Building a 30’ Tall Four-Legged Signal Tower

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Description: A signal tower is a fun project that appeals to Scouts’ natural inclination toward building big and climbing. A signal tower of any size is an involved project, and Scouts attempting one will have to work together as a team. Building the tower involves pre-planning and careful measurement. Larger towers (15’ and up) will also require you to handle heavy subassemblies and undertake some clever rigging.

Any tower tall enough to be worth building is also tall enough to present safety concerns during construction and use. We build towers to completion while they are laying on their sides so that Scouts do not have to work at dangerous heights and then rig and erect them as a complete unit. (Erecting towers is treated in a separate document.) You need to take steps to minimize the fall risk for people climbing the completed tower. On tall towers this may require an integrated fall protection system.

We built the 30’ tower shown in these photos in August 2014 at the Backwoods Engineering Camp at Mount Allamuchy Scout Reservation, Byram, NJ. Since 2015, we have started building our largest signal towers with only three legs. A three legged design is lighter and uses less material than one with four legs, but is harder to properly align during construction.

Design Considerations

Safety: A tall tower presents a serious fall risk during its construction and use. You can eliminate much of the construction hazard by building the tower to completion on its side, though this creates its own safety concerns when you have to erect the completed tower. You will need to move and lift heavy subassemblies while constructing the tower. Make sure that you have enough manpower to move the parts of the tower that you are building. Have a single responsible leader in control whenever moving heavy assemblies, and make all your moves slowly and deliberately. The job of the leader is obviously an important one and is fraught with responsibility. Ultimate responsibility for the group's safety rests in the leader's hands. You need to establish a safe procedure for folks climbing the tower after it is erected. For large towers this will likely include an integrated fall protection system. Only one person should climb the tower at a time.

Materials: Exact sizes and quantities of material will depend on the height of your tower. You will need four long and sturdy spars for the legs of your tower. If you do not have long enough spars, you can splice two shorter ones together with wedged round lashings. Overlap the spars at least 1/3 of their length. We have done this successfully on lightly built towers up to 23'high, but do not recommend spliced uprights for tall or heavily built towers. Make sure that your materials list contains materials for the temporary staging and rigging that you will need to construct and erect the tower.

