A Few Remarks about the Round 4-Legged Stool Project

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A WARNING – PLEASE READ

Woodworking can be dangerous! It's up to you to determine if you can safely use the tools and perform the tasks needed to complete this and any other woodworking project. If you are unsure, STOP! Get advice from someone knowledgeable or do some careful studying on your own. Be safe!

Always wear at least an appropriate N95 dust mask or respirator when sanding or spraying paint. For advice about dust masks and respirators, visit this link:
https://woodworkingtoolkit.com/best-dust-masks-respirators/

READ, UNDERSTAND, AND FOLLOW ALL OF THE INSTRUCTIONS AND WARNINGS THAT CAME WITH YOUR TOOLS. BE CAREFUL!

Why this Stool?

This stool was designed for use by either children or adults with the possibility that it could be used in a wet environment such as a bathroom. So it has to stand up to exposure to some water and it has to withstand the weight of an adult.

- Height: 11 7/16", approximately
- Diameter of Top: 11", approximately
- Horizontal Extent of Legs: 15 35/64", approximately

- Construction: mortise and tenon joints join the legs to the top; 1/2″ oak dowels are used to secure the legs to the stretchers
- Materials: <u>Redwood</u>: legs, stretchers, and top
  <u>Oak</u>: dowels
- Glue: Titebond III or equivalent waterproof glue at all joints
- Finish: Multiple coats of clear satin spar urethane

Features of the Stool

The stool was designed to be functional, strong, and able to take some abuse.

Redwood was used because it's relatively easy to work with, readily available, and reasonably resistant to rot.

I had a concern that the stool might tip over, and so designed it to be reasonably stable. By spreading the legs out far enough that their perimeter is larger than the outer edge of the stool, a reasonable degree of stability is achieved. Figure 1 is a view using SketchUp looking straight down on the stool. It illustrates the concept where artificial lines have been added to show that the area supported by the legs extends beyond the edge of the top.

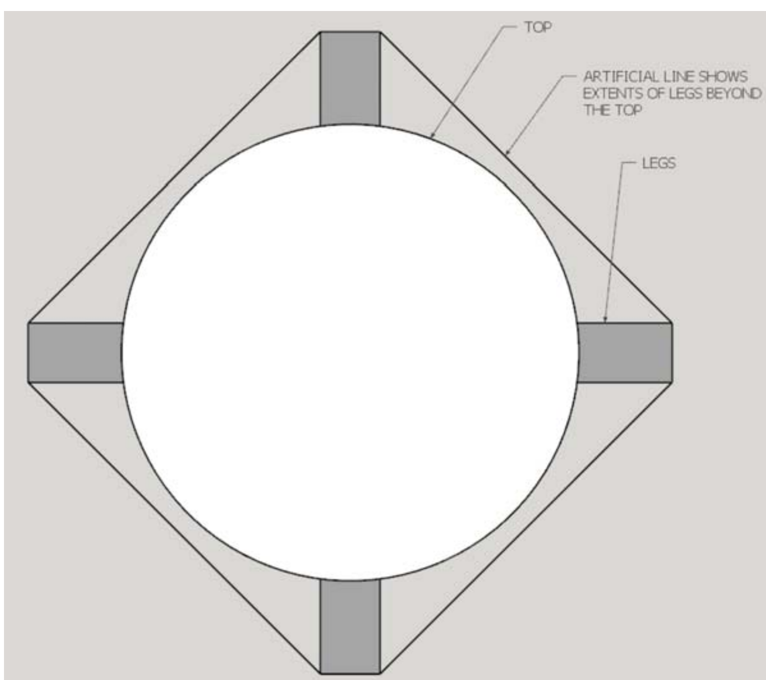

Figure 1. The View looking down on the stool, showing the area supported by the legs

Making the Stool Strong

Regarding strength, the legs are linked securely to the top by using mortise and tenon joints.

Half-lapped stretchers tie opposing legs together. The half-lap joint in the stretchers transfers any lateral forces to all of the legs, thus improving strength and rigidity.

