Structural Design Requirements for Entertainment Venues

The Impact of Stage Rigging Loads

By Shawn Nolan, P.E.

The impact of the entertainment industry on the economy is substantial. In 2005, the average American spent 9.2 hours a day on leisure activities and the average U.S. household spent more than 5% of net income on entertainment activities. Construction of new facilities and renovation of existing structures for entertainment related purposes was between 3% and 8% of the total annual building construction for the United States in 2006. Many of these facilities are intended for live entertainment purposes, such as theatres, concert facilities, outdoor venues and related specialty structures.

Stage rigging needs for entertainment venues present a variety of loading criteria unique to the entertainment industry, which can place unusual demands on a building structural system. Rigging loads result from both permanent and temporary systems and, increasingly, both types of systems acting simultaneously. Rigging systems and equipment are generally used to lift and position lighting, audio, video, scenery, special effects and related items. The magnitude of these loads can range from 5 psf on the roof system of a typical "arena" (usually a general purpose facility intended for uses such as basketball or hockey, concerts or tradeshows) to 30 psf acting on or near the roof system of a typical high school theatre stagehouse. Lateral loads from the rigging can also impose large forces on the venue. Stagehouse headblock beams can see a lateral load of 2 kips/foot for a 50-foot vertical and horizontal span. Rigging loads in arenas can equal or exceed the local gravity loads.

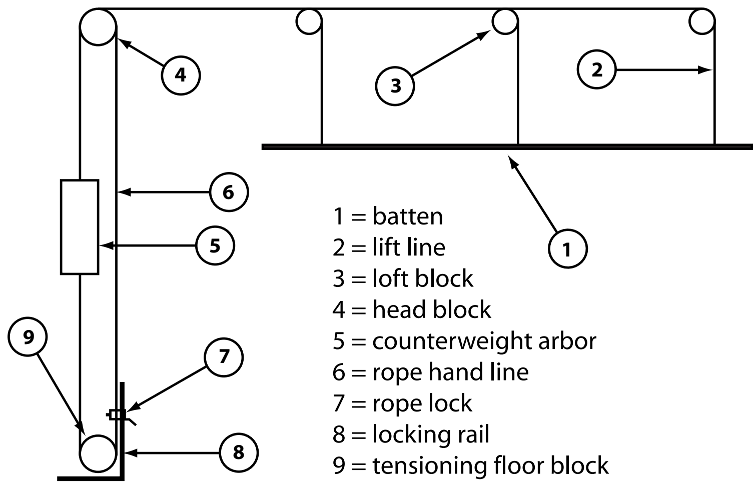

Figure 1: Schematic of standard manual lineset. ©J.R. Clancy Company.

Types of Venues

Live entertainment facilities can be broken down into two broad categories; theatre facilities and concert venues. Sports stadia and other miscellaneous related facilities comprise the balance of venue types. Theatre facilities include school theatres and auditoriums, performing arts centers and commercial theatre (Broadway, regional theatre, other commercial ventures). Concert venues include arenas, auditoriums, convention center facilities and occasionally sports stadia.

Theatre stagehouses provide a dedicated environment for the installation and operation of scenery and stage effects in close proximity to the audience. A facility with a seating capacity of 1500 would typically have a stagehouse 60 feet deep x 100 feet wide, with a roof height of 80 feet. This stagehouse is usually an open room, with no interior obstructions, columns or intermediate floors. The architectural intent of a stagehouse is to provide a space adequate to allow movement of the scenery and effects from within the proscenium opening (the "picture frame") to positions above, below and to the left and right of that opening. Consequently, the stagehouse can have a variety of design challenges including tall unbraced walls with large vertical rigging loads, noise abatement, vibration isolation and access issues.

Arenas are usually long span structures with a footprint of 300 feet x 1000 feet with a 100-foot roof height. These are usually high demand facilities with aggressive use schedules and a wide variety of events occurring over the course of a calendar year. The busiest facilities (The Staples Center in Los Angeles, for example) host over 250 events a year. Rigging loads are usually suspended from steel wire rope sling and bridle assemblies. The loads are lifted by electric chain hoists adapted to the needs of the entertainment industry. Temporary rigging loads in the range of 75 kips acting on an 80- x 100-foot section of the roof structure are common, with the largest events placing loads on the roof system in the range of 200 kips acting a similar footprint.

