Construction Loads Produced During Heavy Lifting, Rigging and Handling Operations

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Abstract

Construction loads produced during the handling operations of heavy component erection, govern the design of all elements of the rigging and handling system, and affect both the existing infrastructure and the respective component being erected. These loads are a function of the gross rigging weight of the component, its center of gravity location, required handling operations, and the configuration of the rigging and handling system being used.

This paper presents a detailed description of the construction loads to be considered in the analysis and design of handling systems for heavy component erection. How these loads combine with each other, and with other gravity and non-gravity loads acting on the existing infrastructure, are discussed. The distribution of construction loads to particular elements of the handling system is dependent on the configuration of the system, and on the handling operations required over the course of erection. Formulae for the calculation of distributed loads are presented. Recommendations are made with regard to handling system design loads, and with regard to evaluation criteria for the effects of construction loads imposed on the handled component and on the existing infrastructure.

Introduction

The erection of heavy components is carried out both as new construction work on “green field” sites, as well as on retrofit projects undertaken in existing plants and on existing civil installations. Some examples include the erection of a steam drum for a utility boiler on a new fossil power plant project, the replacement of a fractionization tower in an existing refinery upgrade project, or the installation of precast concrete girders on an interstate highway bridge replacement.

In each of the above examples, it can be noted that the erection of heavy components is a process that typically involves the components’ receipt in some “as shipped” orientation at an arbitrary location “A”, their unloading and transfer from location “A” to a final setting location “B”, and their final setting to an “as built” orientation at location “B”. In the course of this process, the components are handled in a number of orientations and through a variety of operations. As such, loads are imposed on the rigging and handling system, the existing infrastructure, and the components themselves.

As used in the context of this paper, the rigging and handling system is defined as all of the mechanical equipment and structural installations specifically made to move and handle components from location “A” to location ”B”. In most cases, the rigging and handling system is a temporary installation, and is removed following the completion of heavy component erection. However, in certain cases, systems have been left in place as permanent plant equipment, for use in the ongoing maintenance or future replacement of the erected components.

The existing infrastructure refers to all existing installations that are subject to the imposition of construction loads produced by heavy lifting, rigging, and handling operations. The existing infrastructure further refers to existing installations that create access limitations and define the route to be traversed between locations “A” and “B”. Along this route, the existing infrastructure dictates the available handling clearance and the consequent handling operations to be performed. The existing infrastructure may refer to the boiler support structure from which the steam drum is suspended, the foundations upon which the fractionization tower is finally set, or the existing subgrade that supports the crawler cranes that may be used to off-load the precast concrete bridge girders.

Rigging and Handling System Configurations

The rigging and handling system used for the erection of heavy components on a specific project is determined via a careful evaluation of the project scope of work and existing site conditions, and is consistent with the overall construction plan developed for execution of the work. Each project presents its own unique set of constraints and opportunities. Many rigging and handling schemes have been tried and proven over the years. The challenge to the project team is to choose the scheme that will be most effective in completing erection work in a safe, economic, and timely manner, within the specific constraints of the project.

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The magnitude and distribution of construction loads imposed on the existing infrastructure is highly dependent on the configuration of the rigging and handling system chosen for performance of the work. Several configurations are shown in Figure 1. These configurations are briefly described in the following paragraphs.

The simple hoist and load block system consists of a pair of construction blocks strategically positioned beyond the final desired position of the handled component. Depending on the rigging weight of the heaviest handled component, the construction blocks may consist of single or multiple sheaves. A load line is routed through the sheaves and back to some hoisting mechanism. The hoisting mechanism and the block on the hoisting side of the system are attached to existing infrastructure and remain fixed with the progress of movement of the handled component. The block on the load side of the system is attached to and travels with the handled component. Loads are imposed on the existing infrastructure at the points of attachment of the blocks and hoisting mechanism.

Monorail systems consist of a load block and hoisting system suspended from a trolley or series of trollies that travel on a beam suspended from some existing support structure. A handled component may be raised or lowered and moved in a line coincident with the routing of the monorail beam. Monorail beams may be straight, or they may be curved as required to clear local obstructions and traverse the work.

