a ledge), for example, are mostly accommodated in the factored load criteria

The stresses applied to any structural and mechanical member in the load path will vary due to the bending moments and applied forces, the material of construction, the sizing and modulus of the section under consideration, and the direction of forces applied to the element – giving rise to bending, tension, compressive, shear, or torsion stresses; and combinational stresses remembering that cantilevered structural elements under conditions of bending can be subjected to tensile forces on top of the element and compressive forces on the bottom of the element, about the neutral axis of the single section (or the neutral axis of an assembly of elemental sections to which a bending force is applied). In addition to which, depending upon the cross sectional geometry, the modulus of a structural element may vary in the xx axis and the yy axis of the section, and is in turn a function of the moment of inertia or second moment of area of the cross section. The structural geometry of the section to withstand the applied bending moments and forces must therefore be applied on the strongest axis of the section, which for an 'I' beam would be in line with the yy axis. It is interesting to note, that during the failure mode of an 'I' beam, the beam twists under excessive loading and structurally fails in the xx axis

In the case of box section girder construction, typical of many overhead-travelling cranes, when under longitudinal loaded conditions, the upper member is under compression and the lower member is under tensile forces. Buckling stresses of the side members should also be considered, along with transverse stresses, and racking forces due to a combination of loading and movement, all of which create stresses in the weld and the heat affected zone of the welds

Crane structures of all types are subjected to cyclic loading, and as such, analytical fatigue studies are also an important aspect of the stress analysis of the crane over its predicted life cycle. Crane ropes are especially vulnerable to fatigue due to the reverse bending of the dynamic ropes, particularly over pulleys, in the hoist, luffing/ racking rope systems. As a consequence, the diameter of the pulleys has to be sized in accordance with the size of the rope, in order to reduce the acuteness of the cyclic bending. Static ropes such as bridle ropes on mobile cranes are not subjected to fatigue cycling

Depending upon the site of operations of the crane, brittle fracture may be an aspect of design consideration. Sub-zero temperatures can have profound impact on the strength of certain structural materials, particularly when subjected to impact stresses, and cannot be ignored

Most structural (low carbon, non-alloy) steels, display a yield stress where the molecular structure of the steel changes at the transition point between the elastic and plastic range of the material, where permanent deformation takes place under load. The actual stresses computed in the various members of the crane structure must be below this yield stress, and are compared against the permissible stresses for the particular material under consideration, to establish the degree of safety margin or factor of safety

The stresses in complex crane structures are now analysed by computer software. In the case of a lattice jib, for example, the forces in each node of the crane structure must theoretically be in equilibrium (or approaching equilibrium) under loaded conditions, and finite element analysis (FEA) software has been adopted to calculate the forces and stresses at each member, at the selected node in the structure, under various conditions of loading

Section 6.0 Assessment of Different Types of Cranes

This section discusses the features and arrangements for operating several different types of cranes including

- Floating Marine Cranes
- Container Terminal Cranes
- Bulk Handling Grab Cranes
- Dockside Level Luffing Cranes
- Cantilevered Shipbuilding Cranes
- Overhead Travelling Cranes or Goliath Cranes

Each of the above types of crane have been discussed further in the sections which follow:-

6.1 Floating Marine Cranes

As the name suggests, these cranes are mounted on a floating barge, and employed for lifting objects from the seabed onto the supply vessel close by, or alternatively for one-off heavy lifting operations on the dockside where it is not possible to get a land-based mobile crane on the site of operations. The design of the jib configuration is such that it is capable of slewing and luffing, together with hoisting (lowering) the hook. Whilst the crane jib and load is counterbalanced, it will be fairly obvious to the reader, that either: (1) slewing the load around a fixed radial path, (2) luffing the load inwards or outwards so reducing or increasing the radius of the load, respectively, from the slewing centre, or (3) as the crane takes the load at commencement of the hoisting operation, then the longitudinal and transverse centre of gravity of the barge and crane combined, will vary. Therefore, this has to be compensated for in order to retain the longitudinal and transverse stability of the floating mass. This is normally achieved by altering the position of the ballast, by pumping seawater around the compartmental structure of the floating barge, and is usually computer controlled. The crane and floating barge comprises a massive structure, and whilst the heavy lifting crane design is a fairly conventional type of jib crane, the design of the fixed positioning system and variable stability requirements of the computer ballasted barge is a matter for the naval architect