If the end grain of the stretchers were simply glued to the sides of the legs, the glue joint would be weak. <u>But the joints are strengthened significantly by inserting a 1/2" oak dowel—***with glue***—through each leg and into the corresponding stretcher. The dowel must penetrate into the stretcher at least as far as it penetrates through the leg. Carefully gluing of the dowels is a must.</u> The combination of the dowel and glue as described should assure a strong joint.

But how strong does the doweled joint have to be?

<u>Figure 2 is important to understand.</u> It shows the forces acting on the legs when someone stands on the stool. Force 1 represents the downward force on each leg. Force 2 is the resulting lateral force acting on the end of each leg. (The end of the leg tends to slide outward.) Because Force 3 is closer to the "pivot point" (the top of the leg) Force 3 is *greater* than Force 2 due to leverage.

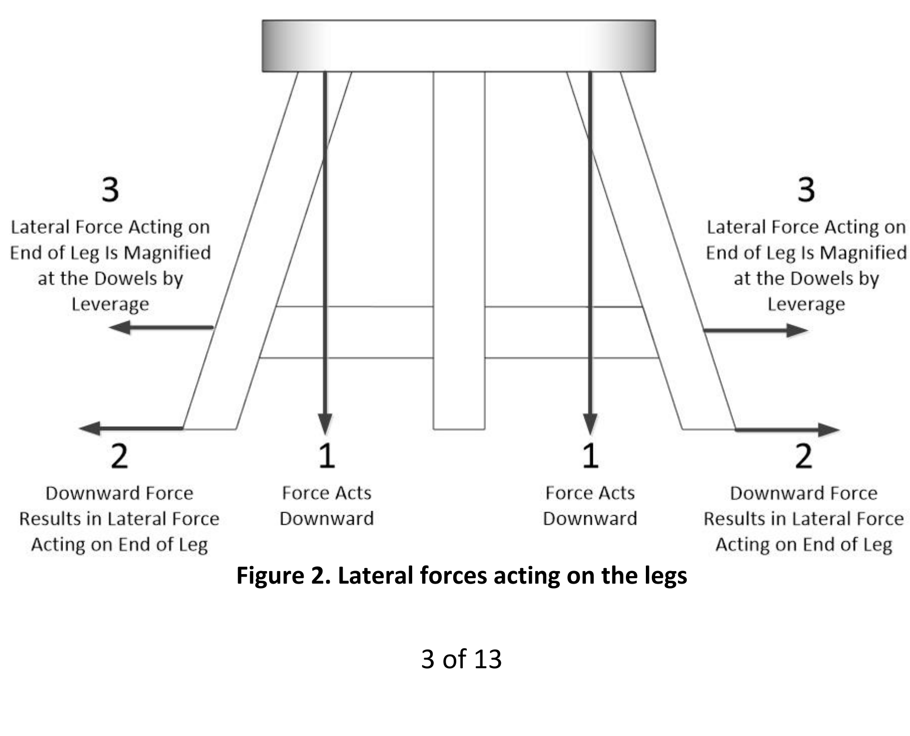

Figure 2. Lateral forces acting on the legs

In the worst-case condition, the stool is placed on a slippery floor and the floor is uneven. This means that ALL of the downward force can act on only two legs, such as the left and right legs in Figure 2. This is true because an uneven floor will cause the stool to rock on two opposing legs—which end up carrying the entire load. Everyone has probably experienced this sort of rocking. Of course, if the floor is slippery, there is no friction with the floor to resist Force 2 or Force 3. Only the dowels that join each leg to a stretcher resist the force. This explains the need for strength in the leg-stretcher joint.

How Much Strength is Needed?

If, say, a 200-pound man stands on the stool, and the stool is rocking on opposing legs on an uneven, slippery floor, then Force 1 for each of the two legs is 100 pounds. <u>The resulting Force 3 acting on each dowel would be about 45 pounds</u>! The fact that a 45-pound force (or more!) could be pulling on the leg-stretcher joint explains why <u>***glued dowels must be used*** to join each leg to the end of each stretcher to enhance the strength of the joint</u>. The 45-pound force given here is calculated in the *Comments* at the end of this paper in case you're interested.