Taut lines and cableway systems are very similar to monorail systems. The monorail beam is merely replaced by a tight line stretched between the required points of traverse. A trolley supports the load blocks and travels on the line, thereby providing the same extent of movement of the handled component. However, geometric deformations of the tight line limit the magnitude of loads that may be handled. Vertical and horizontal components of imposed construction loads are transferred to a supporting structure at the end anchorages of the taut line or cableway. Because of the tension required to limit vertical deflection of the loaded line, the horizontal component of the loads imposed at the anchorages are relatively much greater than the vertical components.

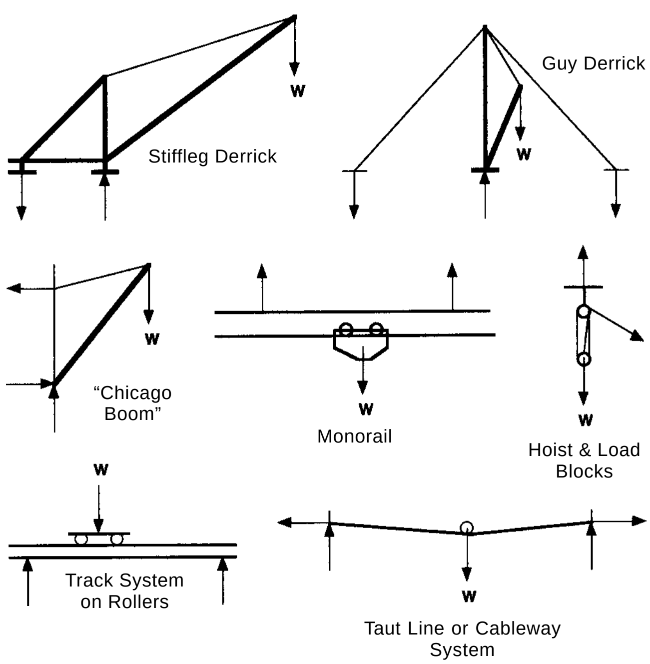

Figure 1 Typical rigging configurations.

Derricks are installed in a variety of configurations. Some common configurations include the stiff-leg derrick, the guy derrick, the "Chicago boom", and the shear leg derrick. The basic derrick mechanism provides the ability to hoist a load up or down, and luff up or down over a range of operating radii. With the exception of the shear leg configuration, most derrick configurations also provide the ability to slew, or to swing a load over a specific arc of operation. Derricks are typically attached to some existing infrastructure. Loads imposed at the attachment points are reactions required to resist the net vertical thrust and overturning moment produced by the lifted load at the specified operating radius.

Liftcrane installations are categorized as fixed or mobile installations. Fixed installations include various tower crane configurations, heavy lift configurations such as Manitowoc Crane's "Ringer" concept, American Crane's "Ring Horse" concept, and FMC Link Belt's heavy lift arrangement, and guy derricks such as American Crane's model number 9310 in a guy derrick arrangement. Fixed liftcrane installations are typically founded on a reinforced concrete slab or mat, or hardwood timber crane mats placed at grade. Reactions to net vertical thrust and overturning moment are developed via resultant ground bearing pressures beneath the mats and the existing subgrade.

Depending on the required height of the mast, fixed tower crane installations may be intermittently braced back to some existing structure. These braces transfer wind loads acting on the tower, and serve to react any net overturning moment imposed on the tower. Up to certain heights specified by the manufacturer, the towers are inherently capable of withstanding these wind loads and overturning moments, and as such, may be free standing. Fixed tower cranes may be provided with a "hammerhead" or fixed boom, a luffing boom, or an articulated boom.

Similar to the braced tower crane, the mast of the guy derrick is subjected to wind loads and overturning moments produced by the lifted load. Wire rope guys are spaced around the circumference of the mast top, and extend to concrete deadmen placed at or below grade. These guys serve to brace the mast top over the full 360° slewing angle of the boom.