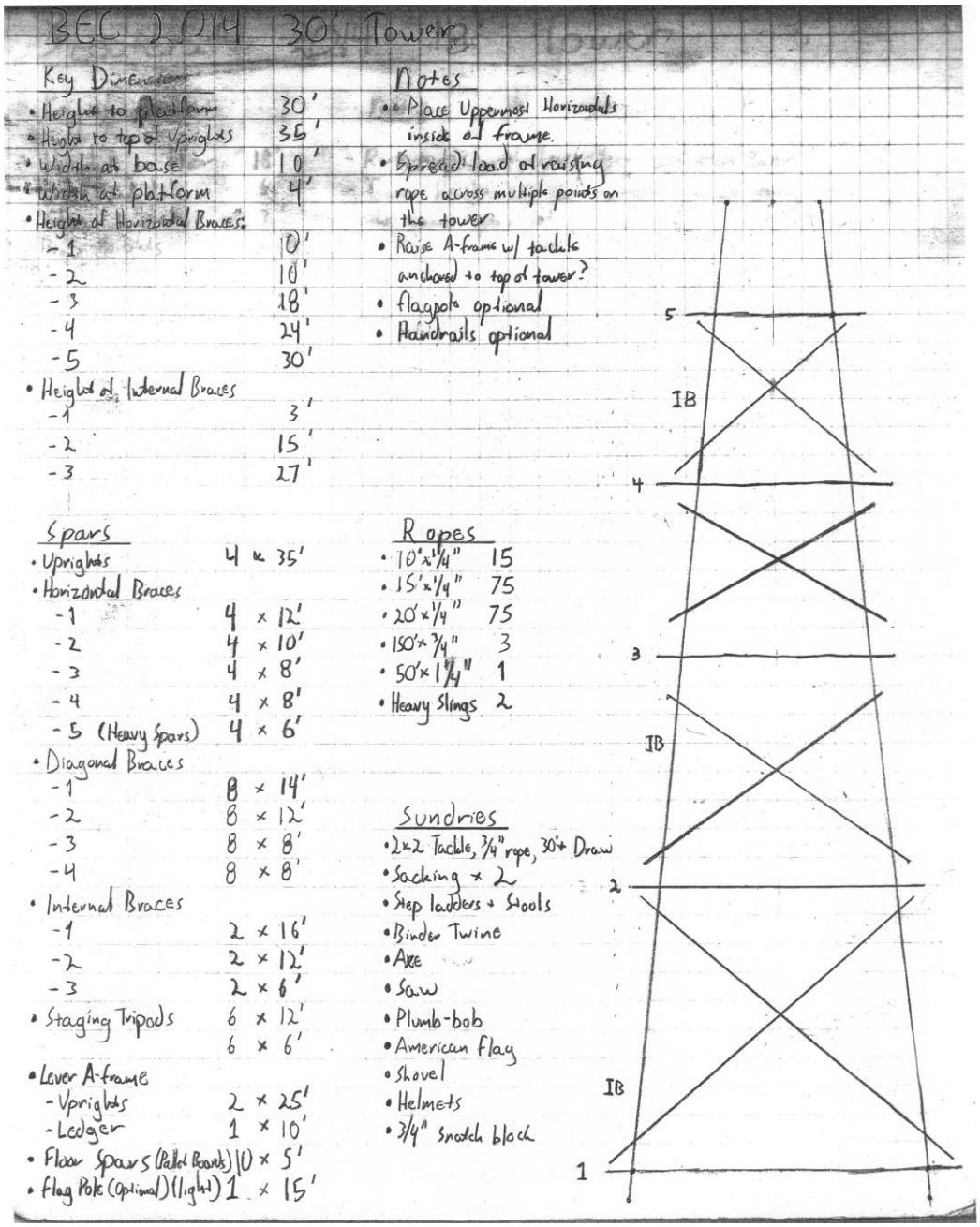
Site Selection and Anchors: Towers look best when built on flat clear sites on high ground or adjacent to lakes/ponds. If your tower is tall/heavy enough that you need to raise it with a block and tackle you will also need to consider the anchorages available at your site. Natural anchors are best.

Manpower: You need a large crew to build a large tower because of the number of lashings to tie, the weight of the subassemblies that must be moved during construction, and the forces required to erect the completed tower. The tower shown here was built by a group of twenty six Scouts working intermittently over several days. Smaller groups can successfully build smaller towers in shorter times, but even a 12' tower needs a group of eight or so Scouts to build and raise. A 20' tower is an achievable one day project for an average size Scout troop.

Proportions: A tower that tapers from a wide base to a narrow top has a lower center of mass, and thus more inherent stability, than a straight sided tower. A well built signal tower with tapered sides should not require any guy lines to help support it, while the straight sided towers we have seen are always guyed. Additionally, a tapered tower is more forgiving of any alignment errors during construction that would cause it to be lopsided when you stand it up. Any tower, even a tapered one, will lack stability if its base is too narrow relative to its height. We try to make the bases of our towers at least ⅓ as wide as the tower's height, 10' wide in this case. The top of the tower only needs to be large enough to hold one person. We build them about 3'x3'.

Plans

A 30’ tower is a complex project and requires a fairly detailed construction plan. We determine the tower’s key dimensions and then draw it to scale on graph paper. We take spar lengths off of the drawing to create a materials list. Drawing to scale also allows you to discover any interference issues between spars and to work out a construction sequence. Since this tower is built on its side and then erected, the materials list also includes rope, spars, and gear for temporary staging to support the incomplete tower and the rigging necessary to erect it.



