DESIGN, CONSTRUCTION AND EVALUATION OF
SEVEN SHANK, THREE POINT RIPPER

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ABSTRACT

This senior project discusses the design, construction, and testing of a seven shank, three point ripper built for de Graaf Ranch. This ripper will replace older equipment that was not built to withstand the horsepower developed by more modern tractors that are used by de Graaf Ranch. This tillage device is designed to meet ASABE standards for horsepower requirements of farm equipment. This implement incorporates a shear pin design that will protect the frame from damage in the event that the ripper encounters a subsoil obstacle that would significantly damage the equipment. The shank was designed to reduce the disturbance of the topsoil while causing more disturbance in the subsoil, thus reducing the need for post till operations, increasing efficiency, and helping to preserve the environment.

Testing of the ripper on eight hundred plus acres of various types of soil confirms that the shank design is an improvement from older design by reducing the topsoil disturbance. The implement operates in a desirable manner and meets all the needs of the consumer.
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# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIGNATURE PAGE</td>
<td>ii</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENT</td>
<td>iii</td>
</tr>
<tr>
<td>ABSTRACT</td>
<td>iv</td>
</tr>
<tr>
<td>DISCLAIMER STATEMENT</td>
<td>v</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>vii</td>
</tr>
<tr>
<td>INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>LITERATURE REVIEW</td>
<td>2</td>
</tr>
<tr>
<td>PROCEDURES AND METHODS</td>
<td>4</td>
</tr>
<tr>
<td>Design Procedure</td>
<td>4</td>
</tr>
<tr>
<td>Construction Procedure</td>
<td>11</td>
</tr>
<tr>
<td>Testing Procedure</td>
<td>20</td>
</tr>
<tr>
<td>REFERENCES</td>
<td>21</td>
</tr>
<tr>
<td>APPENDICES</td>
<td></td>
</tr>
<tr>
<td>Appendix A: Design Calculations</td>
<td>22</td>
</tr>
<tr>
<td>Appendix B: Working Drawings</td>
<td>27</td>
</tr>
</tbody>
</table>
# LIST OF FIGURES

1. Various shank designs. . . . . . . . . . . 2
2. Offset V ripper shank placement. . . . . . . . . 4
3. Ripper boot/tip. . . . . . . . . . . . . . . . 5
4. Forward slope of top of shank. . . . . . . . . 5
5. Rear mounted tumbler on ripper. . . . . . . . . 6
6. Chromium alloy hard face on shank . . . . . . . 7
7. Corners braced by welded plate. . . . . . . . . 8
8. Turnbuckle and 2 pin assembly. . . . . . . . . 8
9. Depth wheel assembly . . . . . . . . . . . . . . 9
10. Three point hitch. . . . . . . . . . . . . . . 10
11. Pin and bushing assembly. . . . . . . . . . . 11
12. Jig with bar and finished bars. . . . . . . . . 12
13. Welds on shank for hard face. . . . . . . . . 12
14. Roll pin to hold on shank tip. . . . . . . . . 12
15. Beveled edge on tubing. . . . . . . . . . . . 13
16. Welding the frame together . . . . . . . . . 14
17. Bracket tacked and clamped into place. . . . . 15
18. Front bracket completely welded. . . . . . . . 15
19. Web welded in frame. . . . . . . . . . . . . . 16
20. Bushings being tacked in place. . . . . . . . . 16
21. Finished depth wheel bracket.  .  .  .  .  .  17
22. Bushing in depth wheel arm.  .  .  .  .  .  17
23. Finished depth wheel arm assembly.  .  .  .  .  .  18
24. Depth wheel assembly.  .  .  .  .  .  .  18
25. Complete three point hitch assembly.  .  .  .  .  .  19
26. Final assembly.  .  .  .  .  .  .  20
INTRODUCTION

de Graaf Ranch is a family owned and operated farm located in Manteca, California. The Ranch produces a variety of crops including walnuts, almonds, tomatoes, alfalfa and wheat on nearly one thousand acres. Subsoil tillage is required for the non-orchard crops after each season due to soil compaction from planting equipment, harvesting equipment, and various other implements that are run through the field each growing season. Subsoil tillage is often done with an implement with shanks that tear up the compacted soil.