6.2 Container Terminal Cranes

These cranes comprise a massive vertical structure that is mounted on rails along the dockside, and capable of traversing into position alongside the berthed vessel. The jib (or boom) is fixed horizontally on stops (which form a substantial part of the structure), when in the operational mode, once the container ship has berthed, but retracted by a rope and winch drive system into the almost vertical position and locked, in order not to obstruct the ship's movement as she berths or gets under way once the cargo is stowed

The configured design is such that during unloading, the electro-mechanical control system operates the crab, which is mounted on rails, along the jib, positioning the lifting frame over each of the containers in turn. The lifting attachments on the frame lock onto the lugs at the four corners of the container. The container is hoisted clear of the vessel, the crab is then racked inwards and subsequently lowered straight onto the road transport parked on the dock between the ship and the crane structure. Alternatively, the container is lowered onto the dock and transported by what is referred to as a straddle carrier to the container storage area in the docks. The containers are secured by a mechanical 'twist-lock' arrangement, which is released remotely once the load is removed from the lifting frame. Loading the containers on the vessel is simply the reverse of this

These cranes are a fairly standard design and, as more and more cargo is shipped by container, they can be seen in every port around the world. The crucial factor is the speed at which the containers can be loaded and unloaded, as shipping companies demand a faster turnaround for their ships whilst in container ports

6.3 Bulk Handling Grab Cranes

These bulk-handling cranes are seen in a number of applications, and quite often will be observed on the dockside loading or off-loading iron ore or grain into, or out of, the holds of a bulk carrier. The crane design is typically that of a mobile crane with a fixed lattice structured jib, mounted on a slew ring, which in turn in mounted on the chassis of the crane, and counterbalanced to the rear of the slew ring in line with the jib. The chassis may be wheel mounted, although quite often bulk handling crane chassis are mounted on crawler tracks. In the case of wheel-mounted cranes, the chassis incorporates four outriggers that are actuated hydraulically, and support the crane – transferring the downward forces of the lifting operation from the chassis to the ground. As such the crane needs to be located on a solid base or firmly compacted ground

The design configuration of the crane is typical of any mobile crane, with its slewing, and luffing motions of the jib, and the hoist (lowering) motions of the grab. The grab itself opens and closes with the bulk load, operated, as with the other crane motions, from the operator's cab. Normally, a forklift truck is lowered in the hold of the ship, once the bulk cargo has reached a certain level in the hold, in order to assist in the grabbing process and ensure a fully loaded grab during each cycle, so far as possible

This type of bulk handling crane is also commonly employed on construction and building sites, and open cast mines and quarries. When used as a crane, without the grab unit fitted, the above configuration is typical of mobile cranes in factories etc

6.4 Dockside Level Luffing Cranes

This type of crane is often observed at docks and harbours. It is sometimes mounted on a fixed structure on the quayside, but more usually, the vertical structure of the crane is mounted on rails and travels along the dock loading or off-loading cargo from the ship. The main feature of this type of crane is the fact that the design configuration of the luffing jib is articulated, and the luffing rope system is such that as the main part of the jib luffs inwards or outwards, the articulated outer member pivots about its fulcrum to 'compensate' for the luffing movement of the inner main structural member, and the load in effect moves inward or outward on a horizontal plane. This increases the actual performance of the loading/ off-loading cycle, and so speeds up the cargo handling and the crane operator does not have to luff and adjust the load height at the same time, so obviating any possibility of the cargo colliding with the ship's structure as the jib is luffed over the ship's side towards the hold