Mobile liftcrane installations may be categorized as crawler mounted, truck mounted, or self-propelled wheel-type cranes.

Crawler mounted cranes travel and operate on "caterpillar" type crawlers. These crawlers are sized and configured to provide overturning stability over the operating range of the crane. Net vertical thrust and overturning moment are transferred to the surface on which the crane is operating via the development of bearing pressures beneath the crawlers. The crawler mounting does not allow for the crane's self-transit between job sites. As such, crawler mounted cranes are moved between sites in a "knocked down" condition via truck, rail, or barge, and are assembled on site.

Truck mounted cranes may be provided with lattice booms or self-contained hydraulic telescopic cantilevered booms. These cranes are provided with rubber tires and either mechanical or hydraulic outriggers. Tires lend road-worthiness to the cranes for transit between job sites, and for travel on site. For all liftcrane operations, outriggers raise the crane off of its tires, and provide the base for operation. Similar in purpose to the crawlers on a crawler mounted liftcrane, the outriggers on a truck mounted crane serve to provide overturning stability and a means for transfer of net vertical thrust and overturning moment to the supporting infrastructure.

Similar to truck mounted cranes, self-propelled, wheel-type cranes travel on rubber tires and operate as a liftcrane on outriggers. However, truck mounted cranes are equipped with separate power and control units for the carrier and the liftcrane, whereas self-propelled, wheel-type cranes are equipped with separate power and control units for travel and liftcrane operations. The basic principles and operation of the outrigger system, and consequent means of load transfer and overturning stability, is comparable for both types of cranes.

Within each of the mounting arrangements, various configurations of the mobile liftcrane's lifting structure are available. Several of these configurations are as shown in Figure 2. The lattice boom may be used in a conventional, or straight boom, configuration, with or without a jib; in a tower configuration; in a luffing jib configuration; or with a mast and additional counterweight in a heavy lift configuration. In each of these configurations, the lengths and length combinations of boom, jib, tower, and mast are specifically determined for the lift being made. Hydraulic telescopic cantilevered booms are tubular steel booms that incrementally extend in length. These booms may be fit with jibs and extensions for increased lifting height, and with masts and additional crane counterweight for heavy lift capabilities. The net bearing pressures developed beneath the crawlers or outriggers vary with the configuration of the lifting structure of the crane.

Overhead cranes travel on a runway structure or pair of tracks above the work area. The crane includes a bridge that spans

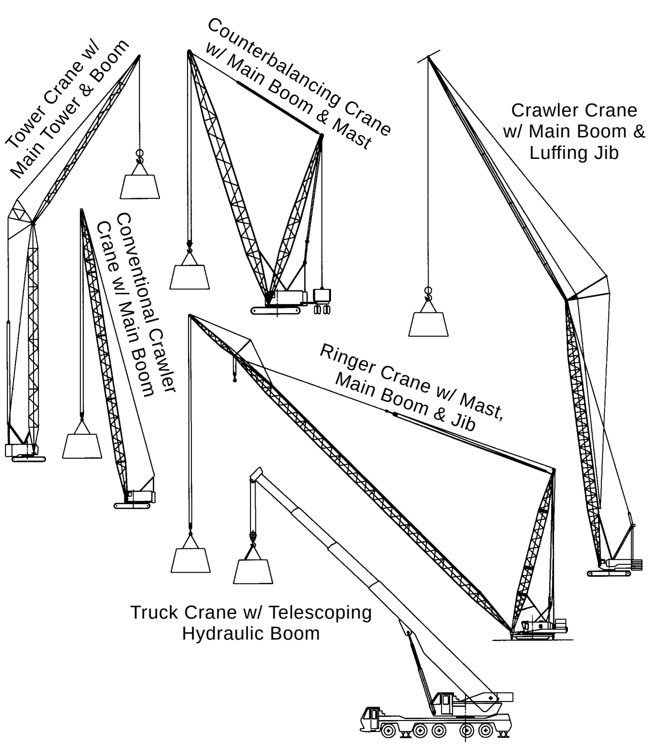

Figure 2 Typical liftcrane configurations.

between the tracks, and a fixed or trolley-mounted hoisting system. Cranes may be top-running on rails or underslung, in which case they are suspended from, and travel along, the bottom flanges of the runway beams. A gantry system consists of an overhead crane mounted on legs that travel on rails. The bridge may be cantilevered on either or both ends.

