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PURSUIT

# Evaluation of Foldable Tractor Roll-Over Protective Structures (ROPS) Clearance

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Tractor rollovers are a leading cause of death in the agricultural industry. While rollovers continue to happen, Roll-Over Protective Structures (ROPS) have shown great ability to prevent or reduce the casualties and injuries associated with rollover events. One authority on the subject even goes so far as to claim that "that fatality rates due to tractor overturns could be reduced by a minimum of 71% if all tractors in the U.S. were equipped with ROPS," (NIOSH, 2009). The potential of this promising statistic has been devalued slightly due to the misapplication of foldable ROPS by leaving the ROPS in the folded down position. Foldable ROPS provide a practical solution to various issues faced by tractor operators. However, a ROPS is not meant to be used in the folded down position, and there are engineering standards that should be used to determine if a folded down ROPS actually offers any protection. This study determined the operator protection provided by ROPS in the extended and the folded positions relative to the applicable engineering standards. To accomplish this, six different sized tractors with different ROPS were analyzed to determine the measurements required to calculate the protection that the tractor and ROPS combination provides in both positions, folded and extended. These calculations yielded results that show consistent trends among all tractors measured. With regards to the engineering standards, all tractors measured provide complete protection when in the upright, extended position and did not provide adequate protection when in the folded position. These results provide useful insights into engineering standards and recommendations.

## Introduction

In 2014, agricultural professions had the fourth highest fatality rate per 100,000 people (Johnson, 2016). This has been the case for decades, and a leading factor in that is tractor related accidents, with the most frequent type of these accidents being rollovers (Smith, 2017). With more full-time workers and youth that live on farms working in agriculture (NIOSH, 2014) and accessibility to both small and large tractors increasing, tractor safety is increasing in importance. These factors imply that increased numbers of inexperienced people are using tractors, so rollovers will increase in frequency and potentially have devastating effects, regardless of the size of the tractor. Rollovers are bound to happen, but the possibility of injury can be reduced.

Roll-Over Protective Structures (ROPS), structures attached to vehicles with the intention of protecting the operator in the event of a rollover, can drastically lessen risk of injury or death. However, it is vital that the ROPS is built to meet engineering standards with regards to the operator clearance zone and that it is properly utilized, implying that the ROPS is in the upright, or non-folded, position. Foldable ROPS are a practical solution to storage and other vertical clearance problems; however, many foldable ROPS are not used in the upright position, largely due to the inconvenience of manually raising the ROPS (Myers, 2015). This leads to the question that this study investigates: what protection do folded and non-folded ROPS provide relative to the operator clearance zone? The answer to this question will change for every tractor/ROPS combination, but general trends can lend valuable information to future safety recommendations, such as whether or not the seat belt should be worn with the ROPS folded down. The current recommendation regarding seat belt use with a folded ROPS states to "not fasten seat belt if the ROPS is in the folded position," (Deere, 2016).

Using data from a sample set of tractors, calculations were made to determine clearance with regards to the applicable regulations. The results should be able to further improve the safety of agricultural practices. This study is intended to determine general trends in how the protection offered by ROPS when folded and extended relates to the engineering standards published regarding the operator clearance zone. The relation discovered showed that folded ROPS do not provide adequate protection, and the results provide data that could be utilized to adjust ROPS to solve this problem.

## Procedure

The applicable engineering standards that were used are SAE J2194 (SAE, 2009) and ASABE S478 (ASABE, 2012). Both standards were used so that a wider range of tractors could be addressed by this study, as SAE J2194 addresses "Wheeled Agricultural Tractors," with weights of 800 kilograms or more, and ASABE S478 addresses "Compact Utility Tractors," with weights of 1800 kilograms or less. The clearance zone in Figure 1 is defined in SAE J2194 and provides the dimensions of the operator protection. The two main differences in the clearance zones provided by ASABE S478 and SAE J2194 are the radii (SAE J2194 using a 900 mm radius and ASABE S478 using a 760 mm radius) and the point on the seat from which the radius originate. For this study, two clearance zones were used: the SAE J2194 zone with the 900 mm radius from the defined seat reference point (SRP), shown in Figure 1, and that same zone, but a radius of 760 mm applied at the same point.

The main value determined in this study is clearance distance. For the purpose of this study, clearance distance refers to the distance between a point on the boundary of the clearance zone given by the relevant standard and the ground plane formed by the line from the front of the hood to the most vertical/forward point on the ROPS when it is either extended or folded. The ground plane referred to is applicable when the tractor is completely upside down. These clearance distances were calculated based on the previously defined clearance zones. The use of both clearance zones allowed for the clearance distances for a wider range of tractor sizes to be accurately represented.