It should be noted that there is a somewhat similar but opposite force acting on the legs where they meet the top, but strength there is assured because the tops of the legs have tenons that are glued into mortises.

Using the Drawings to Build the Stool

<u>This Is Not Standard Documentation – Fill In the Blanks</u>

I generated the original material in this ZIP package just for me, not for a general audience. This gave me the freedom to create a minimal amount of written design documentation. And it allowed the documentation to be technically incomplete. I simply carried some ideas around in my head.

So, for example, the SketchUp design ***doesn't show the dowels needed for strength*** that are glued through each leg and into the stretchers since they were a nuisance to include those in the drawing. I simply knew that the dowels would be part of the final product, so there was no real need at the time to include them in the drawing. But now I'm telling you about it. However, the ***holes*** for the dowels ***are*** shown.

Please be aware that I might not have included every detail that you need to build this project. So I suggest that if you want to build it, carefully look things over and determine ahead of time if you have enough information to go forward.

It might be sufficient to simply guess at any needed information if you can't find it in the included files.

Please be aware that there might be mistakes in the documentation that I accounted for during the build but failed to note in the documentation.

Non-standard Dimensioning

My attitude toward dimensioning is to make it "good enough." Professional mechanical designers follow certain conventions regarding dimensioning. I'm not that careful. So understand this ahead of time when you find any dimensioning that is unconventional.

A SketchUp File and a PDF File

File *Stool_4_Legs_07.skp* is the SketchUp design for the stool. This is useful since I think all of the necessary details are incorporated here. So, for example, if you find a dimension or other detail missing, it can be determined from this file. And, you can orbit and move the model around for a better look at everything.

File *Stool_4_Legs_07.pdf* contains all of the images from the SketchUp file. Use this if you're not familiar with SketchUp.

Note that certain details are deliberately missing: no dowels are shown in these drawings ***but the dowel holes are shown***. You should refer to the figures and to the comments about dowels in this file.

The Details of the Build

Look at file *Stool_4_Legs_07.skp* or *Stool_4_Legs_07.pdf* to follow along with the description.

3/4 View

Look at the 3/4 View page. This inverted view permits an easy understanding of the structure of the stool. The dowel holes through the legs and into the stretchers are shown but not the dowels. Glued-in dowels must be inserted here such that they have as much length in the stretchers as they have through the legs.

Top

Look at the Top page. You can see an edge view of the top as well as a bottom view of the top. The mortises which will join with the legs are clearly shown along with their dimensions and their positions.

The top, like all of the other redwood parts measures 1 7/16″ thick. You might want to modify the dimensions in the drawing if your material has a different thickness.

The mortises are cut 13/16″ deep so that the 3/4″ tenons of the legs don't bottom out in the mortises.

Legs

Look at the Legs page. The details of the legs are important. You can see how the tenon is arranged relative to the rest of the leg. The leg is intended to form an 18° angle from vertical so the sides of the leg and the sides of the tenon are offset by this angle.

As a practical matter, I found it easy to cut the tenons using a band saw. Of course, you will need to do some custom trimming to get a good, snug fit with the mortises in the top.

Since the tenons are to be cut 3/4" long and the mortises in the top are 13/16" deep, the tenons should not bottom out in the mortises.

<u>DO NOT drill the dowel holes in the legs until the stool has been glued and assembled.</u>

<u>Stretchers</u>

Look at the Stretchers page. Each of the two stretchers has dimensions identical to the other, but the notch is cut into the top of one and the bottom of the other. Theses notches should be carefully cut and trimmed so that they make a snug fit when one stretcher is joined to the other.

The depth of each notch should be such that the stretchers bottom out when they are fitted together and the heights of their outer surfaces are the same.

Keep in mind that a snug fit between the notches gives the stool rigidity.