Track system***s*** are typically installed when there is a need to move heavy components in a horizontal direction. The components may be skidded or rolled along the track, and very often, the system is provided with hauling carts designed to handle the weight of the components being moved. The track may consist of an inverted channel on a structural member so as to receive machinery rollers. Alternately, if grooved steel wheels are used for load conveyance, the track may consist of an inverted structural angle on a structural member. If the load is to be skidded into position, the track may simply be a flat plate coated with grease. A hoisting or towing mechanism is provided so as to move components along the track.

Jacking and cribbing systems provide a means to raise or lower very heavy components over relatively short heights. Hydraulic or mechanical jacks are commercially available in a broad range of rated capacities, cylinder heights, and strokes. Cribbing consists of hardwood timber members. In a typical raising cycle, loads are raised a distance equal to the available jack stroke. At the end of the stroke, cribbing is placed under the load, jacks are repositioned to bear on the top of the cribbing, and are ready for the next cycle. This sequence continues until the handled component is at its final required elevation.

Characterization of Loads

In many cases, construction loads imposed on the existing infrastructure are not necessarily the service loads for which the infrastructure was designed. Variations in load magnitude, load type, and point of application are most likely to occur. In order to evaluate the effects of the imposed construction loads, the infrastructure design loads must be thoroughly understood. These design loads, and imposed construction loads, are characterized in the following sections.

Infrastructure Design Loads

Infrastructure design loads are established by governing building codes for the particular installation. In the case of buildings, minimum design loads are typically specified in ANSI / ASCE 7[4] and the Uniform Building Code.[9] Per ANSI / ASCE 7, buildings shall be designed to accommodate the effects of dead load; live load including uniformly distributed, partially distributed, and concentrated loads produced by the occupancy and use of the building; soil pressure, hydrostatic pressure, and flood loads; wind loads; snow, ice, and rain loads; and seismic loads. Further, the building design must account for any self-straining forces arising from differential settlements of foundations and from restrained dimensional changes due to temperature, moisture, shrinkage, creep, and similar effects. In the particular case of heavy industrial installations, live loading includes the weight of water for hydrostatic testing, the weight of any product accumulations such as flyash, slag, and dust, and the weight of any vessel contents such as coal in a bunker. Any pressures, friction loading, and impact that are produced by operating equipment must be accounted for in the design of the equipments' supporting structure.

Particular structural design codes such as the AISC ASD,[2] specify allowable stress ratios for gravity loading conditions and for gravity plus non-gravity loading conditions. Of the loads characterized in the preceding paragraph, gravity loads include the total dead load and certain sustained portions of the imposed live load. All other loads are considered to be non-gravity loads.

For most structures and civil installations, the original design includes some contingency loading. This loading is intended to account for unknowns that may take place over the service life of the installation. How and where this contingency loading is applied can vary from project to project. For industrial support structures, contingency loads are typically applied as concentrated loads at the top of the columns and are a function of the total combined gravity plus non-gravity loads acting at the base of the columns. Applied contingency loads are treated as sustained live loads, but are not relied upon for any uplift resistance.