Auditoriums and convention centers can see the largest range of loads and, perhaps, the most unpredictable loads. Due to the highly flexible nature of these facilities, they can be used for lectures (low rigging load demands) or major trade shows (the Detroit, Los Angeles or New York Auto Show) with very high rigging load demands. A typical single overhead structure, supported by temporary rigging, for an automotive trade show might impose a gravity load of 20 to 50 kips on the building frame; shows of this magnitude can have dozens of overhead assemblies of this size.

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Other types of venues include sports stadia, which can require very unusual rigging arrangements due to the open nature of these structures (imposing very large lateral loads onto structural systems); houses of worship (increasingly requiring large and sophisticated systems similar to the largest commercial theatre stagehouses) and a wide variety of converted and renovated spaces (typically not originally designed for any rigging loads).

Rigging Systems

Systems can be divided into two broad categories; permanent and temporary. Generally speaking, permanent systems are installed in theatre stagehouses while temporary rigging systems are more common in arena environments. Increasingly, arena rigging methods are also being used in theatre environments to supplement or, on a short term basis, supplant the permanent system.

Permanent Systems include manual systems and automated equipment; both used as a means of motivating a "lineset". These systems are composed of multiple linesets. Each lineset typically includes a horizontal round HSS, supported by a series of vertical wire ropes. The wire ropes are reeved through a series of pulleys to either a counterweight arbor or an electric hoist. Each set may have a typical lifting capacity of 1800 pounds, with the sets located at 6 to 8 inches on center throughout the stagehouse. A typical modern high school stagehouse will have 40 linesets. Counter-Weight Rigging Systems have been the most traditional permanent systems, consisting of an adjustable balanced counter-weight arrangement (*Figure 1*). Automated Rigging Systems are being increasingly installed in both modern and renovated facilities. Automated systems are seen as providing a variety of benefits including increased safety, consistency of positioning, ease of operation by less skilled staff and faster loading. The main difference is that the wire rope lines terminate on a cable drum, as opposed to a weight arbor. Typical installations have a variable operating speed of up to 120 feet/minute of vertical lift. High speed systems can operate in the range of 600 feet/minute. These systems are very analogous to commercial cranes in terms of the theory of operation and the types of dynamic loads they can impose on the building frame.

Counter-weight systems have a specific disadvantage in that they require the doubling of the gravity load to lift a specific mass. Since the system requires a counterweight equal to the load, lifting a 1000-pound load, for example, will require 1000 pounds of counterweight as well. Automated systems do not requiring counter-weight and, consequently, they impose significantly less gravity load on the building frame.

Temporary Systems mainly consist of "arena style rigging", which consists of lifting and support of overhead loads by using electric chain hoists that have been adapted to entertainment rigging. Arena style hoists are inverted and "climb the chain". Steel wire rope slings are positioned by riggers climbing on the arena roof structure. Hoists are connected to the slings and subsequently to the show equipment. Load criteria for arena rigging vary widely between events; this has resulted in a system that can seem crude by comparison to general industry, but it is a system designed to be highly adaptable to differing building geometries and show conditions. The most common hoists are 1-ton and 2-ton units; a typical event could have 40 to 80 units total (*Figure 3, Page 30*).

Type of Loads

Static Loads result from the self-weight of the equipment and the loads hoisted by the rigging system. For permanent installation, design loads are dependent on equipment capacities. For temporary installations, maximum allowable loads must be a defined collateral load, which will limit the number and location of chain hoists that can be installed.

Dynamic forces result from loads that move during system operation. Manual systems have relatively low operating speeds and usually have only a few linesets operating simultaneously. The resulting dynamic load increase is relatively small; typical design criteria impose a 25% load increase on the building frame for these dynamic forces. Automated systems can impose much higher forces, requiring thorough coordination of specifications with the forces that can impact the supporting structural system. These types of loads occur in both permanent automated installations and in chain hoist arena style rigging. It should be noted that while arena systems were originally used only to raise and position equipment, with the advent of more sophisticated controls, these units are being increasingly used to actively move equipment during show operations. These systems are relatively new to the market and, as such, have generally outpaced any code-defined load design criteria.