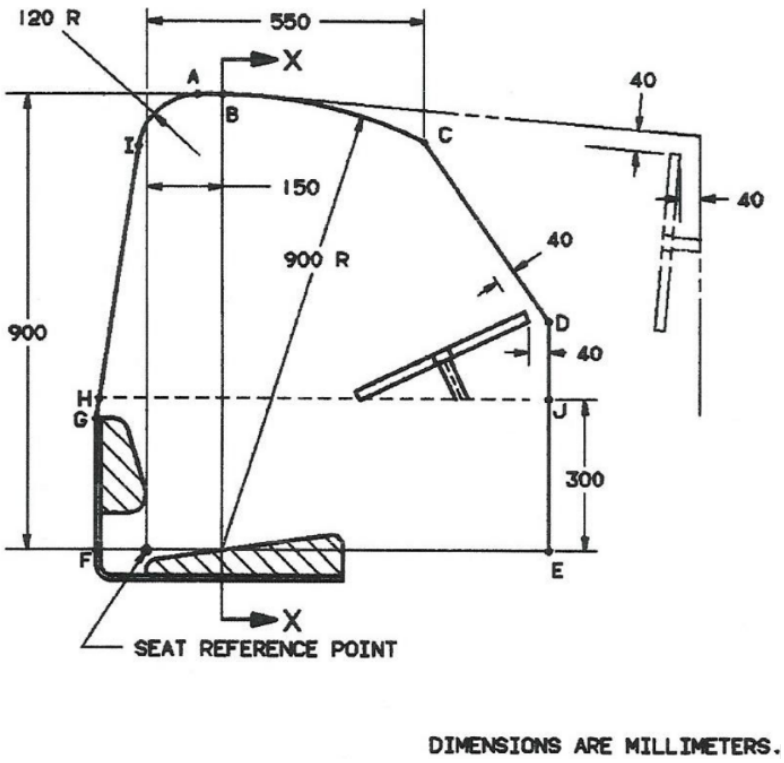


*Figure 1*
*Clearance zone given by SAE J2194 (SAE, 2009).*

To most accurately and completely convey the clearance distance offered by each ROPS, the clearance distance values at two points, points B (measured vertically in line with the center of the arc) and C (measured perpendicular to the ground plane) of Figure 2, have been considered. Though measurements for any ROPS are available, and the measurements of Figure 1 are given, one cannot know how these measurements will translate to clearance distances when a ROPS is attached to a tractor. Therefore, measurements must be taken by hand on a spectrum of ROPS/tractor combinations to assure accurate clearance calculations and determine trends.

To determine the clearance distance, the X (forwards (+) and backwards (-)) and Z (height) position of the following four points must be known based off of a common reference point, which is the ground point below the rear axle. These points are the most vertical/forward point of the ROPS in both the extended (RTP) and folded (FRP) position, the seat reference point (SRP), and the most vertical/forward point of the hood, known as the front-mid hood point (FHP). These points, along with the clearance distances that were calculated, can be seen imposed onto the SAE J2194 clearance zone in Figure 2. The process of acquiring measurements from one of the sampled tractors is displayed in Figure 3.

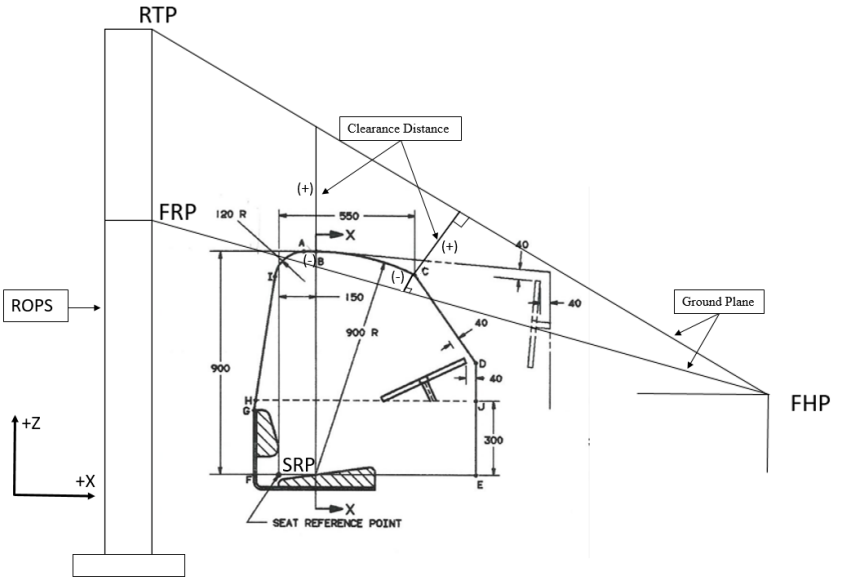


*Figure 2*

*Clearance distance shown relative to the SAE J2194 clearance zone. Dimensions in millimeters.*