New tractors like the ones used at de Graaf Ranch are able to produce 250 or more horsepower, and are suitable for large implements that cover more ground per pass than older, smaller equipment. This production of more power requires implements that are built to handle the additional power. Older equipment was not built to handle the draft forces that are developed with higher horsepower tractors. When these older implements are used with a tractor with too much power they will break, causing downtime for potentially costly repairs.

Older designs of subsoil tillage implements did not consider the topsoil disruption and erosion problems associated with multiple passes of topsoil tillage devices. These devices were required to manage the topsoil disruption from the subsoil tillage device. This new design significantly decreases the topsoil disruption while maximizing the subsoil disruption, thus improving efficiency while decreasing fuel consumption and soil erosion.

Higher horsepower tractors are able to cover more ground at a faster rate and subsoil tillage devices are able to dig deeper into the soil. This raises the issue of subsoil obstacles such as hardpan. Older equipment was designed without shear pin protection on the shanks, so when an obstacle was hit there was often damage to the shank itself or to the main frame of the implement. The new design will incorporate a shear pin design with the frame being able to handle several times the force expected to be felt by the shank. At several times the expected force, the front shear pin holding on the shank will break, releasing the shank to swing and protecting the frame and shank from damage.

de Graaf Ranch needs a subsoil tillage device that will withstand the expected forces developed by a 250 horsepower tractor that they currently use. Subsoil tillage should be maximized while reducing topsoil disruption. It was determined that a seven shank three point ripper would be an ideal implement to suit the needs of de Graaf Ranch.

The objective of this senior project was do design, construct and test a seven shank three point ripper for de Graaf Ranch given the above requirements.
LITERATURE REVIEW

Research was done in order to examine the current hitching method, modern designs of ripper shanks as well as the shear pin design.

Examination of the tractor used at de Graaf Ranch revealed a category 3, three point and quick coupler.

Various shapes of shanks are available for use with their own specific benefits and purposes. The objective of the shank design for this project was to reduce draft requirements, increase subsoil tillage and decrease topsoil disruption. Figure 1 below shows various shank designs that were tested in 2005 by a group of engineers to determine which shank design best fit these three parameters.

Figure 1. Various shank designs. (Raper, 2005)

The shank design for this project was selected and designed based upon these findings of a study by Raper (2005) that illustrated that the SK15W would provide the most desirable results. This style shank displayed much greater subsoil tillage while minimizing topsoil disruption and had relatively low draft requirements when compared to the other shanks in the study.

Draft forces for ripper shanks were determined to be 110 to 161 pounds per inch of depth for a clay loam soil type (Kepner et al. 1972). These forces were used to determine that a seven shank ripper would be suitable for the 250 horsepower tractor to pull at a
maximum depth of 36 inches and a speed of about 2.5 miles per hour. See Appendix A. The shear pin design was designed to release the shank at a force that is greater than that which should be expected from the soil. The frame was designed to be able to handle these loads as well to protect the frame and shank from breaking in the event that an underground obstacle was struck with one of the shanks during operation.
PROCEDURES AND METHODS

Design Procedures

The design constraints for this project were developed through discussions with Alan and Hugo de Graaf, the owners of de Graaf Ranch. Conversation included what changes to they would make to their existing equipment, what they wanted in a new implement, and what tractor they planned on using to pull the new ripper. Calculations can be seen in Appendix A.

Shank Position.

Based on the expected draft forces, it was determined that a seven shank ripper would be the best choice. Not only would it be within the capability of the tractor currently being used at de Graaf Ranch, it would be compatible with larger more powerful tractor to be purchased in the future. A 24 inch spacing was chosen as the distance between each shank. This spacing is very common for rippers and is what was desired by the owners of de Graaf Ranch.

While spacing is important, The layout of the shanks influences how well the implement will handle in the field. Shanks positioned in a V shape is a common way for older rippers to be built because it will pull with the most ease in a straight line. By making a pyramid shape with offset shanks, it was possible to achieve the benefits of the V shape while doubling the space between the shanks. In older V shape rippers, such as the one used by de Graaf Ranch, after crops like tomatoes, the vines would build up on the shanks when ripping the soil. With only two feet in between each shank, the vines and soil would plug up and cause the ripper to not function properly. This design will allow for the spacing between shanks to double to four feet, significantly reducing the chance of plugging. Figure 2 below shows how an offset V is able to achieve four feet of space between each parallel shank while maintaining a two foot gap between each shank.