Imposed Construction Loads

Gravity loading produced during lifting, rigging, and handling operations includes construction dead loads and live loads. Construction dead loads are defined as the distributed loads associated with the weight of all immovable or fixed elements of the handling system. Primary construction live loads are defined as the net rigging weight of the component being handled, plus the distributed loads associated with the weight of the movable or traveling elements of the handling system. In this context, that portion of the construction live load "below the hook" may be referred to as the net hook load, and includes the rigging weight of the lifted load plus the rigging weight of any handling devices such as slings, lifting beams, spreader beams, shackles, turnbuckles, etc. provided between the lifted load and the hook. Further, in certain types of demolition work, where the handled component is an old piece of equipment being removed, adequate allowance must be made for the weight of any accumulated slag, dust, ash, or fluid, in the overall determination of the net rigging weight of the component. Good rigging and handling practice dictates the removal or drainage of as much of the accumulation as possible prior to the start of any handling operations. However, this is not always possible or practical, and appropriate allowances must be made to account for the weight of the accumulation. Secondary construction live loads that may or may not exist in concurrence with handling operations include snow and ice loads, and live loads associated with construction personnel and staged material, tools, and equipment in the vicinity of the work area. A unit allowance of 100 psf taken over the horizontal projection of all platforms (permanent and temporary) in the vicinity of the work area, in most cases, safely accounts for this situation. The existence of these secondary construction live loads needs to be confirmed for each respective project.

Non-gravity loads combine with gravity loads to act on the handled component and all elements of the handling system. However, the non-gravity loads that govern the design of the handling system are generally not the same non-gravity loads that govern the design of the infrastructure upon which the handling system is founded. In most applications, the handling system design is controlled by the worst condition produced by either impact or friction loading, whereas the infrastructure is controlled by the worst condition produced by either wind or seismic loading.

In the context of heavy lifting, rigging, and handling, Shapiro[10] defines impact as the increase in load effect due to dynamic causes. These causes relate to three conditions that may occur in a component handling application: moving a component suddenly from a condition of rest, stopping a component suddenly from a condition of movement at constant velocity, and sudden release of load. In algebraic terms, let W = rigging weight of the component being handled, F = total force imparted on the handling system, and F_i = imposed impact force. Then the imposed impact force is given as:

(1) $$F_i = F - W$$

and the impact factor i is given as:

(2) $$i = \frac{F - W}{W} = \frac{F_i}{W}$$

Depending on the specific configuration of the handling system, some disparity exists with regard to appropriate values for i. The AISC[2,3] specifies a sufficient increase in live load for structures subjected to live loads which induce impact. For cab-operated traveling crane support girders and their connections, the increase in live load should be not less than 25%. For pendant-operated traveling crane support girders and their connections, the increase should be not less than 10%.

European manufacturers of heavy lifting equipment are governed by the FEM[8] which suggests the following impact values for heavy lift equipment:

(3) $$i = \xi v$$

where v is the final velocity achieved by a handled component dropped in free fall (expressed in meters per second) $\xi = 0.6$ for overhead traveling and bridge cranes, and $\xi = 0.3$ for boom or jib cranes, except i is at least equal to 0.15, and for velocities exceeding 1 meter per second, i remains constant.

American mobile crane manufacturers claim that impact loading is not an important consideration for their type of crane and make no design allowances therefore.[10]

In a study conducted by the AISC[1] to determine how best to account for impact in derrick design, it was determined that simply increasing the live load by an impact factor did not yield good correlation with test results. Instead, the AISC task force recommended increasing axial as well as dead and live load bending stresses (but not lateral or side bending stresses) by an impact factor. For lifting full structurally based rated loads, a factor of 20% was suggested, but the tests revealed that greater impact should be expected as loads decrease in relation to net derrick rating.

In light of this disparity, in the design of handling system elements and determination of imposed construction loads, the author has consistently, and successfully, applied an impact factor of 25% to the total imposed gravity loading acting at the point of consideration in the handling system.