<u>DO NOT drill the dowel holes in the stretchers until the stool has been glued and assembled.</u>

<u>Details</u>

Look at the Details page. The dimensions and parts placements shown here should be used to guide your assembly of the stool, not as rigid requirements. It should be clear in the side view at the bottom that the holes for the dowels are centered on the centerlines of the stretchers.

Assembling the Stool and Inserting the Dowels

<u>Assemble the stool before drilling the holes for the dowels.</u> The assembly can be tricky because the legs are positioned at an angle and the fresh glue is slippery. Here are some suggestions.

Make an Assembly of the Stretchers

After carefully determining that your stretchers are cut to the proper dimensions, including the angle cuts on the ends, and the notches fit snugly together, glue and assemble the stretchers to each other on a flat surface. Use precautions to be sure that any glue squeeze-out won't stick to whatever surface you've placed them on. A clamp or weight is useful for holding the joint together while the glue cures.

Assembling the Stretchers with the Legs and Top

This is a task that might seem like it requires 3 or 4 hands. You should do a dry fit before applying glue.

Once the glue on the stretchers has had time to cure, place the top on your bench with the mortises facing up. Put the tenon of each leg into each mortise in the top.

It's important to figure out a way to put the stretcher assembly into place between the legs so that the stretcher assembly is level in each direction and the distance from the end of each leg to the edge of each stretcher is the same for all four legs.

One way to keep the legs from splaying outward is to run a piece of tape from the outside of one leg, across the end of the leg, and then across the end of the opposing leg and onto the outside of that leg. You can do this with both pairs of legs so that the tape forms an "X" across the middle.

With the legs secured in position as described, put the stretcher assembly into place. It's helpful to use a piece of tape to mark the spot on the leg where the stretcher meets the leg.

Once everything is placed where you want it, use some sort of labeling to mark which leg is in which mortise and which end of which stretcher is associated with which leg. You'll want to glue and reassemble these pieces exactly as they are in the dry fit so that any cutting errors won't cause an awkward fit after glue is applied.

It probably won't be possible to clamp the stretchers into position between the legs. If you can't find a way to do this clamping, just rely on the glue to cure with the stretchers simply resting in position.

Let the glue cure for a full 24 hours before performing the next step. You might spend part of that time building the jig described below.

Drilling the Holes for the Dowels

The legs of the stool are offset 18° from vertical. So build a jig similar to the one in Figure 3 with a block set at an 18° angle from horizontal. Part 1 of the jig is a block cut at an 18° angle. Securely attach Part 1 to Part 2 using glue, screws, or nails. Leave enough room on Part 2 so it can be clamped to a drill press table or a bench.

