Technical Notes Volume 1, Number 14

Basic Principles for Suspending Loudspeaker Systems

Introduction:

Contractors and sound installers hang loudspeaker equipment in public meeting places and performing arts facilities as a matter of routine. This Technical Note details rigging practices appropriate for the sound industry, and is intended to familiarize readers with the proper hardware and techniques for hanging installations. To insure a safe installation and to protect workers on the job site, this work should be undertaken only by persons with knowledge of the proper hardware and safe rigging practices.

This Technical Note contains data for rated capacity for various pieces of hardware, based upon manufacturers specifications for products in new condition and free from defects, either apparent or hidden. All rated load values, unless otherwise noted, are for in-line pull—along the centerline of the item. It is the responsibility of the installer to inspect and determine the actual condition of the equipment used, and to incorporate design factors appropriate to the local job conditions. Where doubt exists as to the actual condition or ratings of hardware, it should not be used.

Load ratings shown herein are are based upon usual environmental conditions. Further considerations must be given to item selection when unusual conditions are encountered. All products used for hanging purposes are subject to wear, misuse, overloading, corrosion, deformation, alteration and other usage factors which may necessitate a reduction in the products capacity rating or a reduction in its design factor. It is recommended that all products used for rigging and hanging purposes be inspected prior to each use as a basis for determining if the product may continue to be used at its rated capacity, or removed from service.

Welding of or to load supporting parts and structure can weaken the part or structure, and should be performed only by persons with knowledge of metallurgy and the intended use of the materials being welded.

The material presented in this Technical Note has been assembled from recognized engineering data and is intended for informational purposes only. None of the enclosed information should be used without first obtaining competent advice with respect to its applicability to a given circumstance. None of the information contained herein is intended as a representation or warranty on the part of JBL. Anyone making use of this information assumes all liability arising from such use.

All information herein is based upon materials and practices common to North America and may not directly apply to other countries because of differing material dimensions, specifications and/or local regulations. Users in other countries should consult with appropriate engineering and regulatory authorities for specific guidelines.

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Design Factor:

Design factor is a term used by the rigging industry to denote theoretical reserve capability. The rated capacity of all lifting and hanging equipment is based upon the nominal strength of the equipment reduced by the design factor.

Design factor is a number representing the fraction of equipment nominal strength chosen to be appropriate for the particular application.

$$\text{RATED CAPACITY} = \frac{\text{NOMINAL STRENGTH}}{\text{DESIGN FACTOR}}$$

Example:

Design factor = 5
Rated capacity of equipment is only 1/5 of its nominal strength.

Minimum design factors vary according to the application, and may be regulated from location-to-location. No design factor discussed herein should be assumed to represent a recommendation on the part of JBL. Users must assume all responsibility for the determination of design factors suitable for local conditions.

Shock Loading:

When a load is suddenly moved or stopped, its weight may be magnified many times the original value. This is known as shock loading. Shock loading of lifting equipment should be avoided at all times.

Shock loads will usually be instantaneous and may go undetected unless equipment is visibly damaged. No equipment is designed to compensate for poor rigging practices or foolish planning, however. Every tool and piece of equipment has limitations. Safe working practices demand that these limitations be known and fully understood, and that they never be intentionally exceeded.

A 900 pound loudspeaker cluster dropped four inches could cause a shock load of 4500 pounds if the rigging were attached to rigid structures and of a material that would not stretch. However, because all rigging will stretch under shock loading, the exact shock load on a piece of equipment isn't easily predicted. To protect people and property, all tools and equipment should be limited to stresses that are several times smaller than their minimum breaking strengths.

Although shock loading of equipment and structure is usually confined to lifting and installation, it should also be recognized that other forces (such as earthquakes) can impose shock loads upon structures many times that of the static load. It is therefore imperative that hardware nd structures be capable of supporting several times the weight of the equipment being hung.

Center of Gravity:

The center of gravity of an object is the point at which the weight of the object acts as though it were concentrated. It is the point at which the object may be completely supported or balanced by a single force.

The center of gravity of a regularly shaped object may be estimated fairly accurately by determining its approximate center. Finding the center of gravity of irregularly-shaped objects can be more difficult, but it is necessary, nevertheless. A load will always hang from its attachment point through the center of gravity. It is important to visualize this before making a lift.

All loads to be lifted should be rigged above the center of gravity in order to prevent tipping and possible hazards to equipment and workers. The lifting force should always be located above the center of gravity and exert a straight vertical pull to prevent swinging of the load.l

Ropes:

Before discussing actual rigging hardware and systems, it is appropriate to examine ropes and their proper use. Ropes are used for many rigging functions. Although synthetic ropes of great strength are available, most codes prohibit their permanent use in rigging for a variety of good reasons. Nevertheless, ropes are necessary to lift approved cables, fixtures, tools and equipment into position.

In the interest of safety it is important that ground workers be familiar with the proper use of rope and a few basic knots used in rigging.

Rope Terminology (Figure 1):

1. The Standing Part is the end of the rope which is inactive.

2. The End is the part of the rope that is free—typically the part in which knots are tied.

3. A Bight is the central part of the rope between the standing part and the working end.

4. An Overhand Loop is formed by crossing the end over the standing part.

5. An Underhand Loop is made by crossing the end under the standing part.

6. Tightening. Once formed, a knot must be tightened slowly and with care. Failure to do so could result in a tangle, or an untrustworthy knot.

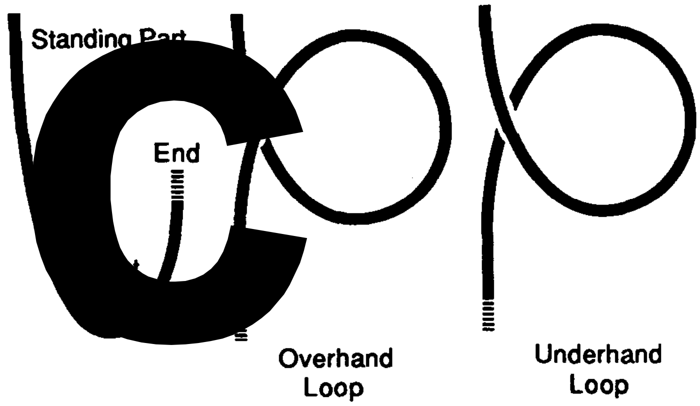


Figure 1. Rope Terminology

Knot Efficiency:

Knot efficiency is the approximate strength of a rope with a knot as compared to the full strength of the rope. It is expressed at a percentage of the ropes rated capacity, and refers to the stresses that the knot imposes upon the rope. When a knot is tied in a good rope, failure under stress is certain to occur at the knot. This is because bends result in uneven stresses upon the fibers, with the outsides of the bends taking a greater share of the load. It follows that the tighter the knot, the greater the percentage of the total load that is carried on fewer fibers.

Bends:

Bends are used to join two pieces of rope, usually temporarily. Typical knot efficiency is 50%. Bends offer some advantage over binding knots, as they resist untying when slackened or jerked. The Sheet Bend is a simple knot to tie, consisting of an overhand loop on one piece, with the second rope end fed up through the loop from behind, around the standing part of the first rope and back down through the loop from the front.

Binding Knots:

Binding knots are also used to join two pieces of rope. In general, binding knots have a knot efficiency of 50%, but can untie easily when a free end is jerked.

In the square knot, the end and the standing part of each line lie together through the bight of the other. In the untrustworthy granny knot, the end and the standing part are separated by the bight. The granny knot is particularly treacherous in that it will appear to be secure—only to slip under load. The thief knot is deceptively similar to the square knot, but has the two loose ends coming out of the opposite sides, instead of from the same side as in the square knot. This knot is almost certain to fail under load.

Loop Knots:

Loop knots are used to hold objects where security is of paramount importance. The bowline, widely used in rigging, won't slip, yet is easily tied and untied. It may be tied in the hand or used as a hitch and tied around an object, usually for lifting purposes (Figure 2).

To tie: Make an overhand loop with the end toward you (Step 1). Pass the end up through the loop from behind (Step 2), then up behind and around the standing part—then down through the loop again (Step 3). Draw up tight. The bowline has a knot efficiency of approximately 60%.