*Figure 3*

*Measurements being taken on one of the measured tractors.*

This study evaluated six different sized tractor and ROPS combinations, with tractors ranging in size from 655 to 3200 kilograms, to determine clearance distances based off of these four points. The measurement of six tractors, which was done using measuring tapes and rulers, produced the results shown in Table 1, with specific tractor model numbers not shown for confidentiality.

| Tractor | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| Standard Applicable | ASABE S478 | ASABE S478 | ASABE S478/SAE J2194 | ASABE S478/SAE J2194 | SAE J2194 | SAE J2194 |
| Weight (kg) | 655 | 752 | 987 | 1315 | 2497 | 3200 |
| SRPX | -95 | -120 | -60 | -80 | 100 | 120 |
| SRPZ | 1020 | 1080 | 1040 | 1120 | 1280 | 1400 |
| FHPX | 1880 | 1880 | 1930 | 2290 | 2670 | 3000 |
| FHPZ | 990 | 1020 | 1140 | 1180 | 1430 | 1500 |
| RTPX | -440 | -110 | -200 | -200 | -100 | -120 |
| RTPZ | 2180 | 2260 | 2300 | 2330 | 2480 | 2570 |
| FRPX | -260 | -250 | -160 | -100 | 0 | -100 |
| FRPZ | 1640 | 1640 | 1680 | 1740 | 1880 | 1960 |

*Table 1*

*Measurements (in mm, weight in kg) taken for six tractor/ROPS combinations.*

Using the measurements in Table 1, a series of calculations were done to produce the clearance distances for extended and folded ROPS shown in Figure 2.

## Results and Discussion

The clearance distance calculations produced fairly consistent results. The clearance distances for the six tractors measured can be seen in Table 2, with positive values representing clearance distances that extend outside the clearance zone and negative values representing instances in which the ground plane intrudes into the clearance zone.

| ROPS | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| Clearance B Extended (900) | 6.1 | 192.8 | 202.1 | 185.3 | 167.3 | 136.3 |
| Clearance B Folded (900) | -375.7 | -421.5 | -324.6 | -319.8 | -342.1 | -394.9 |
| Clearance C Extended (900) | -93.7 | 31.7 | 68.5 | 85.6 | 102.4 | 87.8 |
| Clearance C Folded (900) | -386 | -426.5 | -323.5 | -311.4 | -311.4 | -356.6 |
| Clearance B Extended (760) | 111.1 | 332.8 | 342.1 | 325.3 | 307.3 | 276.3 |
| Clearance B Folded (760) | -235.7 | -281.5 | -184.6 | -179.8 | -202.1 | -254.9 |
| Clearance C Extended (760) | 24.6 | 167.4 | 209 | 230.9 | 252 | 239.2 |
| Clearance C Folded (760) | -23.29 | -272.8 | -168.6 | -155.6 | -153.6 | -198.3 |

*Table 2*

*Clearance distance (Point B or C, extended/folded, 900 or 760 mm radius). All values in millimeters.*

As seen in Table 2, at any point and using either radius, no ROPS provides enough clearance when folded to satisfy the standards, shown in the table as negative values. These clearance distances are more clearly represented with respect to a 900 millimeter radius in Figure 4 and a 760 millimeter radius in Figure 5.