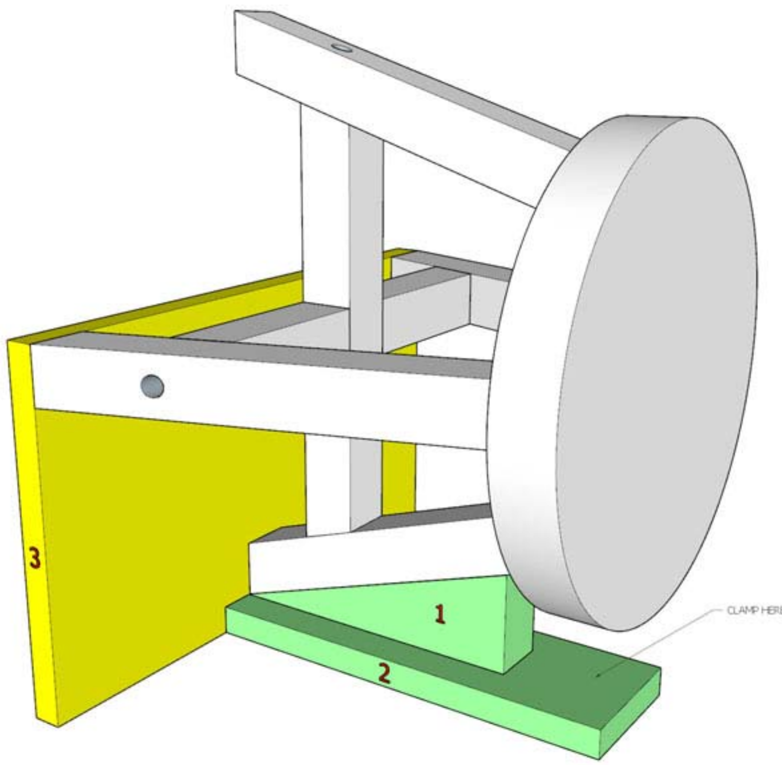

Figure 3. Possible jig for drilling dowel holes

Part 3 of the jig is a vertical guide attached to the other parts of the jig. It forms a rest for the legs to rest against so that the stool is positioned correctly. A vertical wall or other vertical device might substitute for Part 3.

Mark a point on the outside of each leg that corresponds to the centerline of the respective stretcher. Using this mark as a guide, and with the stool positioned as shown in Figure 3, use a drill press (ideally) to drill a 1/2" hole through the leg and into the stretcher. The drill should penetrate a distance into the stretcher equal to the distance that it travels through the leg. Do this for all 4 legs.

<u>Inserting the Dowels</u>

Dowels can be fickle: sometimes they fit into the expected hole size, but sometimes they don't. Check your dowel's fit before inserting it into the drilled holes. It should be a snug fit, neither too tight nor too loose.

If your dowel is too loose, try another dowel.

If your dowel is too tight, you will have to bring it down to the correct size by sanding.

Pressing or pounding a dowel into a hole is a lot like driving a piston into a cylinder: a lot of air pressure can build. This is particularly true when the dowel and/or the hole is coated with glue, making an airtight seal. Since the dowels are going to be driven into the relatively narrow stretcher, the air pressure buildup might be enough to split the stretcher, which would ruin the project.

So I recommended that once you have a nice fit of the dowel into the hole, deeply score the sides of the dowel lengthwise so that there will be a means for trapped air to escape.

Use some sort of feeler, the shaft of a screwdriver for example, to measure the depths of the holes. <u>Make sure to cut the dowels a little bit longer than this.</u>

Once the dowels are prepared, place the stool onto a jig like the one in Figure 3. Coat the walls of a dowel hole with glue but not so much that it puddles at the bottom. Then coat a dowel with glue and carefully drive the dowel into the hole. You should hear a different sound when the dowel reaches the bottom if you're using a mallet or hammer. Repeat the process for the other three legs.

As you rotate the stool in the jig, a newly inserted dowel will extend from a leg so that it interferes with placing the stool on the jig. If that dowel is a snug fit with the hole, there is no need to wait for the glue to cure before using a saw and chisel, or just a flush-cutting saw to remove the excess from the dowel.

One More Step

Okay, so the dowels have been inserted, you've trimmed the excess material from the dowels so that the dowel ends are flush with the sides of the legs, and the glue has cured. There is one more step before applying a finish.

Try to locate a known flat surface. The top of a table saw is a good choice. Place the stool on the flat surface and look for rocking. If you detect any rocking, place a sheet of sandpaper, grit side up, between the longest leg and the flat surface. Slide the stool back and forth against the sandpaper until the stool is steady without the sandpaper.

Apply a Finish

Sand the stool as needed. Be sure to remove all of the dust before applying your finish.

I used a clear satin spar urethane on my stool. When making stools in the past, and using paint, I didn't coat the bottoms of the legs because I didn't want any paint to rub off onto the floor. But when I built this stool I knew it might be used in an area like a bathroom where the floor might be wet. So I did coat the bottoms of the legs on this stool.

Use several coats of finish to complete the job.

COMMENTS
How Much Force Acts on the Dowels?

Look at Figure 4. The vertical distance from the top of the leg to the floor is 10”. Each leg is angled 18° off of vertical. The resulting length of the leg is 10.515” or about 10 33/64”. The resultant length of the other side of the right triangle is 3.249”. These lengths are shown in the figure along with the associated forces.