BEC 2014 30' Tower

Key Dimensions

- Height to platform 30'
- Height to top of Uprights 35'
- Width at base 10'
- Width at platform 4'
- Height of Horizontal Braces:
  - -1 0'
  - -2 10'
  - -3 18'
  - -4 24'
  - -5 30'
- Height of Internal Braces
  - -1 3'
  - -2 15'
  - -3 27'

Notes

- Place Uppermost Horizontals inside of frame.
- Spread load of raising rope across multiple points on the tower
- Raise A-frame w/ tackle anchored to top of tower?
- flagpole optional
- Handrails optional

Spars

- Uprights 4 x 35'
- Horizontal Braces
  - -1 4 x 12'
  - -2 4 x 10'
  - -3 4 x 8'
  - -4 4 x 8'
  - -5 (Heavy Spars) 4 x 6'
- Diagonal Braces
  - -1 8 x 14'
  - -2 8 x 12'
  - -3 8 x 8'
  - -4 8 x 8'
- Internal Braces
  - -1 2 x 16'
  - -2 2 x 12'
  - -3 2 x 6'
- Staging Tripods 6 x 12'
  6 x 6'
- Lever A-frame
  - -Uprights 2 x 25'
  - -Ledger 1 x 10'
- Floor Spars (Pallet Boards) 10 x 5'
- Flag Pole (optional) (light) 1 x 15'

Ropes

- 10'x1/4" 15
- 15'x1/4" 75
- 20'x1/4" 75
- 150'x3/4" 3
- 50'x1 1/4" 1
- Heavy Slings 2

Sundries

- 2x2 Tackle, 3/4" rope, 30+ Draw
- Sacking x 2
- Step ladders + Stools
- Binder Twine
- Axe
- Saw
- Plumb-bob
- American Flag
- Shovel
- Helmets
- 3/4" snatch block

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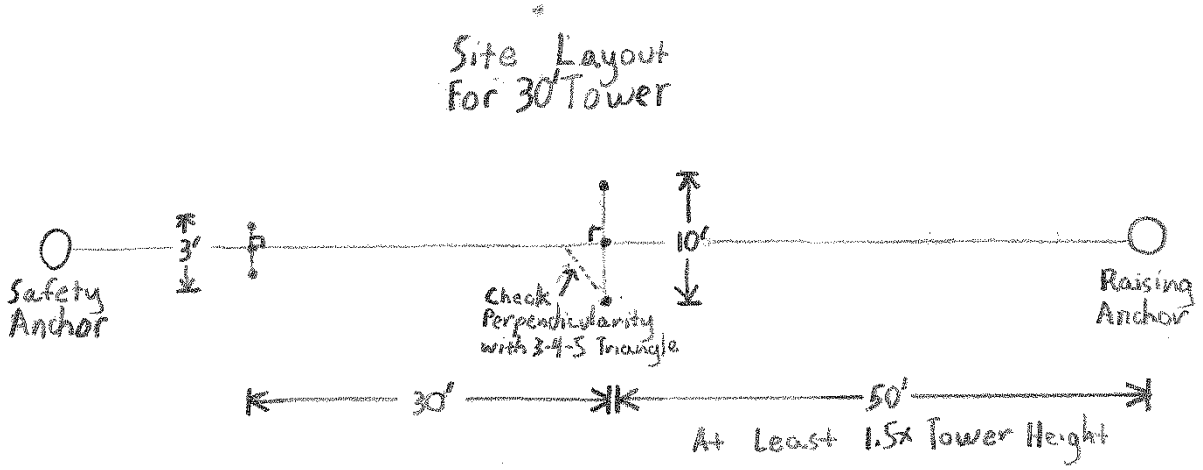
Site Preparation and Layout

Once you have chosen where you will build your tower, you need to find or site any necessary anchors and drive stakes to establish the layout for the first side of your tower. For this type of tower you will need two anchor points, one where you will anchor the block and tackle that you use to raise the completed tower, and another directly opposite it where you will attach a safety line. During construction, the centerline of the tower must lie along the straight line connecting your anchors.