6.5 Cantilevered Shipbuilding Cranes

In essence this type of crane is very similar to the container crane, in as much as the cantilevered jib is mounted on a fixed, or more commonly a mobile vertical structure that is capable of travelling along rails at the slipway or the ship's fitting out berth, and a crab in the line of the load path traverses along the jib length. The configuration of the hoist rope system is such that the rope path passes over a series of pulleys on the crab unit, and as the crab traverses inwards or outwards, the hook remains at a constant height. However, unlike the container crane, referred to above, the cantilevered jib is capable of slewing horizontally and counterbalanced on the opposite side of the slewing ring to the operational part of the jib. The cantilevered crane in essence is similar in concept and configuration to the slender tower crane commonly seen on construction and building sites. The cantilevered crane is commonly referred to as a 'hammerhead crane'

6.6 Overhead Travelling Cranes or Goliath Cranes

Overhead travelling cranes are commonly found in factories, foundries, turbine halls, warehouses etc, and in design they are essentially a bridge comprising a lattice structure or box section girder type, with a crab incorporating the hoist drive system, and which traverses along the length of the bridge. The bridge in turn is mounted on end carriages and travels along rail tracks mounted on a supporting structure at each side of the factory or factory bay. Older types of construction and large overhead travelling cranes incorporated an operator's cab on the underside of the bridge structure, but more commonly modern cranes are operated by pendent control from the floor of the factory. The total geometrical boundary of the crane hook is three-dimensional, in the x, y and z axes, and usually any two of the three movements can be operated simultaneously

This type of crane is often used as high integrity cranes, operating at pile cap level above nuclear reactors during the reactor construction phase, and during maintenance shut down. A variation of this is the polar crane, sometimes employed in nuclear material handling cells. This variation of overhead travelling crane comprises a central column upon which the bridge structure pivots and a circular rail track around the periphery of the cell on which the wheels of the end carriage are mounted. The motions are similar to the conventional overhead travelling crane in the sense that the crab moves laterally (or radially to be more precise) along the bridge rail track, the hook (or more likely a grabbing unit) hoists and lowers from the crab unit, and the bridge travels around a circular path. In view of the operations for which this type of crane is used, they are normally operated by remote control from outside the cell

Finally, the goliath crane is for all intents and purposes an overhead travelling crane, but instead of the bridge comprising of end carriages incorporating wheels that are mounted on rails, which are in turn supported on a structure, the bridge in this case is supported on its own vertical columnar structure at each end. These massive end structures incorporate their own compensating drive wheels on bogies, which are in turn mounted on rail tracks. The three-dimensional geometric boundary profile of the hook is similar to before. These gigantic cranes are to be found in shipyards and have to some extent, taken on the role of the familiar shipbuilding cantilever crane. Smaller sizes of goliath cranes are often located outdoors in steel stockholding companies

Section 7.0 UK Legislation Associated with Crane Operation

In the past cranes have been subjected to statutory regulations of a prescriptive nature, where the prescriptive requirements have depended to a large extent on the site of operation – ie docks, shipbuilding and ship-repair yards, construction sites, and factories, for example. The Lifting Operations and Lifting Equipment Regulations (LOLER) have to some extent simplified the legal complexity for the use of cranes on different sites on the one hand, but to some extent increased the onus on the operating company to assess the risk from carrying out the lifting operation. The following comprises a listing of the essential issues to be addressed

The lifting equipment must be suitable for the operation –

- Assess the risk to ensure the equipment is compatible for the lifting tasks
- Establish the mass of the load to be lifted
- Assess the suitability of the lifting points
- Establish the centre of gravity of the load to be lifted
- Ensure a rapid means of egress from the crane in the event of emergency
- Consider the environmental effects from the weather