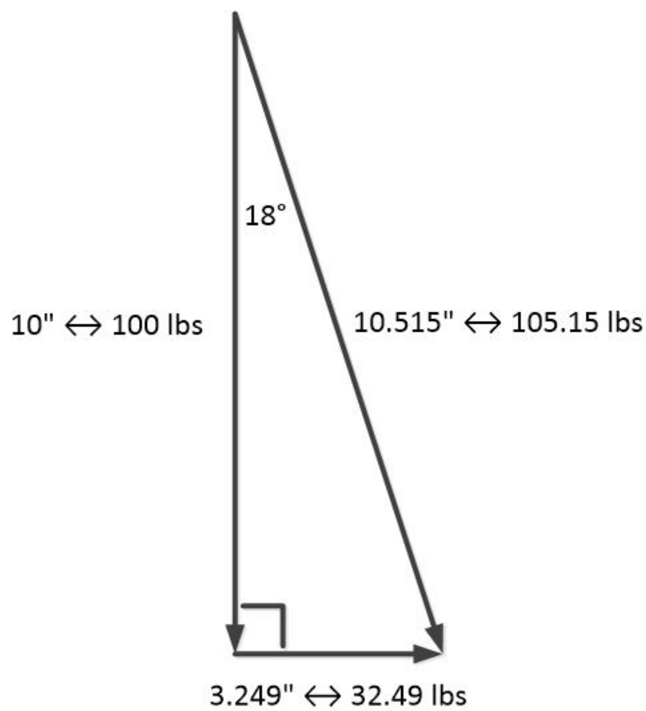

Figure 4. Vector forces associated with each leg

The 100-pound force used in the figure is based on a 200-pound person standing on the stool, the stool is on an uneven floor so that at a particular moment only two opposing legs are supporting the weight (so that each leg sustains a force of 100 pounds), and finally, the floor is slippery so that there is no friction with the floor to resist an outward swing of the leg. That is, it is assumed that only the dowel resists the tendency of the leg to swing outward.

The bottom of the stretcher is 2” above the floor. The centerline of the dowel that joins the stretcher to the leg is centered in the stretcher. Since the stretcher is 1 7/16” thick, the dowel is centered half this distance plus 2”, or 2” + 23/32” = 2 23/32” above the floor.

So the distance of the center of the dowel from the top of the vertical vector in Figure 4 is

$$10 - 2\,\frac{23}{32} = 7\,\frac{9}{32} = 7.281\ inches.$$

Therefore, the force on the dowel is

$$32.49\ pounds \times \frac{10}{7.281} = 44.62\ pounds$$

This is illustrated in Figure 5.

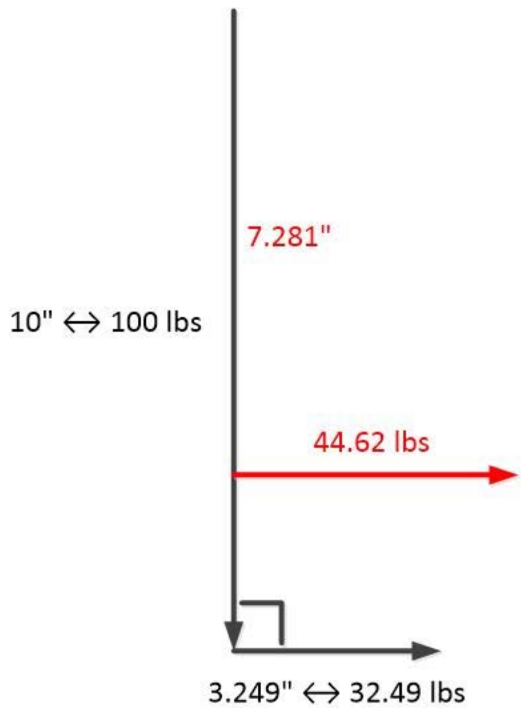

Figure 5. Resultant force on the dowel

Call this force 45 pounds.