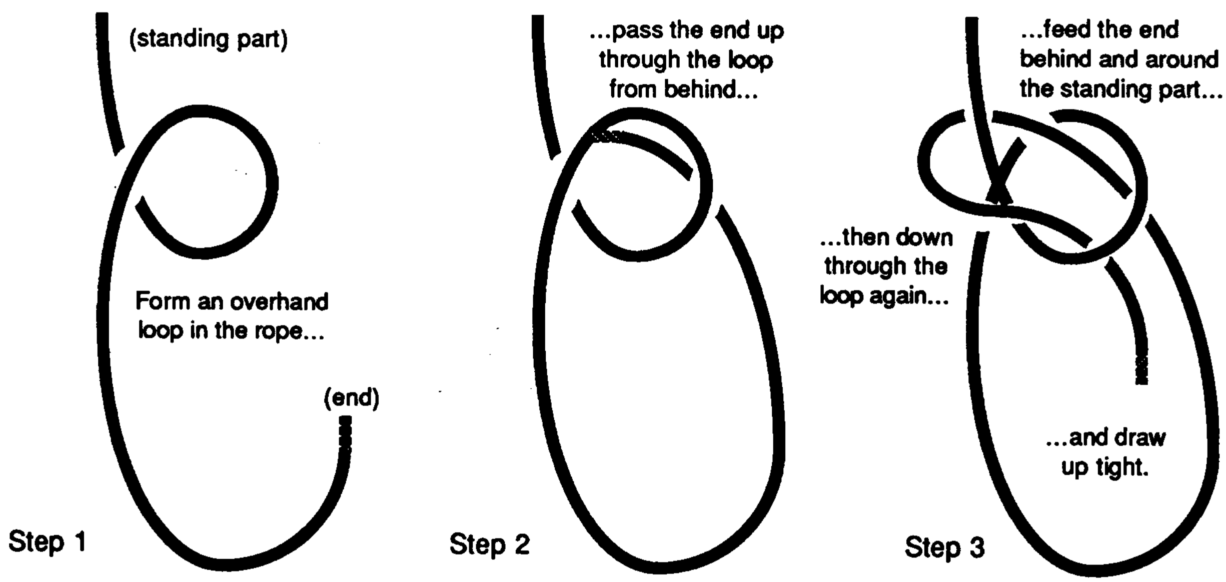


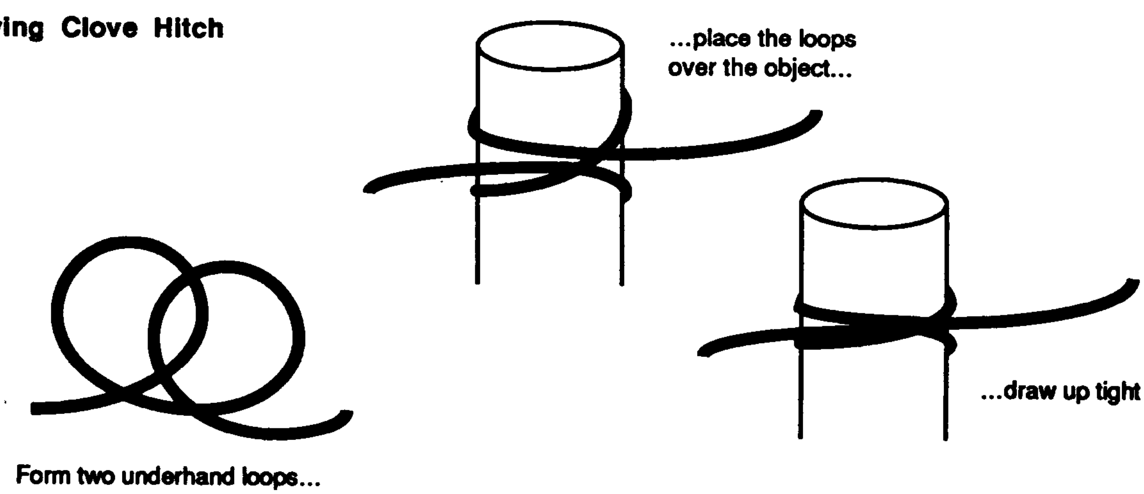
Figure 2. Tying Bowline

Hitches:

Hitches are used for temporary fastenings that untie readily. They are generally tied directly around the object—instead of first being tied in the hand and then placed over the object. Hitches must be drawn up tight, as they have a tendency to slip if loose.

The clove hitch (Figure 3) consists of two underhand loops, which may be tied in the hand and slipped over an object at any point along the length of a rope. Knot efficiency is 60%.

Figure 3. Tying Clove Hitch



Wire Rope:

Most wire ropes are constructed from plow steel, improved plow steel, or extra improved plow steel wire. The wires are woven into strands, which are woven to form the wire rope. Typical wire rope may consist of six strands wound around a central core. The central core supports the outer strands and helps to prevent the rope from crushing under stress. Wire rope core materials may be fiber (abbreviated FC), independent wire rope (abbreviated IWRC), or wire strand (abbreviated WSC).

Wire rope is classified by diameter, number of strands, number of wires making up each strand and core material construction. Rope diameter is measured at its widest dimension. Wire rope is also classified according to the direction the strands and wires are twisted. The distance along the rope required for a strand to make one full revolution is one *lay*.

In *Right Regular Lay* construction, Strands twist to the right, wires twist to the left.

Right Lang Lay construction finds both strands and wires twisting to the right.

Left Regular Lay ropes are constructed with strands twisted left and wires twisted right.

The *Left Lang Lay* configuration twists both strands and wires left.

Regular lay ropes are less susceptable to crushing and deformation because the wires lie nearly parallel to the rope. Lang lay ropes twist the wires across the direction of the rope, and are therefore more flexible and resistant to abrasion damage. If both ends of a lang lay rope are not fixed, however, it will rotate severely when under load.

Most sound and stage rigging requirements are easily handled by two wire ropes: 3/8" and 1/2" 6 X 19 IWRC classification. These ropes in improved plow steel have a nominal strength of 13120 pounds and 23000 pounds, respectively. If we assume a design factor of 5, rated capacities become 2600 and 4600 pounds.

Just as knotting a fiber rope reduces the nominal strength of the rope, bending of a wire rope also results in a reduction in its nominal strength. The tighter the radius of the bend in the rope, the greater percentage of the load is concentrated on fewer wires and strands. This results in a reduction in the rope's nominal strength and rated capacity.

Figure 4 shows the relationship between wire rope efficiency and the ratio of bend radius to rope diameter. The chart is for 6 X 19 class wire ropes. Note that the chart is nearly asymptotic as the bend radius approaches the rope diameter—such as might occur in wrapping a beam with a basket sling. Overloading of a cable under these conditions could result in irreparable damage to the wire rope, or a possible failure.

Experienced riggers always pad beam edges with softeners before wrapping the beam with a sling, and avoid sharp or jagged edges that could possibly injure the wire rope or sling. Heavy burlap or thick polyester is usually used for this purpose.