While there are some code design criteria for loads imposed by machinery, this information may not adequately define the forces that rigging systems can impose on the structure. For example, many automated installations allow for precise synchronization of multiple linesets or hoists, which can result in high dynamic forces if several units are programmed to accelerate or decelerate at the same time. In addition, these automated systems all include some type of emergency stop (E-stop) circuitry, intended to be activated in case of malfunction or other emergency condition. E-stop conditions typically result in the highest force that an automated system can impose on a building frame. For

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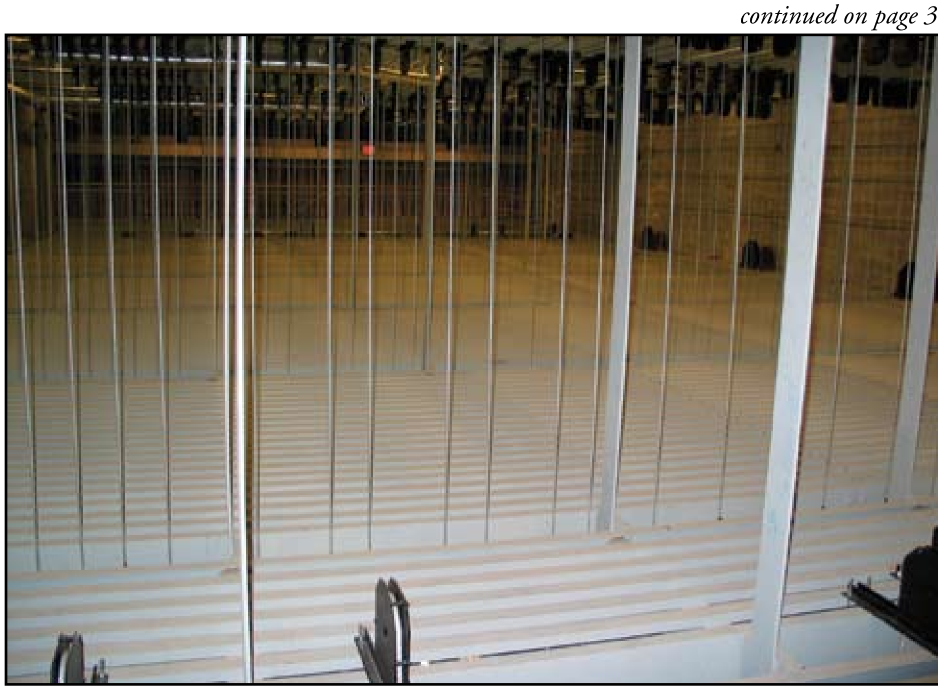

Figure 2: Loft blocks & Gridiron for a typical high school manual rigging system. ©J.R. Clancy Company.

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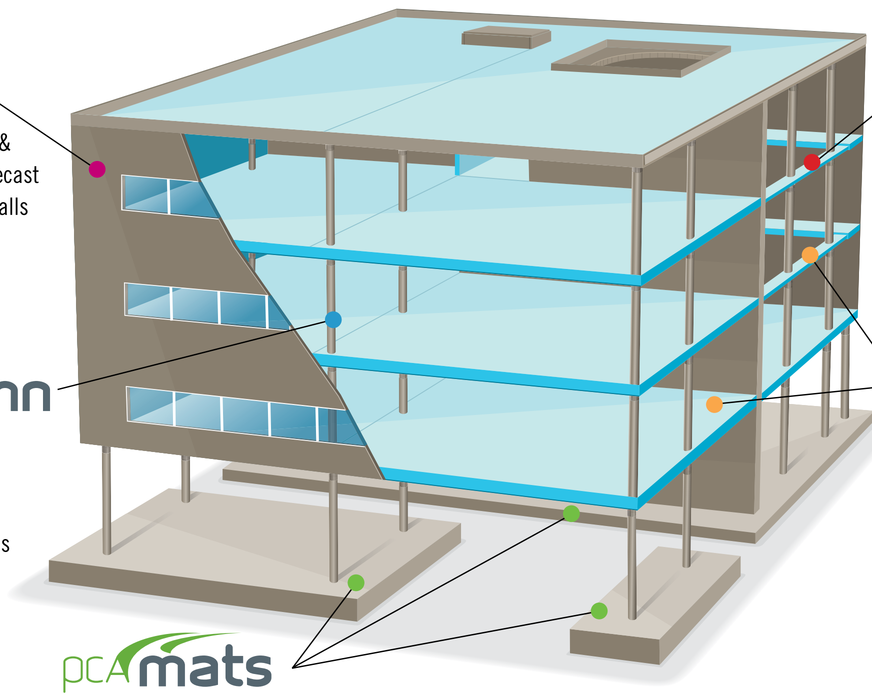

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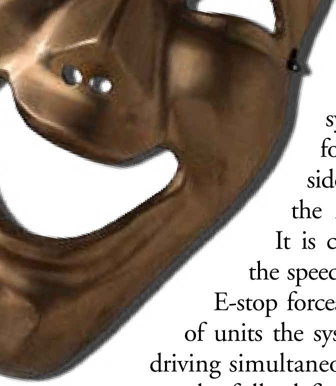

all but the simplest systems, dynamic forces must be considered to fully define the rigging load case. It is critical to consider the speed of operation, the E-stop forces and the number of units the system is capable of driving simultaneously. These loads cannot be fully defined without a dynamic analysis similar to those performed during machinery design.