Friction loading is encountered in a variety of forms in the design of the handling system. Whenever a wire rope passes over a sheave in a multiple part rigging system, a loss of mechanical advantage occurs. This loss of mechanical advantage is associated with the friction encountered at the sheave's bearings. It may be shown that the single line pull, or tension, T, produced in the lead line departing the load blocks is given to be:

(4) $$T = \frac{W}{f + f^2 + \ldots + f^N}$$

where W = sum of the net hook load imposed on the lower load block plus the rigging weight of the lower load block, N = number of line parts in the system, and f = sheave efficiency per line part. Per the Crosby Group, Inc.,[7] for sheaves provided with bronze bushed bearings, f = 0.96; for sheaves provided with roller bearings, f = 0.98. The total friction load imposed by the rigging system is conservatively defined as:

(5) $F = (NT) - W$

In a hauling type application, wherein a component is skidded or rolled from point “A” to point “B”, the handling system must first overcome static friction to cause the component to move. Following the start of movement, the handling system must overcome kinetic friction to maintain movement of the component. These friction forces act in a direction opposite to the direction of motion. They are of a magnitude equal to μN, where μ = coefficient of friction, and N = normal force acting at the interface between the handled component and the surface on which it is being moved. For sliding applications, coefficients of static and kinetic friction, μ_s and μ_k respectively, are tabulated for a range of material combinations in engineering handbooks such as Marks.[5] However, for rolling applications, published coefficients of static and kinetic friction are rather scarce. The manufacturers of wheels, dollies, and equipment rollers used for rigging and hauling applications, typically specify a minimum required towing force per unit of vertical load.

Over the course of construction, design wind loading, calculated in accordance with ANSI / ASCE 7, may act on the elements of the handling system for the period of time that the system remains in place. Wind load may also act on the handled component as the component is being erected. However, the magnitude of that wind load will be appreciably less than the design wind loading for the existing infrastructure. Handling operations will cease long before the wind load approaches the design velocity, simply because rigging crews could not safely handle the component during high wind conditions. Typically, if wind speeds exceed 20 miles per hour, no attempt will be made to execute any type of handling operation.

Seismic loading is considered to act only on the permanent elements of the handling system. The weight of these elements adds dead load to the supporting infrastructure. Because the seismic shear forces are a function of the total vertical gravity loading, the increased dead load represents an increase in seismic shear forces. The chance of occurrence of an earthquake at the same time a heavy component is being moved is remote. As such, seismic loading is not calculated in conjunction with the worst case of moving a handled component.

Similar to the infrastructure design loading, good engineering practice dictates the inclusion of contingency in the imposed construction loading. Contingency on the construction loading is intended to account for unknowns that may transpire over the course of handling operations. The magnitude of this contingency loading is not currently specified in any building code and hence will vary from designer to designer. A contingency load equal to 10% of the total combined gravity plus non-gravity loading acting on the handling system has been successfully applied by the author.

Design Loading for Heavy Lifting, Rigging, and Handling Operations

With construction loads being as characterized in the preceding section, a design loading condition, imposed at the center of gravity of the handled component, is determined as the worst of:

(Component Rigging Weight + Impact + Wind @ 20 Miles per Hour) x Contingency Factor @ 10%;

(Component Rigging Weight + Friction + Wind @ 20 Miles per Hour) x Contingency Factor @ 10%.

Note that in the identification of the design loading condition, impact and friction loading conditions are nonconcurrent events.

Distribution of Construction Loads

The design loading condition is applied at the center of gravity of the handled component. The distribution of that loading into the elements of the handling system and to the supporting infrastructure, is dependent on a number of variables. These variables include the geometry and orientation of the handled component, the three-dimensional location of the center of gravity of the handled component, and the handling operations to be performed.

As an example of how handling operations affect the distribution of construction loads, consider the steam drum[6] shown in Figure 3. In its final position, it is suspended from boiler support steel that is erected prior to the steam drum. The drum is raised from grade to its final elevation via two independent sets of load lines and blocks suspended from the boiler support steel. Each set of load blocks is pinned to lifting lugs equally spaced a distance L/2 outboard of the center of gravity of the drum. The lifting lugs are shop attached to the steam drum shell such that the centerline of their pin holes is positioned a distance d above the steam drum’s center of gravity.

In many cases, the length of the steam drum is greater than the available clear dimension between the main column rows of the support structure. As such, in order to gain the necessary raising clearance, the steam drum is raised at varying angles α from the horizontal. Because each set of load blocks is independent of the other, this is readily accomplished by spooling more rope through one set of blocks than the other.