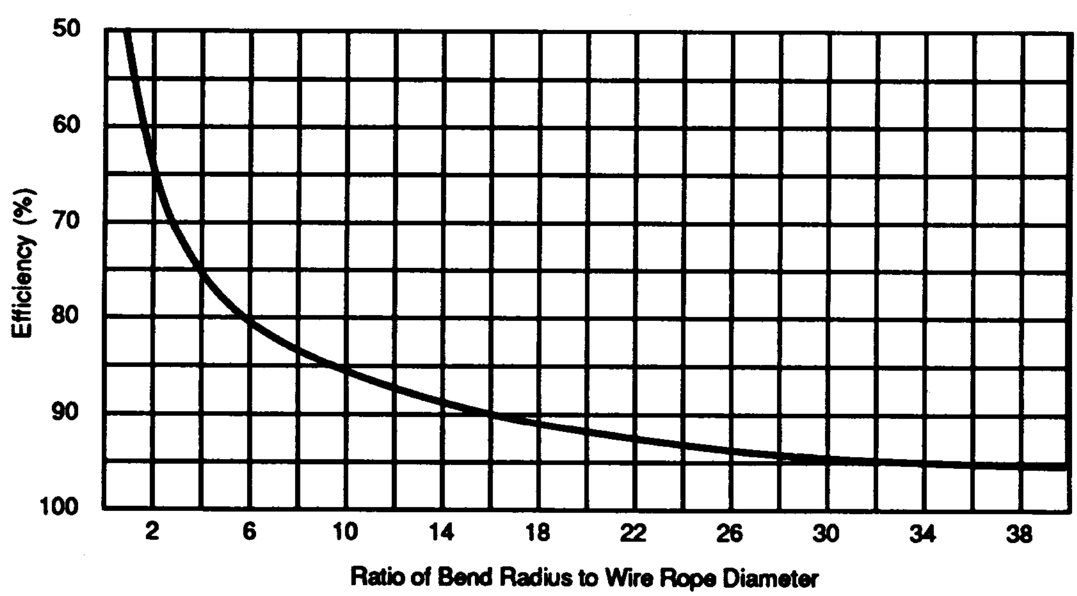


Figure 4. Wire Rope Bend Efficiency

Wire Rope Connections:

In the touring business, wire rope is employed for slings, usually in lengths of 5, 10, 20, 30 and 50 feet. Each end of the sling is terminated in a swaged or zinc-cast eye, which yields a connection that is at least as strong as the wire rope itself. This type of connection is rated as 100% efficient—the strength of the entire cable assembly is that of the wire rope. These slings are also clean in appearance, won't tear flesh or clothing in the process of handling, and do not require periodic re-torqueing. Custom length slings are easily obtained for permanent installations.

Clips are used when eyes must be fabricated to wire rope in the field. Two types of clip are available for this purpose: U-bolt or Crosby clips and J-bolt or fist-grip clips. Only forged clips should be used. Correctly used, clips result in a connection efficiency of 80% (e.g., if the wire rope has a rated capacity of 4600 lbs. and clips are used to fabricate an eye, the rated capacity of the assembly would be 3680 lbs.).

It is important that clips be properly installed. Failure to do so could result in a reduction of rated capacity. U-bolt clips can be installed wrong. The clip saddle must be installed over the live end of the rope to prevent damage to the load-bearing component. J-bolt clips cannot be installed backwards. Always use the proper size clip and thimbles for the wire rope (Figure 5).

The procedure for installing wire rope clips is:

1. Refer to Table 1 for the number of clips, clip spacing and tightening torque.

2. Determine the length of rope required to turn back for proper clip spacing and thimble size. Always use thimbles.

Wire Rope Diameter (in)	Quantity of Clips	Spacing (in)	Torque (Ft-lbs)
1/4	3	1-1/2	15
3/8	3	2-1/4	45
1/2	3	3	65
5/8	3	3-3/4	95
3/4	4	4-1/2	130

Table 1. Wire Rope Clip Data

3. Attach the clip furthest from the loop, a distance from the end of the rope equal to the widest part of the clip. Tighten securely.

4. Apply the second clip as close to the thimble as possible. Turn nuts on firmly, but do not tighten.

5. Add the remaining clips between the first two at the spacing increments from Table 1. Turn nuts on firmly, but do not tighten.

6. Apply a light stress on the rope to equalize the tension on all clips, re-position clips if required, then tighten all nuts to the specified torque.

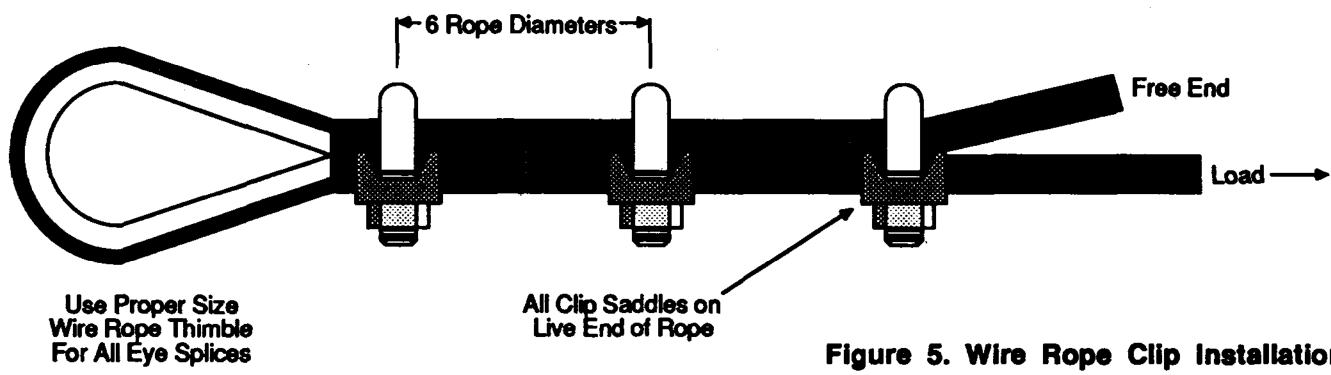
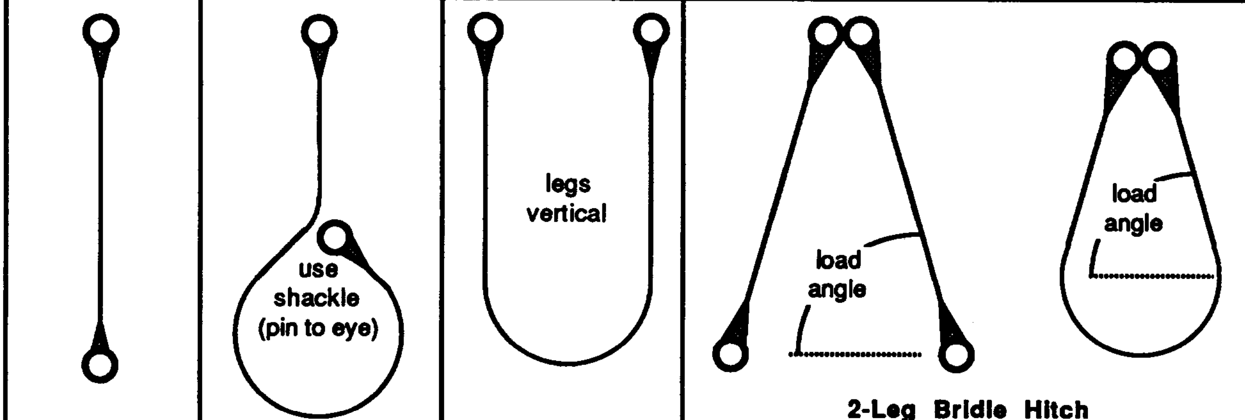


Figure 5. Wire Rope Clip Installation

7. Load the cable and retighten all nuts to the specified torque setting. Do not over-tighten. This step is essential, as the wire rope will stretch slightly, reducing its diameter when loaded.

8. Inspect periodically and retighten as necessary.

Note the final step—Inspect periodically and retighten as necessary. Failure to make terminations in accordance with the above instructions, or failure to periodically check and re-torque as recommended will result in a reduction in efficiency rating. This requirement makes swaged or zinc-cast eyes an attractive alternative for permanent installations.



Rope Diameter (In)	Rated Capacity In Pounds (Design Factor = 5)					
	Single Vertical Hitch	Single Choker Hitch	Single Basket Hitch	2-Leg Bridle Hitch and Single Basket Hitch with Inclined Legs		
				60 Degrees	45 Degrees	30 Degrees
3/16"	650	480	1,300	1,100	900	650
1/4"	1,150	860	2,300	2,000	1,600	1,150
5/16"	1,750	1,300	3,500	3,000	2,500	1,750
3/8"	2,550	1,900	5,100	4,400	3,600	2,550
7/16"	3,450	2,600	6,900	6,000	4,900	3,450
1/2"	4,700	3,500	9,400	8,150	6,650	4,700
9/16"	5,700	4,200	11,400	9,900	8,050	5,700
5/8"	7,100	5,300	14,200	12,300	10,000	7,100
3/4"	10,200	7,650	20,400	17,700	14,400	10,200

Table 2. Wire Rope Sling Data

Slings:

A sling is a looped line used to hoist, lower or carry something. Slings in sound system rigging are generally made from wire rope or polyester fiber, and are used to hitch loads to various parts in the chain of rigging components. Table 2 shows several variations of wire rope slings and tabulates rated capacities for each configuration of hitch based upon 6 x 19 classification, Improved Plow Steel, IWRC at an assumed design factor of 5.

