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Reducing occupational fatalities by using NIOSH 3rd generation automatically deployable rollover protective structure

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ABSTRACT

Each year tractor rollovers cause injuries or deaths for farmers despite the fact that an effective safeguard was available in the form of a rollover protective structure (ROPS); however, many ROPS were removed by the tractor's owners, because the ROPS is too tall to allow tractors to enter farm fields because it may damage produce located on low hanging tree branches while working in an orchard, and the loss of crops means loss of money for farmers.

The NIOSH AutoROPS will provide the same level of protection as the conventional ROPS, but instead of having the post as one solid part as with the ROPS, the AutoROPS has a fixed posts located inside the outside deployable posts to meet the farmer's need of low clearance.

This study addressed the need to build and test the NIOSH 3rd generation of the AutoROPS model based on Alkhaledi et al. (2002) model, which was smaller in size with low overhead clearance zone and to insure that the built model would comply with the SAE J2194 standard for static testing.

The results showed that the 3rd generation AutoROPS absorbed all applied loads in sequence, thus satisfying the SAE J2194 standard requirements. No signs of failure were shown for the AutoROPS' base and the latching mechanisms. The successful testing the NIOSH designed AutoROPS lead to the development of the ANSI/ASABE S599 industry standard, which was approved November 2010 as an American national standard for standardized deployment performance of an automatically deployable ROPS for turf & landscape equipment.

1. Introduction

Safety is the ability to perceive and recognize hazard in order to take corrective actions and minimize any loses (Brauer, 2006). The agriculture Industry remains among one of the most hazardous occupational industries to date. Tractor rollovers are the leading cause of occupational agricultural fatalities in the United States, 1412 farmers/workers died between 1992 and 2005 from tractor rollover (Myers, 2009). The protection of the farmer/worker from possible death or injuries is still a major concern for safety researchers.

After 1985 American tractor manufacturers began voluntarily adding ROPS on all farm (agricultural) tractors sold in the United States over 20 horsepower. The rollover protective structure (ROPS) was developed to prevent farm tractor's operators from fatal injuries in case of an overturn incident by providing a protection zone for the operator compartment (see Fig. 1). NIOSH has estimated that fatality rates due to tractor rollover could be reduced by at least 71% if all tractors in the U.S. were equipped with ROPS (Myers, 2009).

There are many tractors without a ROPS still in use today. These tractors were either built before 1986, or have had the protective structures removed. The question is why would someone remove the ROPS, which could save his life? One answer would be because some farmers/operators removed the ROPS because they need low overhead clearance, (e.g. the convenience of driving their tractor below low hanging trees limbs without knocking some crops out of the trees). Another reason for removing the ROPS is the belief, particularly among older farmers, that they know how to control a tractor, without the need for the ROPS (Alkhaledi et al., 2002).

The need for a more convenient ROPS to fit the farmer's use requirements becomes more important than ever, this is where the idea of the AutoROPS originated. The NIOSH AutoROPS will provide the same level of protection as a conventional ROPS, but instead of having the post as one solid part as with the ROPS the AutoROPS will have the post as two telescoping parts; it has one part located inside of the other to meet the farmer's need of low

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Fig. 1. Factory ROPS mounted on the tractor.

clearance zone. The deployable part of the AutoROPS will only deploy in the event of tractor rollover to provide protection for the operator from severe injury or death.

Some of the fatalities were due to the removal of the ROPS from the tractor, and/or from the driving without wearing a seat belt. AutoROPS are more effective when used in conjunction with seatbelt, because without a seat belt, the operator may not remain in the safety crush zone of the ROPS during an overturn (Kelsey et al., 1996).

2. Review of relevant literature review

Alkhaledi et al. (2002) did a study to increase the level of AutoROPS safety and effectiveness based of SAE J2194 Static Load Standard tests. The first purpose of Alkhaledi work was designing a new generation of the AutoROPS (the NIOSH 3rd generation AutoROPS) that is smaller in size and more cost effective than the 2nd generation AutoROPS which was bulky and heavy. The second purpose was designing the base model for the 3rd generation NIOSH AutoROPS and insures it would be able to absorb the impact energy (impact loads) created during a tractor overturn.

The design for the NIOSH 3rd generation AutoROPS was structurally analyzed using ANSYS® a finite element analysis (FEA) program, the tests and simulations were successfully completed. The results proved that the 3rd generations AutoROPS and the base did absorb all loads applied in sequence and thus satisfied the SAE J2194 standard requirements.

The FEA for the load applied on the AutoROPS was conducted by Gillespie (2000) and focused on the 2nd generations AutoROPS. The study focused on the stresses applied on the posts and the post deflection. Four directions of static loading were applied to the structure to satisfy SAE J2194 standard requirements.

Gillespie determined that the 2nd generation AutoROPS structure satisfied the SAE J2194 standard requirements and no intrusion to the driver's compartment zone was shown. The analysis also indicated that there was no plastic bending at the sliding-fit joint; the study also reported that the structure was heavy and stiff.

Howard (1998) studied the mechanisms performance of the 2nd generation AutoROPS. The study was aimed at the latching mechanisms and energy absorbing (rubber) parts between the deployable posts to insure that they would not fail during impact, and that the upper posts would deploy within the designed time when a rollover signal was sent to pyrotechnic squibs in an internal piston. The results of Howard's study showed the two posts structure consistently deployed in less than 0.3 s and latched securely.