Lateral forces must also be carefully considered. While these forces can be easily determined by vector analysis, these forces can result in load eccentricities and torsion on beam shapes. In the case of permanent systems, lateral forces usually result from redirection of a vertical lift line via one or more pulley assemblies, resulting in horizontal force equal to the vertical load acting in the system. Arena rigging lateral forces result from the use of angled sling assemblies (bridles) to position a load at some location not directly below a structural member. The resulting lateral forces must be considered.

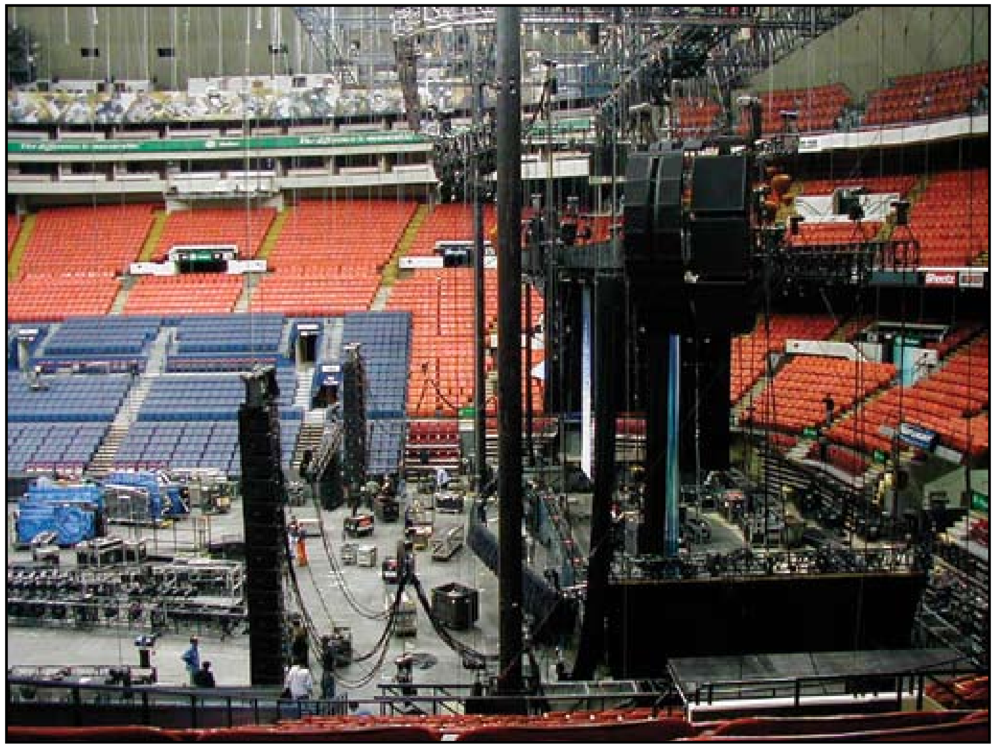

Figure 3: Wire Rope & Chain Hoist Rigging.

Design Criteria

Specifications defining the magnitude of these loads are typically dependent on either code defined criteria or project specific specifications. While the codes are beginning to adopt language addressing stagehouse rigging, the design criteria is not complete. Codes are largely silent on collateral rigging loads for arenas and convention centers. For permanent systems, some guidance information can be found in the New York City Building Code. The State of California Building Code also contains some specific design criteria for stagehouse rigging systems. In addition, some versions of the International Building Code 2006 now contain some minimum code based design criteria for loads imposed by rigging systems in stagehouses. In addition, both the IBC and ASCE 7 contain guidance for load increases imposed by impact due to operation of machinery and equipment.

Project specifications are usually provided by consultants specializing in design of entertainment related facilities. In the United States, the title "theater consultant" is often generally applied to a design consultant providing information regarding any of the types of facilities mentioned above, including arenas and sports stadia. Equipment manufacturers, some large architectural design firms and some engineers specializing in the field also frequently provide specification language.