Polyester or synthetic fiber slings enjoy considerable popularity for the rigging of portable sound and stage equipment. They offer advantages in that they are light in weight, easy to handle, will not damage delicate and unusually-shaped materials and, depending upon the individual sling, are stronger than wire rope. They also are better than wire rope for working tight radius bends. SpanSet™ products are typical of the range of synthetic fiber slings available for this purpose—refer to the manufacturer's data for capacity rating information, as it can vary from product to product. A note of caution regarding synthetic slings: polyester fabric is relatively poor in its fire ratings—consult local building code authorities before installing.

Load Angle Efficiency:

Load angle is the angle between the load (horizontal surface) and the sling. Figure 6 illustrates the effects of load angle efficiency using a two-leg sling to hang one JBL 4846 low frequency system. The load angle affects the sling tension inversely. As the load angle is reduced from 90 degrees to 0 degrees, the sling tension increases from the sling's share of the load to an infinite value.

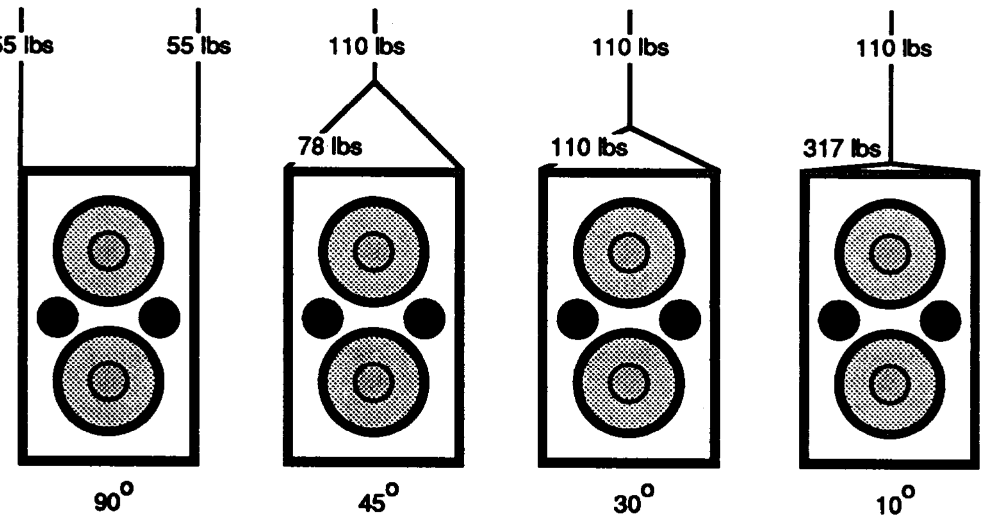


Figure 6. Load Angle Efficiency

The sine of the load angle is numerically the Load Angle Efficiency, e.g., a 30 degree sling angle will have a Load Angle Efficiency of 50% (Sine 30 = 0.5). A Load Angle Efficiency of 50% means that the sling tension will be twice that of the sling's share of the actual load. The JBL 4846 weighs approximately 110 pounds. Using two independent slings, each will be tensioned to 55 pounds. If we were to bridle the two sling legs such that each leg were to form a 30 degree angle with the horizontal surface of the cabinet, each leg would be tensioned to 110 pounds. As the angle between the sling and the horizontal surface is deminished, the sling tension will increase in inverse proportion to the sine of the load angle.

It is important to recognize that the sling tension affects all of the hardware that comprises the sling assembly, including the attachment points. This may result in excessive loading of hardware, especially at the point of attachment to the loudspeaker cabinets. <u>All of the components that attach to the sling will be subjected to a tensile loading equal to that of each sling leg and must be sized accordingly.</u>

Sling tensions may be directly calculated from physical measurements (Figure 7).

A loudspeaker cluster to be lifted weighs 1250 pounds. Using a two-leg sling, the distance (A) from the lift point to each anchor point is 48 inches. The distance (B) from the lift point to the horizontal surface is 24 inches. The tension on each leg of the sling will be A-[48"] divided by B-[24"] times 1/2 the load (2 legs) = 1250 pounds. This represents a Load Angle Efficiency of 50%. These calculations should be performed for each load to be lifted in order to prevent overloading of hardware or a reduction of design factors.

Since the loudspeaker cluster is being lifted from a single point, guy lines will be required to stabilize the assembly from rotating.

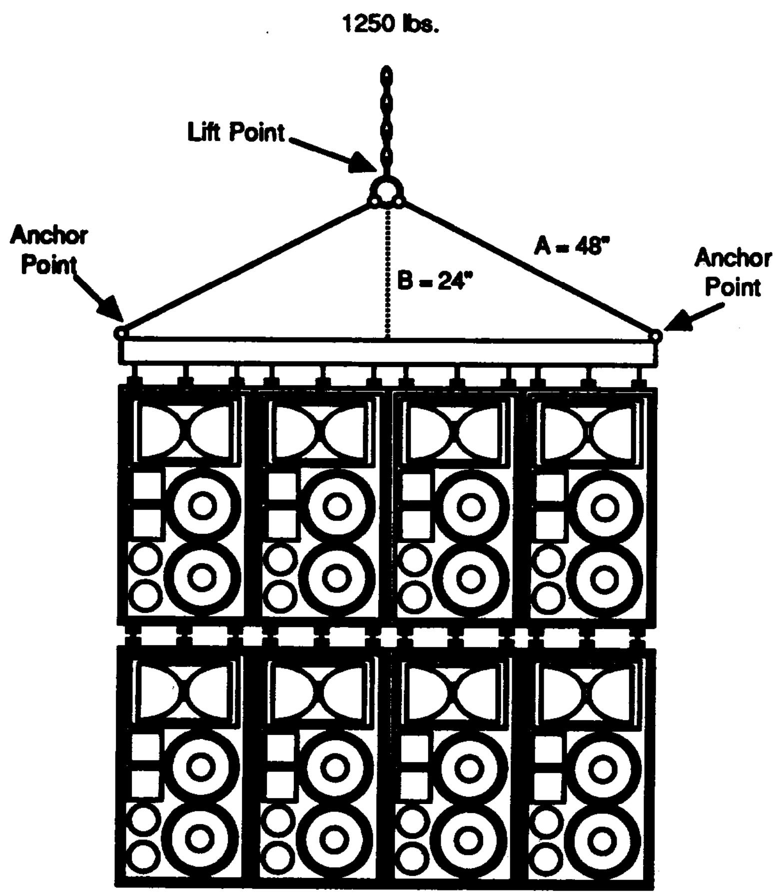


Figure 7. Calculating Sling Tension (see text)

Hardware:

There are as many different sources and quality levels of hardware as there are potential vendors for sound systems, perhaps even more. It should be noted, however, that the consequences of exercising poor judgement in selecting hardware for rigging are not qualitative. In spite of this fact, purchase decisions with respect to hardware are often last-minute items left to installers and technicians having little or no knowledge of safe rigging practices.

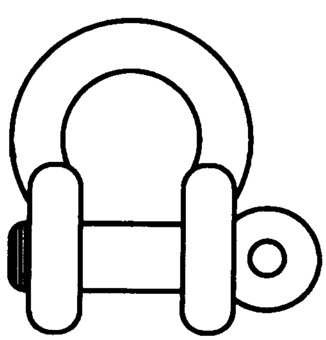
To the uninitiated, many similar hardware items appear identical, yet may be orders of magnitude different in terms of their load capacities. The highly competitive nature of the retail hardware and building-supply business in the United States has generated a nearly endless supply of fasteners of unknown (and suspect) quality and consistency. Just as a chain is no stronger than its weakest link, it is a matter of the utmost priority that all hardware used in a rigging chain be of known quality and strength. This is less a matter of expense than one of good planning, as the use of load-rated hardware will make an insignificant difference in the total cost of an installation.