Initially, suspended in a horizontal orientation from two sets of lines, the steam drum rigging weight, W, is equally distributed to each lifting lug and to each set of load blocks and lines. That is:

(6) $$R_U = R_L = \frac{W}{2}$$

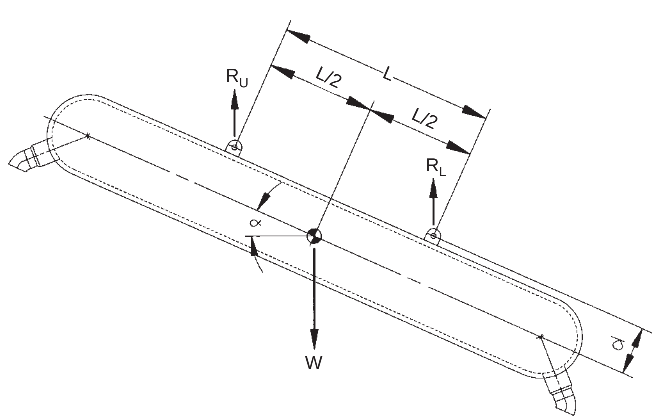

Figure 3 Steam drum raising.

However, it can be shown by alternately summing moments about each lifting lug, that as the drum assumes an angle α from the horizontal, the rigging weight is respectively distributed to the upper and lower lifting lugs as:

(7) $$R_U = \frac{W}{2} + \frac{Wd}{L} \tan \alpha$$

(8) $$R_L = \frac{W}{2} - \frac{Wd}{L} \tan \alpha$$

It should be noted that besides producing a change in the magnitude of the loading distributed to each lug and set of load lines, the change in orientation of the handled component produces a change in the nature of the load imposed on the lifting lugs. In the horizontal orientation of the drum, the lifting lugs and their connections to the drum shell are subjected to a case of pure tension. At the angle α, the lifting lugs and their connections to the drum shell are subjected to combined shear and tension. As the angle α approaches 90°, the lugs and their connections approach a case of pure shear.

A change in the orientation of the handled component, produced by a change in the mode of handling, resulted in a change of magnitude and nature of loads imposed on the component, the handling system, and the supporting infrastructure.

The distribution of construction loads imposed on the supporting infrastructure is governed by the configuration of the handling system. For the same magnitude of lifted load, the nature and magnitude of the support reactions for each of the various configurations previously described will differ. Hence, the loads imposed on the supporting infrastructure will likewise differ.

Design Considerations

As discussed in the preceding sections, the magnitude and distribution of the design loading, and the nature of that loading, govern the design of all elements of the handling system, and form the basis for the structural evaluation of the handled component and the existing infrastructure. While a detailed discussion of that evaluation is beyond the scope of this paper, certain considerations should be made in its performance. These considerations are discussed in the following paragraphs.

Current codes and specifications are vague at best in defining how construction loads should be treated in the overall evaluation of the installation. The specific details of the evaluation are for the most part left to the judgment and discretion of the engineer, but founded on the fundamental principles of structural analysis and design.

Ultimate strength design, based on load factors, has evolved as the established norm for reinforced concrete design. More recently, load and resistance factor design has gained momentum as the preferred method of design in structural steel. However, the author's experience has been that while reinforced concrete installations have in fact been evaluated in accordance with ultimate strength design methods, most structural steel evaluations with regard to imposed construction loads have been performed using allowable stress design methods. This may be due in part to the fact that much of the heavy rigging and handling work performed in the recent past has been performed on retrofit projects; projects that were originally designed in accordance with allowable stress methods. As such, the engineer chose to employ a method of retrofit evaluation consistent with the original design philosophy.