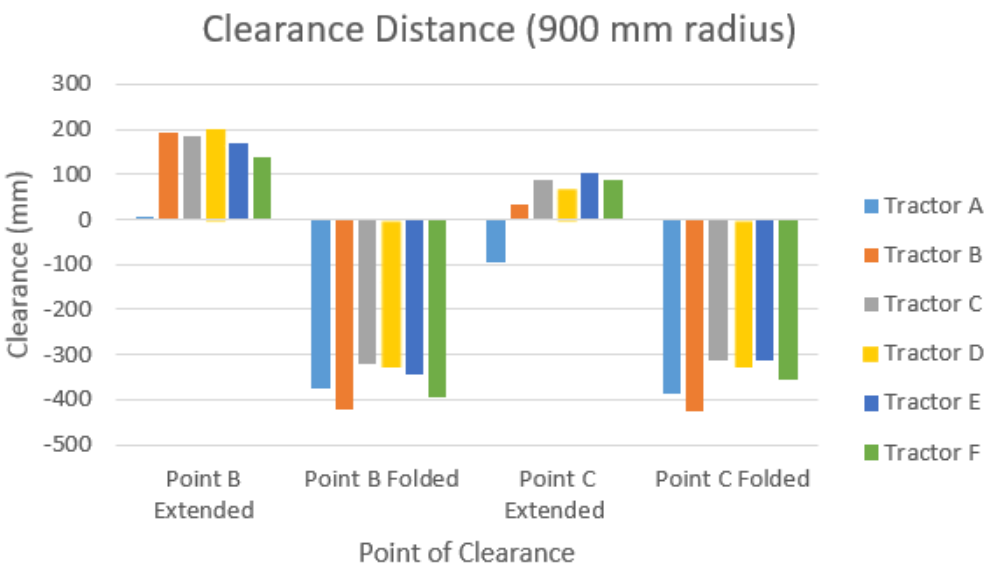


*Figure 4*
*Clearance distances compared, 900 millimeter radius.*

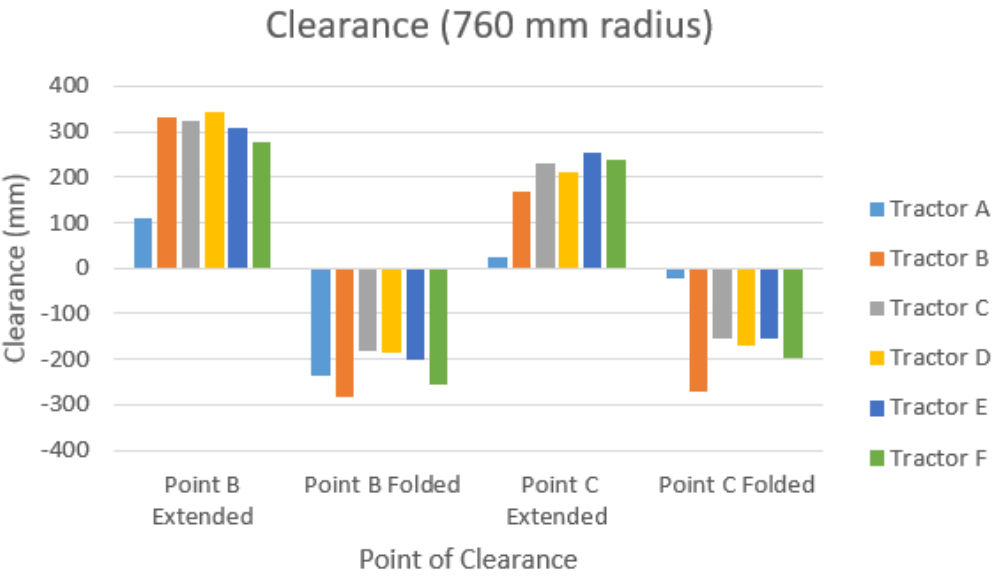


*Figure 5*
*Clearance distances compared, 760 millimeter radius.*

The results consistently show that the clearance distances of the ROPS in the folded position lack approximately 300 to 400 millimeters at both point B and C of Figure 1 to meet the standard clearance zone described in SAE J2194. These results affirm the hypothesis that a ROPS in the folded position does not provide enough clearance to meet the standards; however, these results quantify the lack of protection provided by a folded ROPS. Using the definition of protection given by the engineering standards, the measured ROPS in the folded position do not provide any protection. Most of the measured tractors satisfy both of the applicable engineering standards when extended, the one exception being Tractor A, with respect to SAE J2194. Tractor A falls about 94

millimeters short of the standard clearance distance for point C, but, with respect to ASABE S478 and the 760 millimeter radius, which is the applicable standard based off of weight, Tractor A exceeds standard clearance distance at all points. Note that the weight of Tractor A (655 kg) indicates the smaller radius (ASABE S478) should be used.

The sets of clearance distances calculated provide a fairly complete picture of the overall protection created by folded and extended ROPS. However, due to the distance between points B and C of the clearance zone, a value can be calculated to find the error due to possible intrusion of the ground plane into the clearance zone between points B and C. Determining the length of the sagitta of the arc between points B and C (in doing so, accounting for the fact that the edge of the clearance zone between points B and C is an arc and not a straight line) shows that in the worst case scenario, the ground plane could intrude and produce an error in the calculated clearance zone of up to 24 millimeters.

## Conclusions

While a folded ROPS does not currently provide adequate protection to meet engineering standards, the set of data presented in Table 2 and Figures 4 and 5 does provide an optimistic view for possible adjustment to ROPS themselves and to regulations regarding foldable ROPS. With a difference in folded ROPS clearance provided and regulation requirements of only about 300 millimeters, reaching a common ground of convenience and safety is plausible. Aside from simply raising the point at which the ROPS folds to make up for the difference in clearance distance provided and required by standards, there are other possible solutions. Some possibilities include an automatically deployable ROPS that activates during the event of a rollover, or an assistive lifting mechanism such as a spring or lever arm mechanism to ease manually raising a folded ROPS. These results also provide tangible insights into the recommendation with regards to seat belt use while operating a tractor with the ROPS in the folded position. In doing so, through revising recommendations and regulations, if more tractor operators are educated on proper use of ROPS and the recommendations for seat belt use, it is hopeful that this study could assist in the reduction of tractor rollover related casualties and injuries.

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