Stretch a taut piece of rope or twine between your anchor points. This rope marks the centerline of the tower. Then determine where the base of the tower will lie while you are building it and drive a stake on the centerline. Drive another stake on the centerline at the top of your tower. Measure outwards from these marks to determine exactly where the top and bottom of the tower's upright spars will lie while you are building the tower and drive stakes there as well.[1]

Make sure that the tower's base is at least 1.5 tower heights, preferably more, away from the main anchor or else you will have trouble erecting it if using a block and tackle. The distance from the top of the tower to the safety line anchor is not critical.



[1] It is important that the stakes defining the top and bottom of the tower's legs are perpendicular to the centerline. Otherwise the tower will stand lopsided when you raise it. You can check for perpendicularity by laying out a 3-4-5 right triangle using portions of the tower's centerline and the line from the centerline to the stake as the legs of the triangle.

Laying Out and Lashing the First Side of the Tower

Now you can assemble the first side of the tower. First, lay out two of the 35' legs for the tower so that they are aligned to the pegs that you drove previously[2]. Support the legs a few inches above the ground with wooden blocks or pieces of firewood. This will make it easy to pass your ropes under the legs when you are lashing on the horizontal and diagonal braces.

Lay the horizontal and diagonal braces on top of the legs according to your drawing, and lash them to the tower's legs. Note that when you are lashing in the horizontal and diagonal braces on the first two tower sides you will need to make sure that any excess length in the braces is offset to one side of the tower. If you do not do this, you will not be able to correctly lift and align the tower sides later on.

Use square lashings for all connections between the tower legs and braces, and use diagonal lashings where the diagonal braces cross each other. We use ¼" manila rope to tie the lashings. Because the tower's legs are much thicker at their bottoms than at their tops, you will need to use several different lengths of rope to tie these lashings. On this tower most of the lashings in the top half used 15' ropes, and most of the lashings in the bottom half used 20' ropes. We also needed a few 30' ropes for the bottommost lashings. When you are pulling your lashings tight, be careful that you do not accidentally pull the tower legs out of alignment with the stakes.

[2] All of the tower's weight passes to the ground through its four legs, so you need to select these spars carefully. For this tower we used 35' maple spars that were free of rot and other damage/defects. The spars have a butt diameter of 5" or 6", and a minimum diameter of 3" or greater. The 35' spars that we used in these photographs were still green, but, if you can, you should strip the bark from the spars and allow them to dry for several months before using them. Green spars are slightly more flexible than seasoned ones, but are much heavier. The water in just these four spars added several hundred pounds of weight to the completed tower.

Laying Out and Lashing the Second Side of the Tower

After you have finished the first side of the tower, use it as a template to lay out the second side of the tower. Lay your 35’ tower legs directly over the legs of the first side, and then lay out and lash your horizontal and diagonal braces exactly as before. Once again, make sure that any excess length in the braces is offset to one side of the tower. Excess brace length on the second tower side should be offset in the opposite direction as the excess length on the first tower side. The need for this will become apparent when you stand up and align the two tower sides. Also, be careful that you do not pull the second side’s legs out of alignment while you are lashing the braces to them. After you have finished the second tower side, carefully lift it up and carry it to the side.

If you are careful, at the end of this process you will have two dimensionally identical tower sides, even if you made small errors when you laid out and assembled the first tower side. Since the stability and appearance of the completed tower depend more on symmetry than they do on perfectly hitting the dimensions in your design, it is better to wind up with two dimensionally identical tower sides, even if they both differ slightly (i.e. everything is within 1’ or so of the plan) from your design drawing.

Preparing to Lift and Align the First Two Tower Sides

Now that you have completed the first two sides of the tower you need to stand both of them on their sides, temporarily support them with tripods, align them to the centerline between your anchors, and align them to the correct taper. The picture below shows what the tower will look like when you have completed this step. After doing this, you will then be able to lash in the horizontal and diagonal braces that will form the tower's last two sides.