Almost without exception, load ratings for hardware are for axial loading only—a straight pull along the axis of the fitting. Failure to use a device in the manner in which it is intended to be used can seriously weaken the part and render an installation unsafe. It is the responsibility of designers and installers to make proper use of hardware and hardware systems.

Shackles:

Different types of shackles are available for a variety of applications. The type most commonly used in sound system rigging is the Screw Pin Anchor Shackle (Figure 8). These parts are most often used to join SpanSets or slings to eye bolts or additional slings. Table 3 lists rated capacity information for Screw-Pin Anchor Shackles.

Figure 8.



Screw Pin
Anchor Shackle

Material Size (inches)	Pin Diameter (inches)	Rated Capacity (lbs.)
1/2	5/8	2800
5/8	3/4	4400
3/4	7/8	6400
7/8	1	8600
1	1-1/8	11,200
1-1/8	1-1/4	13,400
1-1/4	1-3/8	16,400

Table 3. Screw Pin Shackle Data

Only load-rated forged carbon-steel shackles should be used for rigging. The load rating will be stamped on the body of the shackle.

Screw Pin Shackles should be snugly finger tightened only. If tools are required to seat the shackle pin it means that the threads are damaged, and the part should be discarded.

Shackles should always be loaded pin-to-end—never on their sides.

The pin end of the shackle should not be allowed to straddle a moving rope, as friction could loosen the pin.

Do not substitute bolts for shackle pins, as the pins are forged and considerably stronger than machine bolts.

Always use packing washers to center narrow loads on the pin. This will prevent the shackle from being pulled at an angle which will weaken and possibly damage the fitting.

Bolts:

steel: *commercial iron that contains carbon in any amount up to about 1.7 percent as an essential alloying constituent, is malleable when under suitable conditions, and is distinguished from cast iron by its malleability and lower carbon content...resembling steel.*
—Webster's Third New International Dictionary

Given this rather broad definition of "steel", there is a wide latitude for specific alloys and the consequential tensile strength and hardness that may be encountered in a steel bolt. When ungraded bolts are used in rigging applications, unknown alloys can result in a fastener that may be unreliable under stress.

Fortunately, graded bolts are easily identified. Figure 9 shows the identifying marks for SAE grade 5 and SAE grade 8 bolts. Table 4 lists rated capacities for SAE grades 5 and 8 bolts using an assumed design factor of 7 on the area at the root of thread.

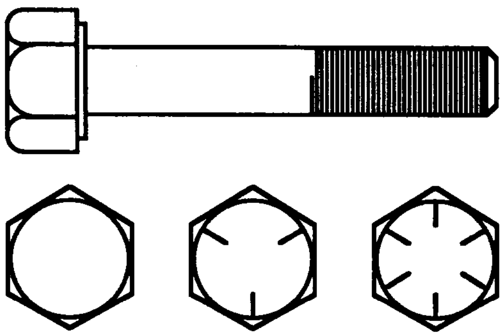


Figure 9. Bolt Grading

Diameter (inches)	Area at Thread Root (sq. inches)	Grade 5 Rated Capacity (lbs.)	Grade 8 Rated Capacity (lbs.)
1/2	.126	2,160	2,700
5/8	.202	3,460	4,300
3/4	.302	5,170	6,470
7/8	.419	6,880	8,970
1	.551	9,050	11,800

Table 4. SAE Grade 5 and Grade 8 Bolts

Eye Bolts:

Eye-bolt fasteners come in several varieties (Figure 10):

Lag-Screw Eyes cut threads into wood and rely upon the strength of the wooden threads to carry the load. The ultimate strength of the bond depends upon the strength of the material and total surface area threaded into it. Wood or wood fiber makes untrustworthy threads and should never be used to support overhead loads.

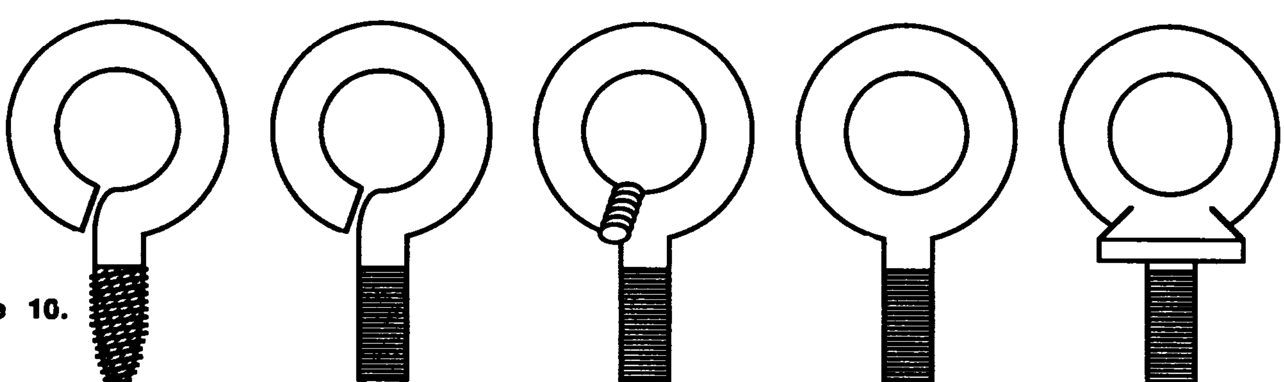
Formed Eye Bolts consist of steel rod bent into an eye with a machine-screw threaded shank. These products are widely available at hardware counters and do-it-yourself building material outlets. These products come from a wide variety of domestic and offshore sources, are unmarked, and may be soft or brittle. The eyes have a nasty habit of pulling straight or snapping where the curvature of the formed eye meets the shank under modest loads. Formed eye bolts must be considered untrustworthy and should not be used for rigging purposes.

***Note:** Often eye bolts are welded closed to prevent opening under load. This practice can damage the metallurgical structure of an already suspect fitting, causing the bolt to lose resistance to breakage under stress and result in an even more untrustworthy part.*

Plain Pattern Forged Eye Bolts are designed for straight pulls only, and are trustworthy to support vertical loads. Note that plain pattern eye bolts should never be used for angle pulls. The rated capacities for plain pattern eye bolts will be the same as for shoulder bolts under vertical load.

Forged Shoulder Eye Bolts are preferred for all applications, especially those in which angle pulls are likely to be encountered. Note that the rated capacity for shoulder eye bolts is reduced substantially for angle pulls. Note also the correct orientation of the bolt for angle pulls (Figure 11). Loading at angles greater than 45 degrees from the vertical axis is not recommended. Table 5 lists rated capacity information for forged shoulder eye bolts.

Figure 10.



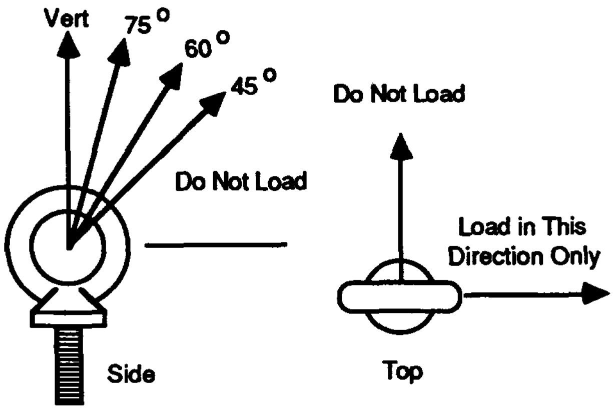


Figure 11. Shoulder Eye Orientation

Size (inches)	Vertical Pull (lbs.)	75 Degree Load Angle	60 Degree Load Angle	45 Degree Load Angle
1/4	500	275	175	125
5/16	800	440	280	200
3/8	1,200	660	420	300
1/2	2,200	1,200	770	550
5/8	3,500	1,900	1,200	875
3/4	5,200	2,850	1,800	1,300
1	10,000	5,500	3,500	2,500
1-1/4	15,200	8,350	5,300	3,800

Table 5. Forged Shoulder Eye Bolt Data

Attachments To Loudspeakers:

Bolts, shackles, clips and eye bolts all develop the greatest strength along their axes—vertical orientation in hanging applications. It follows that the safest location for hanging attachment points will be at the tops of cabinets to minimize angular stresses on hardware. This requires that the cabinet be strong enough to be safely hung from its top. Where multiple enclosures are needed, this can result in cabinets hanging from other cabinets. This makes the loudspeaker enclosure an integral part of the hanging hardware system.