![Offset V ripper shank placement.](image)

As seen in Figure 2, the front three shanks and the two outside shanks make a V shape that allows for good handling when it is pulled through the soil. The offset allows for
twice the amount of space between each shank. This is an effective design that is ideal for de Graaf Ranch due to the large potential for plugging in fields with row crops.

**Shank Design.**

The shank is the most important part of the ripper because it is what does the tilling of the soil. Its shape and size will determine the amount of subsoil tillage, topsoil disruption, and draft force required to pull the implement.

Subsoil tillage is determined by the boot, or tip, of the shank. The boot is the widest part of the shank. Its purpose is to shear and lift the soil, reducing soil compaction from other implements used in the field during the growing and harvesting season. Figure 3 shows a standard boot for a ripper shank.

![Figure 3. Ripper boot/tip.](image)

The upward angle of the top of the boot helps lift the soil as the shank is pulled through the soil. Lifting the subsoil helps loosen and turn the soil, reducing or eliminating compaction that has occurred. As the soil re-fills the cavity that was made from the tip, it is loosened and allows for maximum infiltration of water and root growth for the next crop.

Topsoil disruption is minimized by the forward sloping top of the shank that can be seen in Figure 4. As the soil hits the top of the shank the downward angle tends to push the soil down, causing the soil to flow smoothly around the side of the shank. The shank cuts through the soil and does not lift the soil up like older shanks that were either straight up or sloped backwards. Backward sloping shanks lift the soil several inches in front of the shank and cause lift throughout the entire soil profile. This causes the topsoil to become unlevel and requires multiple passes with a disc or other topsoil tillage implement to smooth the roughness and reduce the size of clods that are produced. The forward sloping shank creates no lift in front of the shank, reducing the need for multiple passes with topsoil tillage devices or completely eliminating them through use of a tumbler shown in Figure 5 below.
Additions to rippers like the tumbler seen above can reduce or eliminate the need for additional passes with topsoil tillage devices with the larger and more powerful tractors used today. The addition of a tumbler device on a forward sloping shank ripper can reduce the number of passes to finish a field to just one pass that does it all. This reduction of passes increases efficiency and reduces wear on the tractor and fuel consumption which is both financially and environmentally beneficial.

A 1½ inch shank width was chosen with a bolt pattern of two 1¼ inch bolt holes spaced eight inches apart. These holes were placed 2 inches from the top and front of the shank. This is a standard shank pattern allowing these custom made shanks to be replaced with interchangeable, aftermarket shanks if the need arose.

To reduce wear on the shanks, the front of the shank is lined with an easily replaceable chromium alloy steel that is much harder than the mild steel the body of shanks are made of. This hard face will extend the life of the shank several times what the steel alone
would last. Figure 6 shows the chromium alloy blocks welded to the front edge of the shank.

![Figure 6. Chromium alloy hard face on shank.](image)

**Frame Design.**

The frame of the ripper is what holds the implement together and attaches it to the tractor. The frame was built of 7” x 7” x 1/2” square tubing and 5” x 7” x 1/2” rectangular tubing. This size tubing gives the frame enough strength to handle the loads created by the shanks and is a standard size that will allow mounting a device, like the tumbler shown in Figure 5, to be done without any modifications to the mounting brackets. See calculation III in appendix A. There is a strong possibility that an addition such as this will be attached in the future. With that in mind, the square tubing frame was the best choice.

To make the frame stronger and to reduce the likely chance of welded corners from cracking, each welded corner was designed so that there is an overlap of one inch plate that was used as the mounts for the shanks, the mounts for the depth wheels, or the three point hook up where the tractor connects to the ripper. This overlap helps make the corners stronger by securing the welded areas with more weld and material. Other implements generally use extra plating to strengthen corners where overlap of other material is not possible. However, it was not necessary with this design because it was designed to have each welded corner of tubing covered by one inch plate. This design reduces the need for extra parts that would have otherwise been necessary. It also improves the visual appearance of the implement by making the corners smoother and more fluid in appearance after removing the large plates welded on for strength. Figure 7 shows the corners of the ripper braced with one inch plate.
Depth Wheel Design.