You need to take special care during this stage of construction because of the potential for injury when lifting the heavy tower sides, and because the alignments that you make in this step will be critical to the stability of the completed tower. Before beginning take the following preparatory steps:

1. Double check the position of the layout stakes and centerline rope to make sure that they haven't shifted during construction.
2. Build four staging tripods that will temporarily hold the tower sides upright at their tops and bottoms while you are lashing in the remaining braces. We used 12' spars for the two large tripods at the bottom of the tower and 6' spars for the two small tripods at the top of the tower.
3. Make sure that you have a plumb line and memory rope or tape measure. You will need these to set the taper of two sides.
4. Check that all participants have work gloves and sturdy footwear and check the area for tripping hazards. The adult leader in charge should conduct a safety briefing before beginning the lift (see next page for details).

Lifting and Supporting the Tower Sides

Now each tower side must be stood on its side and supported with the staging tripods. This is the most dangerous step in building and erecting the tower and requires the care and deliberation of everyone involved.[3] This job must be done under the direction of an experienced adult leader. The job of the leader is an important one, and it is fraught with responsibility. Ultimate responsibility for the group's safety rests in the leader's hands. Before beginning to lift, the leader needs to conduct a safety briefing that:

1. Reviews general safety procedures including PPE, escape routes, and lifting with the legs rather than the back.
2. Explains the chain of command. The leader will have absolute charge of the group and his instructions must be followed exactly. Once the lift begins, Scouts need to remain quiet to hear the leader's instructions and should only speak up to voice safety concerns.
3. Assigns and explains jobs. The leader will direct from the side. Three to five Scouts will put the staging tripods in place. The remaining Scouts will lift and hold the tower side.
4. Reminds Scouts that when lifting heavy loads all movements should be slow and deliberate so as to minimize inertia.
5. Addresses any questions or concerns that Scouts might have.

Lift the tower sides one at a time and align them roughly with the layout stakes. Support them with the staging tripods and brace the legs of the tripods with rope so that the legs cannot kick out. Note in the photo that we lashed the bracing spars for this tower side in place so that any excess length points upward when it is stood up. This is necessary so that the tower will bear evenly on the ground and so that you can accurately set the tower's taper.

[3] The tower sides shown in these photographs weigh an estimated 700lbs each, and the Scouts are lifting them directly from within the fall zone. This is heavier than normal because of the tower's size and our use of green spars for legs, but smaller/lighter assemblies are also potentially dangerous.

Aligning the Tower Sides

After you lift and support the two tower sides, you need to align them with each other and with the centerline between the anchors so that the completed tower will be symmetrical, stable, and easy to erect. Adjusting the tower sides for alignment involves similar risks as in standing up the sides, so use the same processes and safety procedures that you used before. There are four alignments[4] that you need to check:

1. Each tower side needs to be plumb (Standing vertically). Check this by dropping a plumb line from the upper leg and aligning so that it hangs directly above the lower leg. The tower sides twist easily, so you need to check and adjust for plumb at the top and bottom of each tower side.
2. The butts of the tower's legs need to be the same distance from the raising anchor, and/or the line between them needs to be perpendicular to the tower's centerline. If not, the tower will lean when erected. If the layout stakes are properly positioned, you can place the butt of each leg against the corresponding stake to attain this alignment.
3. The tower needs to taper evenly from top to bottom. The taper should be the same on all four sides of the tower. If you built both tower sides carefully you can use the layout stakes to make this alignment. If you deviated slightly from the stakes, then use a memory rope[5] or tape measure to set the taper so it aligns with what you built.
4. The centerline of the tower needs to fall on the centerline between your raising anchor and safety anchor. This will make the tower easier to erect once it is complete. This alignment should not be a problem unless you've bungled your layout badly. This alignment is the least important of the four, and you can be off by a couple feet without major problems.