A five-to-one design factor is generally assumed for hanging hardware. It follows that loudspeaker cabinets must be capable of similar design factors. With the exception of the JBL Concert Series, few loudspeaker systems and components are load-rated and suitable for hanging without modification. The secure attachment of hanging hardware is no assurance that a cabinet will not pull apart under its own weight. An unmodified cabinet will be no stronger than the material that it is made from and the joinery techniques used to assemble it. As a general rule, all wood and wood-fiber loudspeaker systems over 50 pounds require structural reinforcem for hanging installation. There are many different methods of reinforcing cabinets that can provide acceptable safety margins, two of which are shown in Figure 12.

For plywood enclosures, hanging hardware is shown bolted to steel reinforcement plates that are securely attached to the cabinet in a steel-wood-steel sandwicl

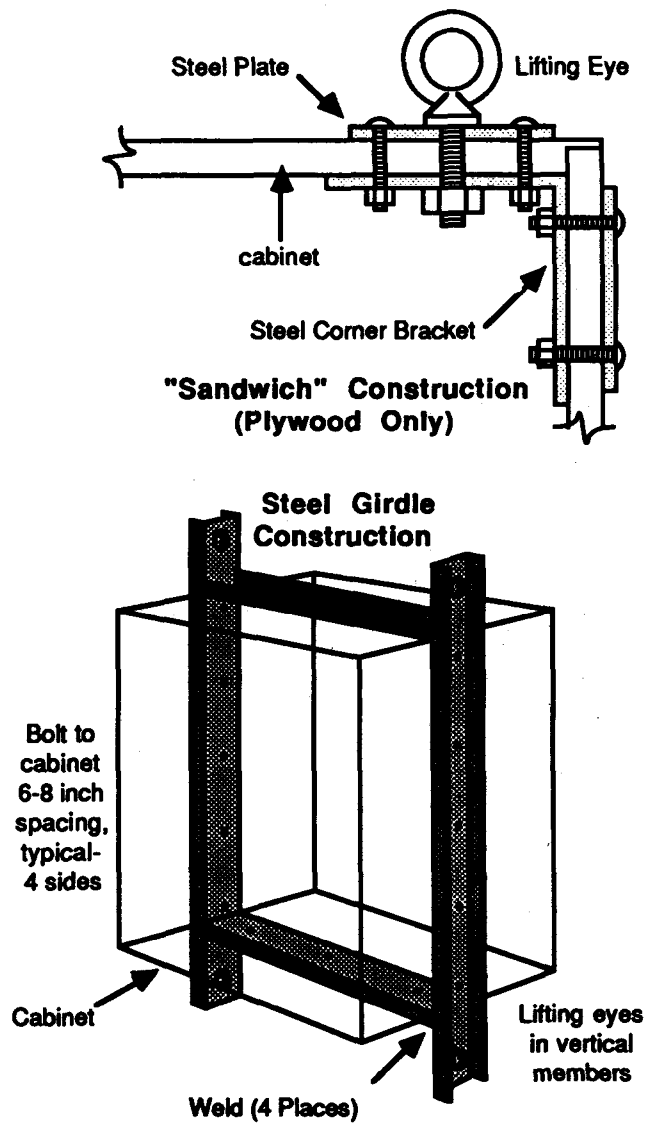


Figure 12. Cabinet Reinforcement

configuration. One corner is shown. All load-bearing panel intersections should be similarly reinforced with steel plates. This reinforcement method is not suitabl for wood fiber or particle board cabinets.

Particle board and wood fiber cabinets should be externally reinforced with continuous steel strap or welded steel channel secured to the box so as to completely surround the enclosure, capturing dadoed-in baffle and back panels. This reinforcement method is suitable for all types of cabinets. If the baffle board isn't dadoed into the side walls, the cabinet shouldn't be hung and an appropriate substitute found. Never rely upon the internal bond strength of particle board or wood fiber cabinets to carry the weight of a large (over 50 pound) system.

Small loudspeaker systems are subject to the same mounting considerations. Because they are small and fairly light, however, installers tend to make assumptions which frequently prove unsafe in the long term. While the structural failure of a small loudspeaker cabinet seldom presents a serious hazard, it can be avoided by anticipating conditions that could affect the choice of mounting techniques.

Caution: Small loudspeaker systems often employ snap-in grill assemblies, which usually attach to the cabinet with Velcro or similar re-usable fasteners. These mounting techniques, while satisfactory for home use, should not be relied upon for overhead installation in public places. Appropriate modifications are required.

Most small loudspeaker systems employ miter-folded particle board construction techniques (Figure 13). A plank of particle board is grooved longitudionally for inserting the baffle and back panel, milled transversely to the depth of the veneer to form the miter joints, then assembled by folding the sides around the back and baffle. Glue is applied at all panel intersections before folding, and the assembly is wrapped with elastic cord and set aside until dry. This type of construction depends upon the integrity of the glue bonds at panel intersections and the internal bonding strength of the particle board for structural integrity.

Figure 14 shows a variation of this construction technique. In this example, the top, bottom, baffle and back are miter-folded and the completed sub-assembly locks into dadoed grooves in the side panels. This

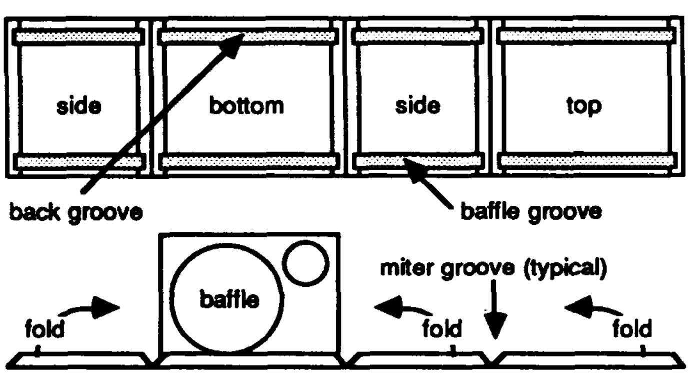


Figure 13. Miter-Fold Construction

method of joinery enables the attachment of hanging hardware to the top, bottom or back (depending upon total system weight), but the system should not be suspended from the sides.

Many other variations in construction and joinery are possible. It is the responsibility of the installer to examine the system and construction methods used to determine a safe attachment scheme for hanging hardware. In small JBL systems that incorporate hanging hardware or attachments for hanging hardware, the locations

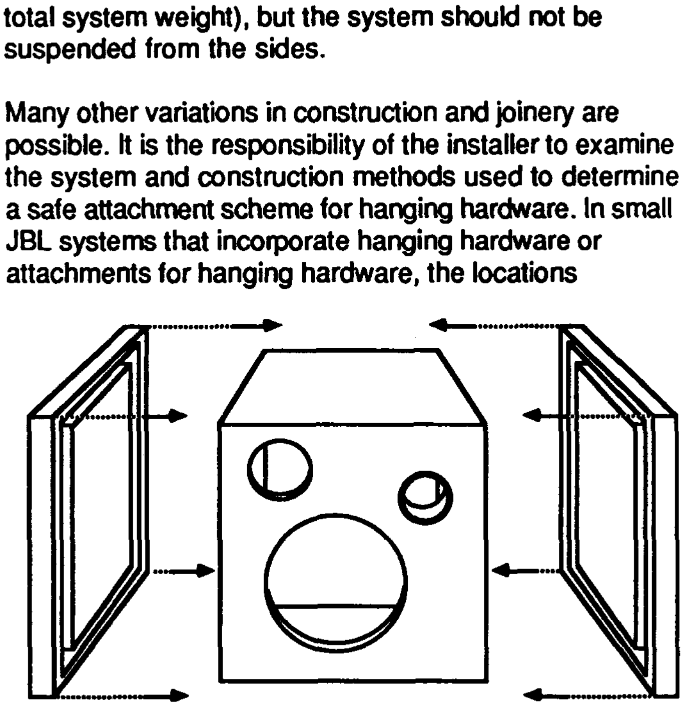


Figure 14. Alternate Miter-Fold Construction

provided have been chosen on the basis of strength of construction and the joinery methods used in the enclosure. No other method of suspension attachment is recommended for these systems.