The depth wheels keep the ripper at a desired depth. They allow the tractor’s hydraulic system to be used to solely raise and lower the ripper, without having to be used to keep the ripper at a constant depth. Depth wheels are very important in situations where the subsoil has obstructions such as hardpan that have been broken up by larger rippers. The ripper without depth wheels would constantly be pulling deeper and would eventually catch a piece of hard pan. This could cause the shear pins to break on the ripper or a shank to bend, resulting in costly repairs and possible damage to the ripper and/or the tractor. Through the use of a depth wheel, the ripper can be set to just above any hard pan allowing the tractor to have a less constant load on its hydraulic system and keep the ripper from hitting obstructions.

The depth wheels are fully adjustable through a turnbuckle system combined with two different end pin locations. The turnbuckle allows for very fine adjustment of the depth and is an easy and effective method for raising and lowering the wheels. The two bottom pin system allows for a shorter turnbuckle to be used for a wider range of adjustment.
To get the adjustment needed to raise and lower the wheels over 30 inches without the two pin system, the turnbuckle would need to be very long which would become more expensive and harder to find. Figure 8 shows the adjustable bottom pin and the turnbuckle assembly.

The wheels were chosen as rubber tires over steel wheels based upon the soil conditions that the ripper will be used in. Steel wheels are commonly used on rippers because they are durable and last a long time. However, they typically have problems with sticking in clay soil when it is moist. The clay soil will continue to build layers causing the depth wheels to be ineffective at keeping a steady depth. Rubber tires do not tend to have as much of a problem with soil sticking to it. Even though rubber tires wear faster and may not last as long, they were chosen for this application because of their ability to not stick to moist soil. A relatively inexpensive automotive tire that is easily replaceable was used so when the tires wear out they can be replaced without the hassle of finding a similar tire. Figure 9 shows the complete depth wheel assembly with the rubber tires installed.

![Figure 9. Depth wheel assembly.](image)

The depth wheel placement is crucial for stability with the ripper in the field. The wider the wheels are, the more level the ripper will be when it goes over rough soil. Rippers are often used in unleveled fields from which a previous crop has been removed and disrupted the soil. The tractor is rigidly hooked to the ripper with no rotation from side to side. The depth wheels keep the ripper from sinking on one side more than the other while maintaining the depth of the ripper. Placing the wheels as far outward as possible was most effective because they stabilize the ripper and allow the mounting brackets to be used as support for the front corner of the frame.
Three Point Hitch Design.

The three point hitch was designed to meet the ASAE standard S217.12. The tractor used at de Graaf Ranch uses a category three, quick coupler, three point attachment. The ripper was designed so that it could be attached to a category three or category four tractor. If a tumbler attachment was to be used on the back of the ripper a larger tractor with a category four hitch would be needed to lift and pull the ripper. The hitching system was designed with this in mind, so various locations for the top pin were built into the three point frame. Figure 10 shows the three point frame assembled with multiple holes in the top for various hitch points.

![Figure 10. Three point hitch.](image)

Also seen in Figure 10 are supports welded in between the three point hook up. These supports add strength to the frame and protect it from the welds bending and cracking by making them more rigid. These were both problems associated with the older designs used at de Graaf Ranch.

Pin and Bushing Design.

All pins and bushings on the ripper were designed with wear and ease of repair or replacement in mind. There were various pins throughout the project that are expected to wear and will need to be replaced in the future. To reduce the work associated with replacing worn parts, the bushings were made from a much harder steel than the pins to make sure that the pins wear and not the bushings. Worn pins can be removed more easily by removing the bolts that hold them in place and replacing them with new ones. The bushings are welded into the frame and brackets that hold the pins and various moving parts together. If it was necessary to remove a bushing it would require torching and re-welding of the new busing. This would be very time consuming and would cause the need for repainting. A bushing and pin assembly for the depth wheel is shown in Figure 11.
Construction Procedures

Most of the cutting was done at BRAE shop, including all of the plasma cutting which was used for all the pieces built from plate steel. Some parts which required precision tolerances, like the bushings and pins, were built by a metal shop to dimensions and tolerances designed specifically for this project. See Appendix B for part drawings. Construction of this project was done primarily in the shop at de Graaf Ranch.