[4] On a four sided tower you can adjust these alignments more or less independently of each other. A similar tower built with three sides requires much less material, weight, and work to complete, but on a three sided tower adjusting one of these alignments affects the others, which makes aligning the tower much more difficult.

[5] In this sort of work symmetry and consistency between the four sides of the tower are more important than absolute conformity to the dimensions and proportions on your construction drawing, and you can deviate from them 1' or so as long as you deviate equally on all four sides of the tower. As a consequence, you can build this entire tower without the use of a tape measure. Instead, use a memory rope, which is nothing more than a suitably long rope with knots or other marks along its length that record the critical measurements of your project. For a tower, these measurements are the width at its top, the width at its bottom, and its overall height.

Lashing in the Internal Braces

The tower sides, when supported solely on the tripods, are still in a somewhat precarious position. Adding diagonal bracing between the two tower sides stabilizes them significantly and also prevents the tower from racking when it is being erected. The photo below shows the internal braces on the completed tower. This tower has internal braces at its top, middle, and bottom, but a smaller tower only needs two internal braces.

Use a small group of responsible Scouts to lash in the internal braces, and be careful not to pull the tower sides out of alignment when tightening the lashings. Use square lashings to tie the braces to the tower's legs, and use diagonal lashings where the braces cross each other. For a tower this size, you will need a stepladder to lash in the braces at the bottom of the tower. Leave the staging tripods in place even after the internal braces are complete. You should not take the tripods out until immediately before you erect the tower.

Lashing in the Last Two Sides of the Tower

Now you can lash in the horizontal and diagonal braces that will form the two remaining sides of the tower. Use square lashings to attach the braces to the tower legs and use diagonal lashings to join the diagonal braces where they cross each other. On a tower this size, you will need to use a stepladder to reach some of the lashings at the tower's base.

Finishing Touches

All of the structural parts of the tower are now complete, but you may want to add some finishing touches before erecting it. These might include:

Floor: This is a necessity if you plan to climb the tower. We dismantle hardwood pallets and use their boards to make the floor. You can use spars instead, but they are slightly heavier than the pallet boards. Because weight at the ends of the tower has a disproportionate effect on the tower's center of mass, a heavier floor will make the tower marginally harder to erect. Use floor lashings, a variation on the square lashing, to install the floorboards.

Flagpole: A flagpole attached to the top of the tower adds greatly to its visual impact. Use a light spar about half the tower's height, and round lash it to one of the tower's legs. Halyards are prone to tangling on the tower's various projections, so we usually tie the flag directly to the flagpole before erecting the tower. If you intend to keep the tower standing for a long period of time (i.e. for the duration of a summer camp) it is worth the trouble to install a halyard. Take care if tying an American flag directly to the flagpole that it does not touch the ground before you erect the tower.

Handrails: If you want to install handrails at the top of the tower you should select legs for the tower that are slightly over length, and then square lash the rails to the legs where they project above the platform. You may want to leave one side of the tower without a handrail so that it is easier for climbers to get onto the top of the tower.

Safety System: If you intend to fit your tower with a fall protection system, you will need to attach it to the top of the tower before erecting the tower. Safety systems are discussed in more detail on a subsequent page.

Erecting the Tower

Rigging and erecting the completed tower is complicated, and erecting towers is discussed in detail in a separate document. To summarize briefly, we tied a 1¼" rope to the top of the tower and ran it over a pair of 25' high shear legs that we stood up vertically at the base of the tower. We attached a block and tackle of 6" blocks and ¾' rope that gave a mechanical advantage of 5x to the end of the 1¼" rope and tied the other end of the tackle to the raising anchor. We ran the fall line of the tackle through a snatch block to a safe location for Scouts to pull on it. We tied a ¾" safety line to the top of the tower and took a roundturn around the safety anchor. When the Scouts pulled on the tackle, the rope running over the shear legs applied a vertical force to the top of the tower and began to lift it off of the ground. The shear legs pivoted with the tower as it rose off of the ground. When the tower reached an angle of about 45° the shear legs no longer applied any upward force to the raising rope, which is held to the shear legs by friction alone, so at this point the legs fell away. Once the tower was almost upright it wanted to fall into position by its own weight. The four Scouts manning the safety line slowly slacked it off to lower the tower into position. We maintained good alignments throughout construction, so the tower stood straight, all four legs bore evenly on the ground, and it required no guy lines.