When particle board cabinets are to be suspended from T-nuts and eye bolts, installers should be aware of loading limits that attend this practice. New particle board will exhibit an internal bond strength of 60-70 psi (ASTM D-1037). A 1/4-20 T-nut in 3/4 inch material will subtend approximately 1.4 square inches of bonded surface, resulting in a nominal (breaking) strength of 85-98 pounds. Using an assumed design factor of 5, the maximum axial load on a single T-nut would become 17-20 pounds. Reduce these factors by one-third for half-inch material. This is for particle board that is new or in new condition only. Clearly, this is not an acceptable suspension method for large loudspeaker systems.

Conventional particle board is limited in application to interior use only—typical temperature and humidity conditions as encountered in a domestic residence or office environment. The resins used in the manufacture of most particle boards will not withstand prolonged exposure to moisture or high humidity. Wide variations of temperature will yield conditions of moisture saturation followed by evaporation, under which essential bonding agents will be leeched from the material. This process can eventually result in a cabinet with little more strength than a graham cracker.

The Installation Environment:

We have examined hardware systems and precautionary measures to ensure that the connections to the loudspeakers are made in a safe and secure manner. What remains is to properly hang the system in the installation environment.

For new construction, the sound system contractor should inform the architect of the planned hang points and the total weight to be concentrated on each point. The architect will then be able to provide the necessary load capacities and attachment fixtures as a part of the structural plans and specifications. <u>This information should be supplied for each and every suspended component, regardless of size and weight.</u>

The task becomes more difficult in existing buildings and structures when adding sound facilities or remodeling existing systems. Most projects are undertaken without the professional services of an architect or structural engineer. Under these circumstances, the sound system contractor is left to his own devices to render a safe installation.

It is virtually impossible to predict the local conditions that a sound contractor may encounter in an installation environment. However, the following guidelines apply equally to any installation circumstance:

1. **Never** attach or suspend loads to/from a wall or ceiling surface. Always make a secure attachment to *structural* members.
2. **Be absolutely certain** of the structural integrity of any member that is to be used to support external loads—hidden structures can have hidden weaknesses.
3. **Do Not** rely upon nails or wooden threads to support overhead loads—nails, wood screws, lag screws and lag screw eyes are untrustworthy.
4. **Never** assume anything. Owner or third-party supplied suspension points may be inadequate for the intended use.
5. **Recognize your limitations.** Seek help from competent outside sources—architects, structural engineers or rigging specialists—when uncertain or in doubt.
6. **Safety first.** Public safety demands that those responsible for placing equipment in potentially hazardous locations do so with full knowledge and use of appropriate precautions and safety measures.

Hanging A System:

The first step in hanging a sound system is to obtain qualified advice about the load carring capacity of the building or structure. The engineer or rigger will need to know how much weight needs to hang where. If the load isn't too heavy and you're not fussy, you may be fortunate enough to be able to hang in straight drops. Figure 15 shows a portion of a such a hanging system. Although the example shown is a portable sound system, the principals involved are identical for fixed installations with the substitution of a one-leg sling for the chain hoist. We will examine the rigging hardware system, beginning at the top.

The I-beam is shown wrapped with a SpanSet used as a basket sling. The corners of the beam are padded with softeners (burlap) to ease the tension of the outside fibers of the sling. We have chosen a sling that is of sufficient length to yield a 68 degree sling load angle, which gives us a load angle efficiency of better than 90%. Since our sling has a rated capacity of 7900 pounds at an assumed 5:1 design factor, the sling will have a rated capacity of 7900 pounds x 2 (basket sling) x 90% (the load angle efficiency), or 14,200 pounds.

An alternative sling is wire rope. Wire rope is preferred in some venues and by certain riggers and fire marshalls due to its ability to withstand greater heat than a polyester sling before failure in the event of fire. When using wire rope around a beam, however, the bend radius often equals the diameter of the wire rope. This results in a efficiency rating of 50%—the strength of the basket (both legs) would be virtually the same as that of a single wire rope. <u>Wire rope beam-wraps need to be padded carefully.</u>

The two ends of the sling are then coupled with a 1/2" 6 x 19 wire rope sling assembly using a 5/8" screw-pin shackle having a working load limit (rated capacity) of 6500 pounds at an assumed 5:1 design factor.

Important: Carefully adjust shackles and slings to assure that the load is carried by the end and the pin of the shackle. Do not allow the shackle to be turned so as to load the sides, as the shackle will be weakened considerably.

The wire rope has a rated capacity of 4600 pounds at the same 5:1 design factor. This sling section may be omitted in venues with low enough ceilings for the chain hoists to bring the loudspeakers to trim.

The chain hoist hook connects directly to the wire rope sling eye. Chain hoists come in a variety of capacity ratings and climbing speeds. Because we need to hang in many different locations, we have no desire to lift the

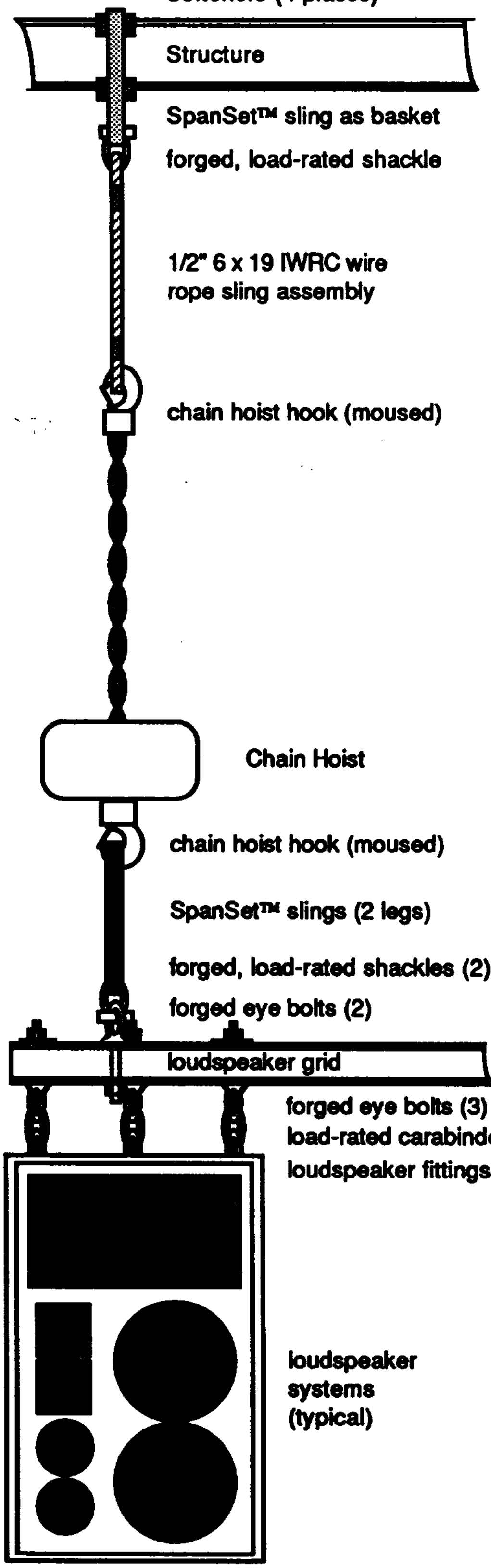


Figure 15. Typical Rigging Chain

chain hoists into position each time by hand. Rocky Paulson of Stage Rigging modified the CM hoists to operate upside-down and climb the chain. We choose a brace of Rocky's 1-ton hoists. The rated capacity of the hoist is for lifting purposes and includes a generous design factor. The CM hoists also include a clutch which will slip if the hoist is overloaded. Both hoist hooks should be equipped with working safety latches, or be safety-wired (moused) closed to prevent the slings from slipping out of the hook before commencing a lift.