Shank Construction.

The shanks were constructed from 1.5 inch mild steel and were cut using the CNC plasma cutter at the BRAE shop. A 4’ x 12’ sheet of steel was used to make 8 shanks so that there was an extra built in case the need arose to replace a shank. To make replacing the chromium alloy hard face easier, a 1.5” x .75” steel bar was cut, heated, and bent to fit the front side of the shank. A jig was built to easily replicate the part. The hard faces were then welded to them after being broken into pieces so they could be placed around the curve. The addition of this bar allowed for the hard face to be welded to it rather than the shank. The bar could be welded to the shank in just a few spots making it easier to replace than having to grind and cut multiple welds that hold the hard face on. Figure 12 shows the constructed jig and the bent bar, as well as the stack of finished bent bars before they were welded to the shank. Figure 13 shows the amount of welding that is required to attach the hard face compared to the weld that is required to attach the bar to the shank, illustrating the difference in replacement effort and time.
Figure 12. Jig with bar and finished bars.

Figure 13. Welds on shank for hard face.

The boot tip of the shank is held on by a roll pin. A hole was drilled through the shank and a roll pin was punched through to hold it on as shown in Figure 14.

Figure 14. Roll pin to hold on shank tip.
The holes holding the shank were drilled with two consecutive drills to make the drilling process easier. First, a jig was built with holes that were marked and drilled with precision on the mill. The shanks and plates holding the shanks were marked with the jig so all the holes were the same and all the shanks and plates would be interchangeable. After marking the shanks, a pilot hole was drilled followed by two passes with increasing sized bits until the desired hole size was acquired. This completed the shank construction process.

Frame Construction.

First, the pieces of tubing were cut using a band saw. Tubing is built with a welded seam that is visible on the outside of the tubing wall. The angles of the tubing for the project were cut so that each seam faced downward and would not be visible after the project was completed. Following cutting, the edges of the tubing that were going to be welded were beveled to allow for deep penetration of the weld. A significant amount of material was removed from the 1/2" thick wall tubing. Figure 15 shows the tubing after the edges were beveled.

![Figure 15. Beveled edge on tubing.](image)

Also visible in Figure 15 is the light grey line on the middle of the tubing where the welded seam is. This seam is very visible even after a layer of primer and paint.

Once the pieces of tubing were cut and beveled they were laid out to make sure each piece fit properly. Once all pieces were tested, a level surface was necessary to lay them on to ensure that the frame was square. Due to the weight and magnitude of the project it was easiest to start with the pieces on a concrete floor. However, the concrete floor was not perfectly level so three points that were level were selected to use as supports for the corners of the frame. This ensured that the frame would be put together square. Each corner was then checked for the proper angle and tacked together using a mig welder.
All of the corners were tack welded rapidly and then allowed to cool to make sure the angles stayed the same and the pieces did not move as the welds cooled. As a weld cools it will shrink and can move the material a significant amount, causing the angles to be off and the parts to not line up properly. After cooling, the frame was completely welded together. Figure 16 shows the frame being welded together while resting on the three level surfaces.

![Figure 16. Welding the frame together.](image_url)

After the outside frame was welded together the center support beams were welded in place. Once the center beams were in place, the frame was sturdy enough to be rotated and moved to allow for the welding of all sides and the later addition of mounting brackets for the shanks.

The mounting brackets were cut using the CNC plasma from one inch plate and the holes were drilled using the jig for the shanks to make sure that all of the holes were perfectly aligned. The frame was marked where each bracket would go, and lines were drawn to keep everything square with the frame. It is crucial that the shanks run straight with the frame so it was very important to make sure the brackets were welded perfectly square with the frame. A piece of 1 1/2" material was used to separate each bracket with an extra thin sheet of metal to allow for the shank to be easily attached to the frame.

If the brackets were welded too close, after paint and if there were any imperfections, the shank would not fit so it was important to leave enough room. Multiple tacks were done on edges that would not cause the piece to shift from shrinkage due to the weld cooling. This ensured that the pieces would not move after the clamps were taken off. Figure 17 shows the brackets clamped together with the spacer and a tack on the front edge.
The brackets were welded in place on both the inside and outside edges after being tacked and clamped in several places. A stick welder was used to weld the inside edge because there was not sufficient room for a mig welder tip to fit. Figure 18 shows the front bracket welded in place. Multiple welds were used in passes to apply sufficient weld to hold the brackets in place.