Consistent with allowable stress design methods, all handling system elements are sized such that stresses induced by maximum imposed construction loads are less than some allowable level. Structural members are sized in accordance with allowable stresses established by the AISC for strength and stability, whereby an appropriate factor of safety is imposed on the minimum yield stress for the steel material. The safe working load, or SWL, for rigging and handling hardware such as wire rope slings, shackles, and load blocks is established via destructive testing and the imposition of a factor of safety on a determined proof load. Depending on the particular piece of hardware, that factor of safety ranges from 3.5 to 6.

Based on allowable stress design methods, it should be realized that the maximum loads imposed by handling operations are construction loads whose effects in most cases are felt only instantaneously. Only the dead load associated with the weight of the handling system itself is a sustained condition. Hence, any evaluation of rigging and handling loads in conjunction with any gravity and non-gravity loads acting on the existing infrastructure, should be conducted for transient conditions and should be governed by an allowable combined stress ratio of 1.33. Only the dead load of the handling system, in conjunction with gravity loads acting on the existing infrastructure, is sustained and governed by an allowable combined stress ratio of 1.00.

The combinations of imposed construction loads with other gravity and non-gravity loads acting on the infrastructure over the course of handling operations must be determined on a case by case basis for the project. In the case of new construction, more and more load is added to the supporting infrastructure with the progress of erection. Hence heavier lifts made early in the sequence of erection may prove to be less critical than lighter lifts made near the completion of the erection sequence. In the case of retrofit construction, wherein a single component is being replaced, the existing load of all other components in place must be dealt with throughout the course of handling operations. For any particular project, the construction logic and sequence of erection must be established and understood before the effects of imposed construction loads can be properly evaluated.

It has been shown that variations in the orientation of a handled component throughout the course of its movement cause a redistribution of its rigging weight to its lifting lugs, the handling system, and the supporting infrastructure. Depending on the severity of the variation from a final installed orientation, at some point in the course of handling operations, a single lug and set of rigging could conceivably be subjected to the full rigging weight of the handled component. As such, the lugs, their attachment to the component, the handling system, the supporting infrastructure, and the component itself should be designed to accommodate the full rigging weight of the component.

Conclusion

The character and magnitude of loads produced during heavy lifting, rigging, and handling operations may be significantly different from the service loads for which a particular installation has been designed. These differences mandate the necessity for an evaluation of their effects to ensure that construction will proceed in a safe and expeditious manner, consistent with the project plan, and will result in a high quality installation upon its completion.

References

1. American Institute of Steel Construction, Inc. (1974). *Guide for the Analysis of Guy and Stiffleg Derricks*, AISC, Chicago, Illinois.

2. American Institute of Steel Construction, Inc. (1989). *Manual of Steel Construction – Allowable Stress Design*, Ninth Edition, AISC, Chicago, Illinois.

3. American Institute of Steel Construction, Inc. (1994). *Manual of Steel Construction – Load & Resistance Factor Design. Vols. I & II*, Second Edition, AISC, Chicago, Illinois.

4. American Society of Civil Engineers (1996). *ANSI/ASCE 7/95 – Minimum Design Loads for Buildings and Other Structures*, ASCE, New York, New York.

5. Avallone, Eugene A. and Theodore Baumeister III, ed. (1987). *Marks' Standard Handbook for Mechanical Engineers*, Ninth Edition, McGraw-Hill, Inc., New York, New York.

6. The Babcock & Wilcox Company (1992). *Steam / its generation and use*, 40th Edition, S. C. Stultz and J. B. Kitto, ed., The Babcock & Wilcox Company, Barberton, Ohio, Chapter 39, "Construction."

7. The Crosby Group, Inc. (1998). *General Catalog – Blocks & Fittings for Wire Rope & Chain*, Tulsa, Oklahoma.

8. Federation Europeene de la Manutention (1970). *Rules for the Design of Hoisting Appliances*, Second Edition, Paris, Section I, "Heavy Lifting Equipment."

9. International Conference of Building Officials (1996). *Uniform Building Code*, International Conference of Building Officials, Whittier, California.

10. Shapiro, Howard I. (1980). *Cranes and Derricks*, McGraw-Hill, Inc., New York, New York.