Stability of Lighting Towers

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Lighting instruments frequently need to be positioned where architectural fittings are not provided. An instrument or group of instruments (such as side lighting for dance) must be positioned vertically in the wings away from walls, must occupy as little floor space as possible, and must remain stable at any required height.

Light Towers as Levers

Free standing lighting trees might be thought of as levers. A lever is defined as a rigid member which is free to turn about a pivot point called a fulcrum. The rigid member is measured to gain either force or distance for a specific mechanical utility. An effort or weight is applied to one end of the rigid pole and a corresponding effort called "resistance" appears on the other side of the fulcrum. The effort and resistance must balance if the system is to remain static.

Figure 1 illustrates a first class lever. The mechanical advantage (MA) is computed by dividing the effort distance by the resistance distance as measured from the fulcrum (F). This represents the mechanical translation of distance into force available to do work.

Figure 2 illustrates second and third class levers. In the second class lever system, the resistance is placed between the effort and the fulcrum. The third class lever finds the effort between the resistance and the fulcrum. The distance from the fulcrum to the load (resistance) and the fulcrum to the effort (force) is appropriately divided to find a mechanical advantage. This MA can represent any size lever, as it is only the ratio which determines the gain in movement or force.

Lighting towers are not designed to do work in the active sense. Instead, they passively hold weights over the floor at a static distance and therefore represent equilibrium. Because the instruments have weight, the pole holding them up has distance, and the base attachment represents both pivot and resistance, the elements of leverage are present and the tower can be studied as a leverage system.

If the light tower is attached through the floor by means of a socket, it could be a first class lever with the surface of the floor representing the fulcrum and the area below the floor the resistance (see Figure 3). In theatres, however, rigid vertical construction must be limited to the surface and above.

A light tree is drawn in Figure 4. The base is usually a weighted iron casting threaded to accept a 1 1/4" to 2" iron pipe. The larger diameter pipe, of course, is more rigid. The iron pipe is the lever arm for the effort or payload of the system.

If the vertical pipe is the lever arm for the effort, the diameter of the base must be the lever arm for the resistance. This makes one edge of the base the fulcrum or the point around which the system forces would revolve when the

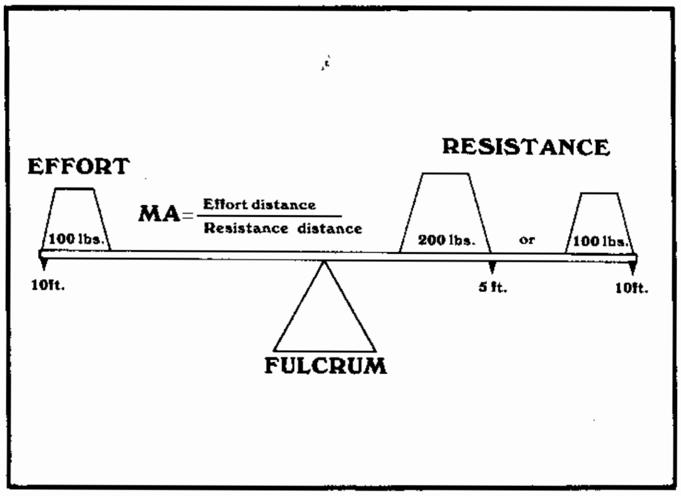

Figure 1. The First Class Lever.

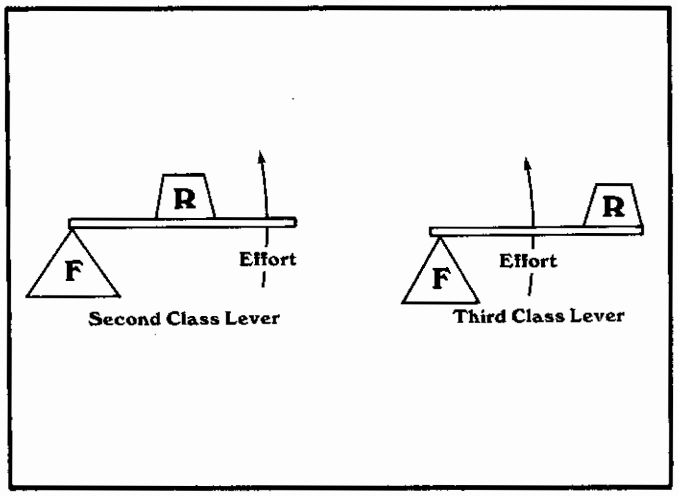

Figure 2. Second and Third Class Levers.

unit is put in motion. The mechanical advantage of the light tree can be figured by dividing the height at which the instruments are attached to the pipe by the base diameter.