Because this tower was tall and heavy, before beginning construction we performed calculations to make sure that our ropes and gear were sufficiently strong to erect it. These consisted of estimating the weights of the tower's individual parts and using these to calculate its weight and center of mass. Using this information we calculated the forces on our ropes, blocks, anchors, and shear legs.[6] If you specify your gear conservatively, these calculations are not necessary for smaller towers (Up to 20' or so).

[6] We estimated that the tower weighed about 2000lbs and that it would require 1635lbs of tension on the raising rope to erect. In a frictionless world, this translates to a 327lb pull on the fall line of the tackle. We attached a spring scale to the fall line when we raised the actual tower and measured a 330lb force, so our estimate was slightly high.

The Completed Tower

Climbing the Tower

The side of a tower of this type is broadly similar to a ladder except that many of the rungs are slanted. Therefore, anybody comfortable climbing a ladder ought to be able to climb your tower without undue difficulty if you have done a good job of building it. When climbing your tower, follow these common sense safety practices:

1. Always maintain three points of contact with the tower while climbing.
2. Maintain a non-judgmental atmosphere. There is no shame in deciding not to climb the tower or in only climbing partway up.
3. Scouts not actively climbing the tower should stand a safe distance away and not yell to or otherwise distract the Scout who is climbing.
4. Only one person should climb the tower at a time.
5. Wear a helmet.

Safety Systems

Depending on the height of your tower and applicable safety standards, you might choose to install a fall protection system on the tower. Be sure to have multiple redundant attachment points for any system that you install. Several types are discussed below, but we only have extensive experience with the auto-belay.

Auto-belay device: This is a mechanism that works similarly to an automotive seatbelt. Climbers harness themselves to a lanyard that extends and retracts easily unless shocked by the force of a fall at which point it locks. One is pictured below attached to the top of a tower. Note that it has three independent attachments to the tower. The auto-belay is fast to use and eliminates many potential sources of human error, but it is heavy, expensive, and its reach is limited. We borrow one from the ropes course at Mount Allamuchy Scout Reservation.

Top Rope Belay: Climbers harness themselves to a rope that runs through a pulley at the top of the tower and down to a belayer on the ground. This is the same system often used in rock climbing. It requires trained and attentive belayers and has the potential for human error.

Rope Grab Fall Arrester: These devices are widely used in industry. They move freely up and down a fixed rope and have a cam mechanism that locks onto the rope if activated by a fall. Do research before you purchase one, because some only work with steel cable, some only work in one direction, and some require you to hold down a lever to move them along the rope.

Rabbit Ears: The climber's harness has two short lengths of rope or webbing with clips on their ends. He must clip and unclip the ropes from the tower one at a time as he climbs it. Rabbit ears are easy to fabricate, but we do not recommend this method because of the added demands that it puts on the climber and because it is much slower than the other options.

Disassembling the Tower

When you are ready to disassemble your tower, the easiest way to get it back on the ground is to tie a rope to the top and pull it over from a safe distance. Expect to break some spars and ropes if you do this. Most of them will be near the top of the tower because that is where it will hit the ground at the highest speed. Remember to remove expensive parts of your safety system and flags from the top of the tower before you do this. You can bring smaller towers to the ground more gently by running a rope from the top of the tower to the hitch on a vehicle and rolling the vehicle toward the tower lay the tower down gently. We have done this successfully with towers up to 20’ high.

Once the tower is on the ground, do not pull it apart willy-nilly. Disassemble the tower in reverse order from how you put it together. Have a plan to get the elevated tower legs back on the ground safely.