Rigging loads are usually considered an additional live load. However, careful consideration must be given to load combinations. While a conservative approach is to consider 100% of the rigging load to act in addition to other live loads, this may be overly conservative resulting in an uneconomical design of the structural frame.

For permanently installed systems, in some cases, code language is specific and will not allow for any interpretation by the designer. (The NYC Building Code requires design of structure supporting stage rigging to support 100% of the rigging load, plus a 25% impact load, plus a 50 psf live load on the rigging system "gridiron" – which is the access platform supporting the rigging system). While these loads may be reasonable for a Broadway theatre, rigging systems installed in high schools or lower use venues have a low likelihood of ever seeing 100% of these loads acting simultaneously. In these environments, reduction factors similar to those applied in the case of roof live loads may be applied. As the area of the structure supporting the loads increases, a reduction factor may be applied to account for the low probability of a large area seeing the total rigging system capacity. Codes are generally silent on this issue however; many consultants apply factors up to 0.75 for the entire stage roof area. In addition, low use facilities can frequently apply a similar reduction to the live load imposed on the gridiron floor.

Arena rigging typically imposes relatively large point loads at a wide variety of locations throughout the roof system. Due to the very unpredictable nature of the loads that will be applied by any event, a conservative "multiple point load" approach is frequently applied. In this case, the structure might be designed to support a collateral rigging load of 4 kips at +/- 20 feet on center along both the lateral and longitudinal axes of the building, with a lower capacity for rigging above seating areas. Some venues restrict rigging loads to one area of the building, which can result in first cost reductions but can limit the flexibility of the facility in the future. As with stagehouses, a logical reduction factor can be applied if the loads act over a large area of the roof.

Calculation of seismic forces resulting from rigging loads can be controversial. Most rigging loads are suspended, unguided loads. Wire rope acts as a tension only member and, as such, will not impose large lateral shear forces from a suspended load. However, in the event of a seismic occurrence, the design should consider the maximum lateral drift and the associated lateral acceleration. This motion and acceleration can then be applied as a component vector force resulting from horizontal displacement of the building frame relative to the suspended load.

Useful information on stage rigging design at the following Web Sites:

www.JRClancy.com	Has good glossary of terms and basic rigging system design criteria.
www.cm-et.com	Columbus McKissick is a provider of hoists for entertainment rigging.
www.ESTA.org	The Entertainment Services Technology Association is a technical trade organization for the entertainment industry. They are engaged in writing of ANSI standards impacting areas such as rigging.
www.theatreconsultants.org	The American Society of Theatre Consultants is a trade organization of individuals specializing in the design of entertainment related facilities.

Conclusion

Stage rigging systems act in addition to other lateral and gravity loads. They must be considered to act logically in conjunction with other loads. A clear set of design criteria must be established during the schematic design of the building. While there is some guidance in some of the model codes, most projects will need additional specification developed in conjunction with a knowledgeable specialty firm to ensure an adequate, but not overly conservative, design.

There are two very distinct challenges to the adequate design of the building system, one occurring at project onset, the other, during the life of the structure:

- Performance venues function as multi-purpose machines and, as such, are intended to be highly flexible in daily use. Predicting the manner in which loads will be imposed is, at best, an educated guess. A well designed operational program, developed in conjunction with experts knowledgeable in the field, will help ensure an efficient design considering both initial costs and day-to-day operations.
- The daily use of these structures can impose large unpredicted loads on the building system. It is essential to provide clear and direct loading information to the end user in a fashion that is conservative and easily understood by the layman. A typical scenario might have a show arrive at a venue at 10 p.m., work all night to unload 120,000 pounds of gear, perform the show and be moving to the next venue less than 36 hours later. The pace is frenetic and there is usually no time to reanalyze the system for a specific show. Concise communication of the structural limitations of the building frame will ensure safe operations for the life of the venue.

Rigging systems impose unusual loads on the building system frame. Design of the systems can be somewhat challenging but, if the programming needs of the structure are defined early in the design process, these somewhat unique loads can be considered rationally during the design of the entire structural frame.▪

Shawn Nolan, P.E. has 30 years of experience in the technical side of the entertainment industry. As Division Coordinator for the Entertainment Structures Group he supervises projects for rigging installation and analysis throughout the U.S. Shawn may be contacted via email at ***Shawn.Nolan@entertainmentstructures.***