This erroneously assumes that the resistance weight of the base (R), centers on the edge of the base opposite from the fulcrum. More often the greater concentration of base weight is centered around the pipe socket in the center of the base. This means that the base has an effective R distance closer to the radius, or 12" on the commercial bell bases measured for this consideration.

Assembly

Figure 4 indicates that 20 lbs. of instrument at 10' has an MA of five. Therefore, 100 lbs. are needed to stabilize the tree. If the 12" R Value is used, the MA doubles for instruments. A 200 lb. base weight is then needed to stablize the 20 lbs. of instrument load at ten feet.

Hanging lights lower on the pipe tower will therefore provide a more stable assembly. The design may call for lights to be hung at a much higher level, however. This article will assist the lighting technician in making the taller tower safe rather than inhibiting the design.

If the base of the light tree could be extended, then the resistance would gain mechanical advantage rather than the "load." There are very distinct limits to this as the tree base must be as narrow as possible, so as to interrupt as little floor space as possible. For dance, light bases are a hazard to the feet of the performer, and shows with shifting wagons will be hung up on the bases. Figure 5 pictures a light tree found at Canada College in Redwood City, California, which consumes rather narrow wing space while being reinforced in the onstage direction by additional base depth.

Light towers are structured in many different ways representing the physical possibilities of various theatre forms. If the theatre is a strict narrow angle procenium with limited sight lines and deep stage space, the wings might be very wide and the light trees able to occupy considerable space. Instruments might then be side-armed off either side of the central pole. The instruments are balanced so that lateral stability is assured: the tree is as stable front to back as it is side to side. Figure 6 represents the light tower with balanced loading.

Often, however, the wings are narrow and the instruments are hung with the yoke directly behind the instrument. The tree

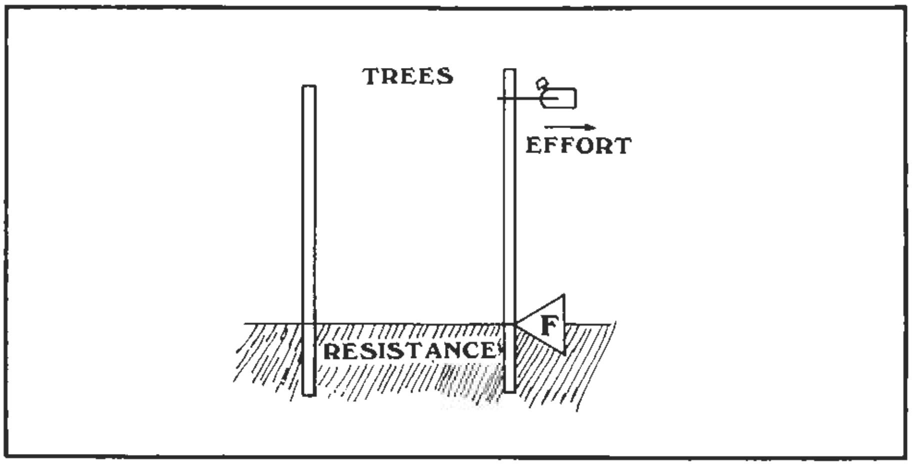

Figure 3. A lighting tower as a First Class Lever would need to attach through the surface of the floor.