The final piece to be welded in the frame was a support web that helps hold the front together. This piece spans the support beams in the front of the frame to help hold everything in the front together. When the ripper is used the tractor is hooked up to the front of the ripper on the three point hitch and this is where all the force will be applied to pull it through the soil. Figure 19 shows the web welded in the front of the frame.
Figure 19. Web welded in frame.

Depth Wheel Construction.

Construction of the depth wheel assembly started with welding the bushings in the holes that were pre cut with the plasma cutter. It is crucial for the bushings to line up in all directions in order for the pin to be able to fit properly. Bolts will be used to hold the pins in place. To make sure the parts were symmetrical a threaded rod was used to make sure the bolt holes lined up as the bushings were tacked into place. The bushings were laid out, measured and placed on a flat welding table to be tacked in and tested. Once the bushings were tacked, they were clamped to the frame and tested with the pins. With the pins in, the bushings were tacked in several more places to ensure that they did not move after they were taken down to be completely welded into place. Figure 20 shows the bushings being lined up and tacked in place to be tested.

Figure 20. Bushings being tacked in place.
After the bushings were tacked and tested, they were taken down and fully welded on the inside and outside. After welding, the welds on the inside were ground off so that a smooth surface was available for the depth wheel arm to slide on. When the grinding was finished, the brackets with fully welded bushings were mounted with clamps and pins were inserted to ensure proper alignment and proper space. Figure 21 shows the finished brackets ready to be welded to the frame.

![Figure 21. Finished depth wheel bracket.](image)

Next the depth wheel arm had bushing holes cut and the edges beveled for maximum penetration with the welder. The bushings were welded in place, and the outside edges were ground to a smooth finish to allow movement on the inside of the brackets that hold them during wheel adjustment. Figure 22 shows the bushing welded in the depth wheel arm on the inside and outside.

![Figure 22. Bushing in depth wheel arm.](image)
The corners of the end of the depth wheel arm that were attached to the frame were cut and capped so that they could freely rotate without interference. This also prevents them from filling with soil while the ripper is being used.

After the bushings were welded in the depth wheel arm, pin holes and bushings were welded together in the same manner as the mounting bracket for the depth wheels. Next holes were cut for the spindles. The spindles were welded together and then welded into the depth wheel arm. Figure 23 shows the finished assembly of the depth wheel arm.

![Figure 23. Finished depth wheel arm assembly.](image)

Finally, to finish assembly the arm was capped, the turnbuckles were welded to bushings, and the turnbuckle bushings were drilled and tapped so that grease could be applied to these bushings. Grease is necessary in these pins because they need to be able to move and rotate when the depth wheels are adjusted. Grease will keep them protected from wear and rusting which would cause them to cease. Figure 24 shows the final depth wheel assembly attached to the frame. Hubs for the wheels were assembled and placed on the spindles. With this act, the depth wheel assembly was complete.

![Figure 24. Depth wheel assembly.](image)
Three Point Hitch Construction.

The three point hitch is a crucial part of the ripper project. It is where the tractor will be attached to the ripper and where all of the force will be transferred from the tractor to the ground. The hitch has to be square with the frame and the shanks and must be able to support the ripper as it is lifted and pulled through the soil.

First the bushings were welded and lined up in the same manner described for all other bushings. It is crucial for them to be lined up properly so that the tolerances built in allow movement and rotation of the pins. The lower arms were lined up and welded to the frame like the brackets that hold the shanks. Their location was marked and a straight line from front to back was drawn to ensure that they were perfectly square with the frame. They were spaced with a piece of tubing, clamped and tacked to hold them in place as they were welded. Once the lower arms were welded in place, the upper plates were welded in place with a pin through each set of holes to make sure that all three top sets of holes lined up. The top plates were welded in place and finally the back supports for the top plates were welded in place.

The final pieces that were welded in place were the support members that help hold the three point hitch in place. These were fitted between each ear of the lower arms, adding increased side support to reduce the chance of bending the ears. Also a strip of flat stock was added to the bottom of the frame in the front to reduce flexing of the frame and to add additional strength to the frame. Figure 25 shows the complete three point hitch assembly.