Below the chain hoist, the loudspeaker grid is carried by a two-leg SpanSet sling assembly to support the grid front and back.

Important: Do not use a single sling to support a load carried on two points—the sling could slip in the hook.

Assuming a 45 degree load angle for each sling leg, the load angle efficiency is 70%. Each sling leg has a rated capacity of 5280 pounds, therefore the sling capacity becomes 7390 pounds, or 3695 pounds per leg.

The sling attaches to forged carbon steel 3/4" shoulder eye bolts using 5/8" shackles, described previously. Each eye bolt is limited to a rated capacity (tension) of 1300 pounds at a 45 degree pull angle. This tension will be realized when each eye bolt is loaded to 900 pounds because of the 70% load angle efficiency. Clearly, the eye bolt is the weakest link in this rigging chain.

Our loudspeaker grid design has been certified by a licensed structural engineer and welded by certified craftsmen. Each loudspeaker hangs from three points using 1/2" shoulder eye bolts and load-rated carabinders. The eye bolts are the weaker element, having a rated capacity of 2200 pounds for a straight pull. We have chosen Concert Series loudspeaker systems, which incorporate three top attachment points, each of which has a rated capacity of 1000 pounds at an assumed design factor of 5:1.

Knowing the number and weights of the loudspeakers and the grid, the tension on each part of the two-leg sling can be calculated. Assuming a total weight of 1250 pounds, each leg of the sling must carry 625 pounds. Given the load angle efficiency of 70%, each sling, shackle and eye bolt will be tensioned to 884 pounds—well within the 1300 pound rated capacity of the eye bolts.

Rules for Safe Lifting:

1. Do not overload any piece of equipment.

2. Sling the material to be lifted properly. Do not allow

slings to be placed against sharp objects or rough or cutting surfaces.

3. Always align lifting equipment over the center of gravity to enable a straight vertical lift. Never attach a hoist or lifting line to the load at an angle.

4. Always use properly-installed load-rated hardware and fittings. Double-check all connections before lifting.

5. Carefully inspect all lifting equipment—everything in the rigging chain—before making a lift. Replace any worn or defective equipment.

6. Never lift or support overhead loads from an open hook. Always use safety hooks, latches or other devices when material is being hoisted overhead.

7. Use Tag Lines to control any load which may become unmanageable during lifting.

Conclusion:

Safe sound system rigging is the application of known and simple engineering principles along with a healthy dose of common-sense and know-how to a relatively uncomplicated set of problems. There are no viable shortcuts in rigging equipment, tools and techniques—the potential losses resulting from property damage and personal injury following the failure of second-rate hardware or faulty rigging practices can be staggering. Safe sound system rigging is no accident.

Glossary of Rigging Terms:

BACK-STAY Guy used to support a boom or mast. Also, that section of a main cable, as on a suspension bridge, etc., leading from the tower to the anchorage.

BASKET HITCH A U-shaped two-leg hitch formed from a single sling.

BENDING STRESS Stress imposed on the wires of a strand or rope by a bending or curving action.

BIGHT The bend of a line, rope or cable.

BREAKING STRENGTH The ultimate load at which a tensile failure occurs in the device being tested. This is synonymous with actual strength.

CABLE A term loosely applied to wire rope, wire strand and electrical conductors.

CENTER OF GRAVITY The point through which a load will hang from any attachment point.

CHOKER A short sling that forms a slip noose around an object that is to be moved or lifted.

CLEVIS See SHACKLE

COME ALONG Device for temporarily holding or pulling loads on rope, chain or wire rope.

DEFLECTION a) The sag of a rope in a span, usually measured at center span. b) Any deviation from a straight line.

DESIGN FACTOR The ratio of the nominal strength to the total working load.

EFFICIENCY Ratio of the nominal strength of a modified rope or wire rope to the nominal strength of an unmodified rope or wire rope—usually expressed as a percentage.

EYE BOLT A machine bolt incorporating a circular fitting at the end for attachment purposes.

EYE, OR EYE SPLICE A loop, with or without a thimble, formed at the end of a wire rope.

FC (Fiber Core) Cord or rope of synthetic or vegetable fiber used as the axial member of a wire rope.

FITTING Any functional accessory attached to a cable, rope or sling.

FLAG Marker placed on a rope so as to locate the load position.

GUY LINE A strand or rope used for stabilizing or maintaining a structure or lifting load in a fixed or predetermined poisition.

HITCH A rope knot that unties readily that is used for temporary fastening.

IWRC (Independent Wire Rope Core) A wire rope used as the axial core of a larger wire rope.

KINK A deformation of a wire rope caused by a loop being pulled tight. It constitutes irreparable damage to and an indeterminate loss of strength in the rope.

KNOT EFFICIENCY Ratio of nominal strength of a knotted rope to the nominal strength of a unmodified rope—usually expressed as a percentage.

LOAD ANGLE Angle between the load (horizontal surface) and the sling.

LOAD ANGLE EFFICIENCY The sine of the load angle defines Load Angle Efficiency, e.g., a 30 degree sling angle will have a load angle efficiency of 50%. The tension on each leg of the sling increases according to the reciprocal of the sine of the load angle.

MOUSING Wiring the throat of a hook to prevent a choker from jumping out of the hook.

RATED CAPACITY The load which a new rope, new wire rope, sling or fitting may handle under given operating conditions and at an assumed DESIGN FACTOR.

SAFETY FACTOR See DESIGN FACTOR

SAFE WORK LOAD Refers to that portion of the nominal strength of ropes, slings, chains and fittings that can be applied either to move or sustain a load. The term can be misleading, however, as it is valid only for new wire ropes and equipment in "as-new" condition. See RATED CAPACITY.

SHACKLE A U- or anchor-shaped fitting with a pin.

SHOCK LOADING A sudden movement or jerking of a load, such that the forces upon the hardware system are magnified over those imposed by the static load.

SLING An assembly that connects the load to the lifting device.

SOFTENERS Anything that is used to protect the load or cable, also rope and slings, from damage while making a lift, or hanging from a beam. Also used to prevent a load from slipping.

SPANSET Trade name for polyester slings widely used in sound and lighting rigging work.

STRESS The force or resistance within any solid body against alteration of form; in the case of solid wire it would be the load on the rope divided by the cross-section area of the wire.

SWAGED FITTING Fitting into which wire rope can be inserted and then permanently attached by cold pressing (swaging) the shank that encloses the rope.

THIMBLE Grooved metal fitting to protect the eye, or fastening loop of a wire rope.

WEDGE SOCKET Wire rope fitting wherein the rope end is secured by a wedge.

WSC (Wire Strand Core) A wire strand used as the axial member of a wire rope.

References:

Committee of Wire Rope Producers, American Iron and Steel Institute "Wire Rope Users Manual" (Committee of Wire Rope Producers, 1000 16th Street, N.W., Washington, D.C. 20036, 1985).

Crosby Application Instructions for Crosby Clips (The Crosby Group, P.O. Box 3128, Tulsa, OK 74101, 1985).

Crosby General Catalog (The Crosby Group, P.O. Box 3128, Tulsa, OK 74101, 1986).

Newberry, W. G., "Handbook for Riggers", Revised Edition, (Newberry Investments, P.O. Box 2999, Calgary, Alberta, Canada, 1977).

Paulson, Rocky, personal communications with the author (Rocky Paulson, Stage Rigging, Inc., P.O.Box 95, San Carlos, CA 94070).

Southern California Edison Occupational Safety and Health Division, "Rigging Standards Manual" (Los Angeles, CA 1982).

SpanSet publication "Safe Lifting" (West Coast Wire Rope & Rigging Co., Inc., 597 85th Avenue, Oakland, CA 94621).

Stage Rigging, Inc., "Products and Services Catalog" (Stage Rigging, Inc., P.O.Box 95, San Carlos, CA 94070).

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8500 Balboa Boulevard, P.O. Box 2200
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