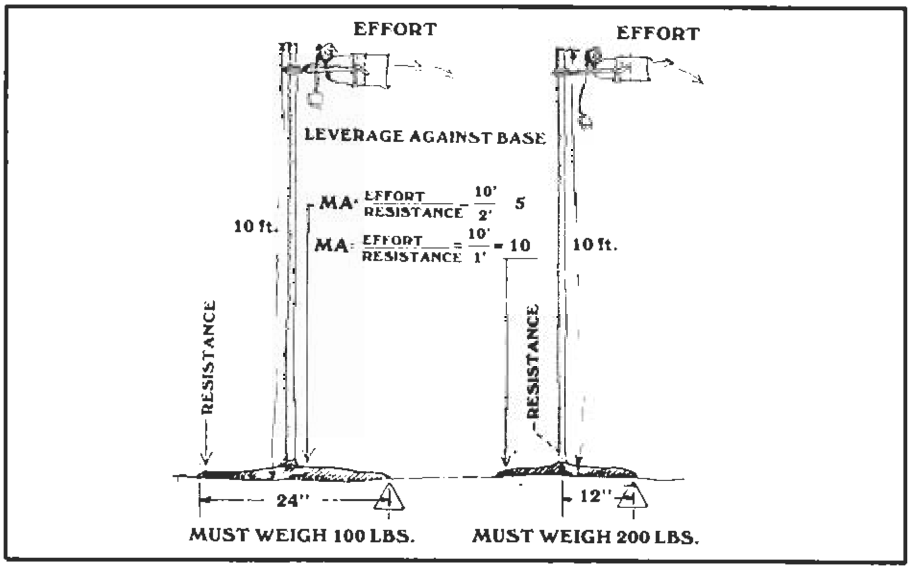

Figure 4. The Independent light tower is a Second Class Lever.

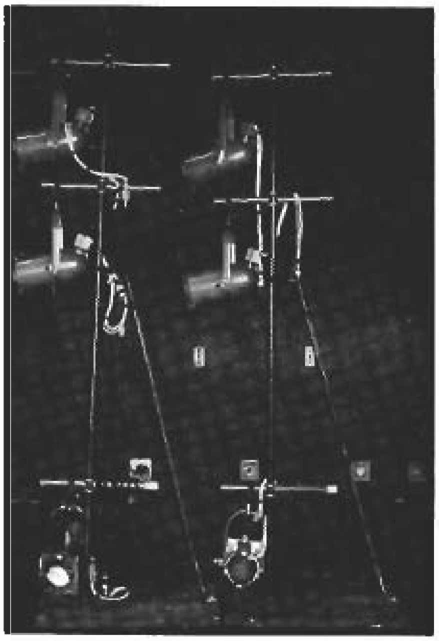

Figure 5. Reinforced light towers designed for asymmetrical loading.

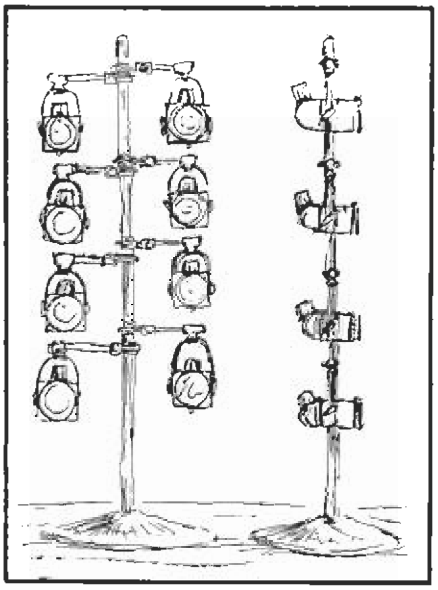

Figure 6. Symmetrically loaded lighting towers. Two opposite loaded sides balance each other while two unloaded sides also balance each other.

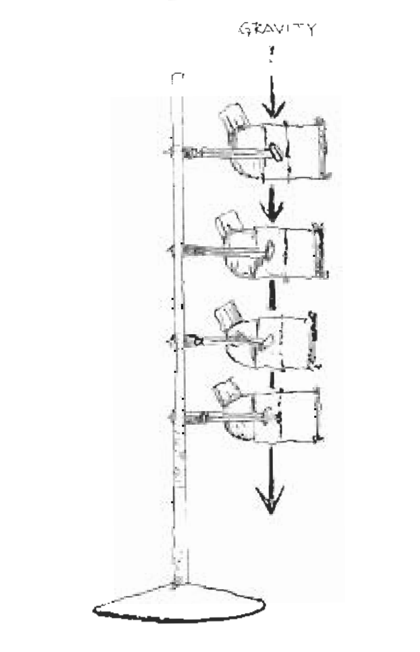

Figure 7. Instrument load falls outside the bell base radius when the tree is asymmetrically loaded.

then only uses 8 or 10 inches of wing depth. This also means that the tree is heavy on the onstage side of the support pipe (Figure 7).

Instruments weigh anywhere from 10 to 30 lbs. This weight is downward force. When the instrument is hung away from the pole, the weight pulls away from the pole. This translates into a portion of the weight going straight down with gravity and a smaller vector force pulling away from the support pole. This vector pull is increased as the instrument physically moves away from the pole. This means that a consideration of center of gravity might also help understand the lighting tower's stability.