![Figure 25. Complete three point hitch assembly.](image)

Final Assembly.

The final steps were to put all the pieces together to test them before sandblasting, and painting. All pieces fit and worked properly the first time. Each piece was then taken
apart and the frame was taken to a sand blasting plant to have it prepared for paint. Once
the ripper was sand blasted and prepared for paint it was time to add color. A blue and
black color combination was chosen to set this ripper apart from any other. Most
equipment comes in yellows, silvers and greens. The blue color was chosen to make it
stand out and be different than other piece of equipment available for purchase on the
market. A layer of primer was applied first then the color was applied shortly after.
Three coats of paint will ensure a long life and a nice shine that makes the ripper look
nice for years to come. Figure 26 shows the final assembly completely painted and put
together.

![Figure 26. Final assembly.](image)

**Testing Procedures**

Testing of the ripper was done on several hundred acres of land with a variety of soils
including sand, sandy loam, and very high clay content soil. The ripper worked just as it
was designed to do, developing large amounts of subsoil disruption while leaving the
topsoil only slightly disturbed. Also, testing in soil with a large amount of tomato vines
showed that the offset design allowing four feet of space between shanks worked very
well to eliminate clogging. There was no sign of clogging in the worst conditions that the
ripper will ever be expected to see. The ripper worked very well and continues to do its
job tilling over 800 acres over twelve months with no problems.
REFERENCES


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APPENDIX A
I. Draft force Calculations

- The draft force was determined using the worst case scenario under full shank penetration. The worst case is with soils that will cause 161 lbs of force per inch of depth on each shank.

Max depth of shank = 36 inches

161 —— * 36 in = 5800 ———

5800 —— * 7 shanks = 40600 lbs

II. Shank Bolt Calculations

<table>
<thead>
<tr>
<th>Bolts 1.25 in bolt</th>
<th>shear strength =0.6* yield strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>8</td>
</tr>
</tbody>
</table>

Table 1. Shear strength of bolts
- This calculation was done to determine when the grade 5 bolt that holds the front of the shank on will fail to determine if the frame will be protected by the shear pin system.
- In the event that an underground obstacle is struck the shear pin in front should fail protecting the frame.

It was determined from the calculations that a force of 7 times the expected force would cause the shear pin to fail.

\[ F = \text{Shear pin failure force on shank} = 7 \times 5,800\text{lbs} = 40,600\text{ lbs} \]

\[ F_x = \text{failure force} / 2 = 20,300\text{ lbs} \]

\[ F_y = F \times 36\text{ inches}/2\text{ pins}/4\text{ inches} = 182,700\text{ lbs} \]

\[ \text{Resultant } R = \sqrt{F_x^2 + F_y^2} \approx 183,824\text{ lbs} \]

\[ \text{Shear} = \frac{R}{A} = 91,912\text{ lbs} / (\text{Area}) = 74,897\text{ psi} < 75,00\text{ psi allowable} \]

**III. Torsion in front frame.**

- This calculation was done to make sure that the frame could withstand the torsion developed by an underground obstacle that would cause the shear pin to fail.
Tr/J = Torsion

T = 7 expected draft force * 36 inches

r = 2.63 from steel construction manual

J = 133

\[ = 7 \times 5,800 \times 36 \times 2.62 / 133 = 28,792 \text{ psi} \]

The beam alone with hold the torsion. With the added support at the bottom of the beam as well as the beam being at a 30 degree angle there is no concern for the beam to fail before the shear pin does so the frame should be safe from failure due to underground obstructions.

**IV. Weld calculations.**

This simulation was done using the expected forces to be seen on the shanks. The part was sufficient so it is assumed that the 3/4 inch welds would be adequate to hold the brackets on.
V. Lower 3 pt arm calculation.

This stress analysis was done and determined that the arms would be sufficient to handle the expected draft loads.

VI. Draft link

The draft links were designed and based off of the standards for quick coupler attachments and are based off of horsepower ratings so there are no calculations necessary. It was determined that a category 3 system would be used.
APPENDIX B
All rounded corners
1/2" radius
All Angles: 45 deg or 90 deg,
All Rounded Corners 1/2 "Radius
3 pt support in
3 pt support top