The lifting equipment must have adequate strength and stability –

- Review the SWL of the equipment for the lifting tasks to be undertaken
- Ensure operability of visual and audible overload indicators
- Assess the ground conditions where appropriate

- Ensure crane has suitable out-riggers to increase stability where appropriate

The lifting equipment must be appropriately certified –

- Lifting equipment to be proof load tested and certificated
- Lifting plant must be inspected in accordance with the examination scheme (Alternatively the inspections to be on a yearly frequency for cranes, and 6 month frequency for lifting gear, and undertaken by a competent person)
- Lifting equipment to be visually inspected prior to use by the operator

The safe working load must be prominently displayed on all lifting equipment
The lifting gear must be stored to a suitable storage area to prevent deterioration
(Note that most accidents that take place during lifting operations, come about due to the fact that the lifting gear is unsuitable for purpose)
The records, reports and equipment information on the lifting equipment to be on file

A competent person or alternatively a responsible person resident on the site, must plan the lifting operations. This is imperative for multi-crane operations, and should comprise –

- Method statement outlining the operations
- Computer aided design plan of load path geometry – to ensure that all cranes are operating well within their SWL for the particular hook radius at all times
- Check the paths of the load and lifting equipment
- Ensure compatibility of the SWLs of all lifting gear used
- Visual inspection of the crane and the lifting gear
- Review any proximity hazards
- Review adequate visibility of operator(s)
- Ensure sufficient headroom where necessary
- Barrier-off the site of operations
- Review the level of supervision for the operations
- Pre-operational consultation with crane operator(s)
- Ensure adequate means of communication during the lift
- Ensure trained operator(s), slings-men, banks- men etc
- Consider environmental factors

Section 8.0 Inspection of Cranes

Like any other large structural machinery, crane inspections require a great deal of knowledge and experience. As such a detailed description of machinery inspections is beyond the scope of this paper. However, fundamentally this would incorporate a visual inspection on the components in the direct line of stress throughout the load path, commencing at the hook with possible fatigue cracking at the intrados, deformation at the extrados of the hook due to physical damage having a possible affect on it's integrity, wear in the pulley assembly of the return block, broken wires in the strands of the hoisting/ luffing etc ropes, and working back through the rope system and structural element integrity (including main structural members, struts, ties, bracings, and rope anchorages), to wear and impact damage on mechanical parts, and to the electro-mechanical drive machinery and controls systems. This would include, an inspection emphasis on all the points of maximum bending stress, tensile and shear stress points, and points where fatigue cracking is likely to occur, and along with areas of corrosion (particularly prevalent in a marine environment), in all the structural and mechanical load bearing elements of the crane. Where fatigue cracking is suspected on an ageing crane, the visual inspection would be supplemented by non-destructive testing such as dye penetrant or ultra-sonic testing. In addition to the above, the operational control systems would be checked, including functioning of the limit switches, any interlocking arrangements between separate control functions, and the safe load indicators

Prior to the crane being taken into service, during the commissioning, the crane would be proof load tested beyond its safe working load, and certified by an competent person employed by an inspecting authority. This would entail: (1) an initial inspection of the crane, (2) witnessing a functional and performance test of the crane, operating the travel limit switches and recording the speed of the various crane motions, respectively, (3) witnessing the application of the safe working loads and proof loads at various radii of the jib, (4) from a reference point, taking measurements of the structural deflections (where appropriate), and (5) a re-inspection to ensure that no permanent deformation has taken place in the structure or mechanical elements in the direct line of stress

Section 9.0 About PMSC Limited

Dr. Eric Long is an associate of PM Safety Consultants, which is a specialist Systems Assurance company, offering Systems Safety advice and Reliability, Availability and Maintainability assurance support to a range of industries worldwide. Our web site is located at www.pmsafety.com PMSC has undertaken several safety studies and developed reliability models on various crane types under normal and fault conditions such as for example, dropped loads and crane toppling as a result of snagged loads or ledged loads.