Study of Gravity

The center of gravity is a theoretical point in any object at which its weight may be located for balance purposes. When the lighting instruments are attached to the pole from one side with their yokes behind them, most of the weight is at a point about 14" to 18" from the pole. This places the center of gravity over the very rim of the base or even beyond the base edge.

> If the position of a body in stable equilibrium is slightly altered, the body tends to return to its original position. A body in stable equilibrium cannot be overturned unless its center of gravity is first raised.

The quoted source, *Modern Physics* by Metcalfe, Williams, and Dull (Holt, Rinehart & Winston, 1964), uses the example of two bricks. One brick is lying on its side and when raised, its center of gravity raises from A to B (Figure 8). When the brick is lowered to a lying position, the center of gravity must slightly raise over its C position to be lowered to D. The energy required to raise the brick's center of gravity from A to B is much larger than the slight energy required to raise the brick's center of gravity above C. This helps prove that the brick is more stable on its lowered position with the enlarged base area and the lowered center of gravity. For lighting towers this parallels the tipping over of the loaded tree. In order for the tree to fall, the area of the base requires a slight lifting of the tree as the unit rolls over. This slight lifting helps keep the tower upright.

Lighting Tower Bases

The heavier the base, the more stable the light tower. Also, when more of the base weight occurs further from the center and nearer the rim of the base, the weight can assert more leverage. The better bases are those cut from 1/4" or 3/8" flat boiler plate steel with a pipe fitting welded onto the top center of the base.

Using a flat steel plate allows placing extra stage weights on top of the base when additional stability is needed for extra tall trees with many units very high on the pole (Figure 9).

A common flat base variation uses 3/4" plywood with a pipe flange bolted to the center. These are used as a pedestal for local weight and serve to make a very expensive large area base. It should be firmly noted that there is considerable stress at the point where the pole attaches to the base plate.

Plywood may not be able to withstand the point shear, and sufficient weight could pull bolts right through the plywood. With a load of 50 lbs. at an average of 6 feet above the floor, the load on one bolt might be 50 x 6 (300 lbs). This might be within the longitudinal capacity of the bolt, but not within the point shear strength of the plywood especially if the plywood has open checks in the interplys. The plywood also has sufficient flexibility to allow an asymmetrically loaded pole to sag sideways. This deflection might be enough to allow the center of gravity to move off center pulling the tree over quite easily.

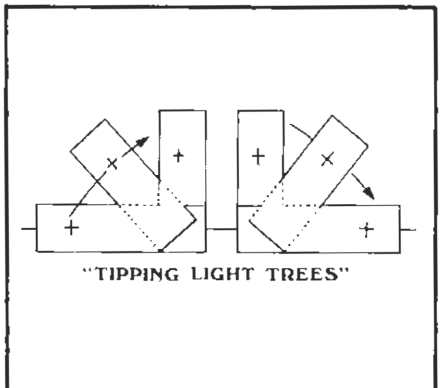

Figure 8.

Stability

Once the instrument load is attached and the usually almost equal cable load is also attached, the stability of the light tower is critical. If possible, attach a pipe cap with forged eye bolt or drill the pipe or tube tower so that a safety line can be attached and spot-lined somewhere immediately above the tower. This will catch the tower in the event that it gets bumped or otherwise starts to fall.

Dependent lighting towers are desirable wherever possible. If the necessary vertical light pipe can be placed near some solid attachment such as a wall and still have open sight lines to the stage allowing the light to accomplish its task, the tower will be more secure, and the cables will probably also be able to run to circuiting free of the floor.

Use the same 1 1/2" or 2" black pipe found onstage as towers or pipe battons. Selecting pipe and pipe fittings, the shape necessary for the architectural site can be fashioned, and pipe flanges can be attached to the ends of the pipe. The pipe flange is then bolted to the vertical surface either with lag screws or machine bolts.

Whether the above procedure is used, or cut and welding square tube or other technology is selected, the principles are

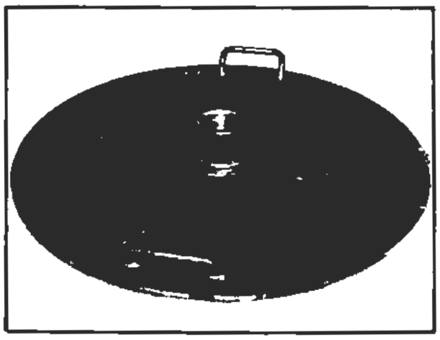

Figure 9. Boiler plate flat steel base for light trees. Base courtesy Musson Theatrical, Los Gatos, Calif.