Harris (1995) tested the first generation AutoROPS according to the SAE J2194 ROPS Standard. Those deployable AutoROPS were designed and built for use on the Ford 4600 farm tractor. The tests were aimed to see if the internal mechanisms such as the springs, pistons, and materials could withstand rollover forces, and to confirm that the operator compartment zone would not be compromised in the event of a overturn. The results of those tests showed that the internal and deployment mechanisms worked as designed, and the chosen material withstood the applied loads.

3. Statement of the problem

The purpose of this study was to physically build and test the NIOSH 3rd generation AutoROPS model based on the Alkhaledi et al. (2002) model in the lab to the SAE J2194 static load tests standard. The lab testing was used as a validation of the Finite Elements Analysis model.

The second purpose of this study was to insure the base and the latching mechanisms of the 3rd generation AutoROPS would not fail during testing based on SAE J2194 static load standard tests.

4. Method

4.1. Description of the 3rd generation AutoROPS

The NIOSH 3rd generation AutoROPS was built based on Alkhaledi et al. (2002) design and dimensions with one modification added to it. The design for 3rd generation AutoROPS consists of the outside deployable posts and inside fixed posts and an overlapping area in between them.

The AutoROPS was constructed using square and rectangular steel tubing. The telescoping deployable top section was constructed from (3.5□ × 3.5□ × 0.1875□) square mild A-500 steel tubing. The fixed lower section was constructed from (2□ × 3□ × 0.25□) rectangular steel tubing, making this more similar in material and dimensions to the commercially available fixed ROPS than previous AutoROPS designs. The lower fixed posts welded to the base which has two plate connected method around the axle housing by four grade eight bolts (see Fig. 2).

Alkhaledi's AutoROPS design model was modified by adding two gussets to the top corners to increase the strength with adding minimal extra weight to the design. The AutoROPS was installed on Ford 4600 model tractor – located at the NIOSH test laboratory in Morgantown, West Virginia. The nature of the NIOSH AutoROPS is to be in the retracted position, until a potential safety hazard of overturn is determined to be imminent. It is during the deployment time period that potential safety hazards exist that are not

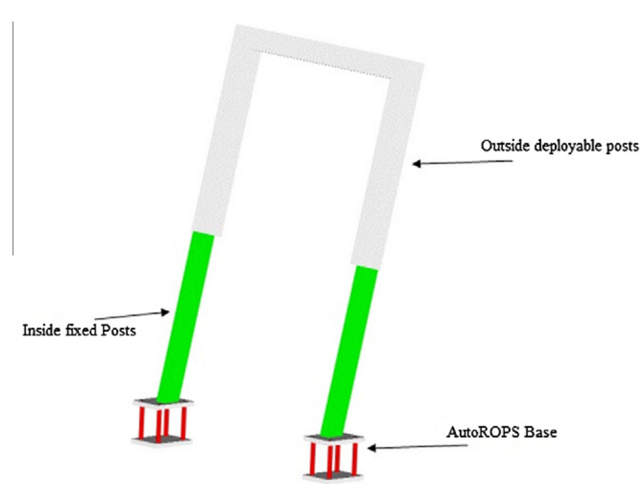

Fig. 2. NIOSH 3rd generation deployable AutoROPS.

present in a traditional fixed ROPS and not addressed in the standards.

This design was tested in a more conservative method by using the maximum weight of the tractor, 8220 lbs instead of the curb weight of the tractor, 5288 lbs. During testing the tires were removed and the base was fixed to the test bed. The base bolts used in the 3rd generation AutoROPS base were pre-stressed to 27,327 psi.

The operator clearance zone was constructed using the SAE J2194 standard. The standard gives mandatory dimensions as well as those, which are dependent upon the particular type of tractor. The clearance zone frame was built out of steel tubing and coated with Styrofoam; then the frame was placed at the proper location on the tractor.

4.2. Procedure

Four sequenced static tests were applied on the AutoROPS structure. The maximum and permanent deflection of the AutoROPS were measured and recorded during the tests. The horizontal loading tests were applied from the rear and the side while the vertical load was applied from the top.

After the four static loads were applied, determination of failure was determined by if the AutoROPS intruded into the occupant clearance zone or if the structure failed to absorb the applied energy of the loading. Success was measured by the ability of the AutoROPS to absorb the required amount of energy without intrusion in to the clearance zone.

The determination of the occupant clearance zone was an important process. Each tractor has its own unique clearance zone, and each zone has its own reference point. This reference point can be determined by the ISO 3462 standard, which calls for the seat to be in the uppermost inclined position (see Fig. 3). Once the seat position is known, the clearance zone can be easily built and modeled.

The static load was applied by a stiff load application device normal to the direction of load application. The static load was distributed uniformly; the rate of the AutoROPS deflection should not exceed 5 mm/s based on the ASAE J2194standard 1997.

4.2.1. First longitudinal loading

The first load was applied horizontally and parallel to the longitudinal median plane of the tractor (see Fig. 3). The load was applied to the upper most transverse structure that would touch the ground first in case of back overtur. The required energy for this impact is:

$$E = 1.4m_t(\text{J}) \quad (1)$$

where m_t is the mass of the tractor.

The mass for this case is 2404 kg (5288 lbs), according to Nebraska tractor test – wheels and accessories were removed, E = 29,785 in lbs (1 J = 8.851 in lbs)

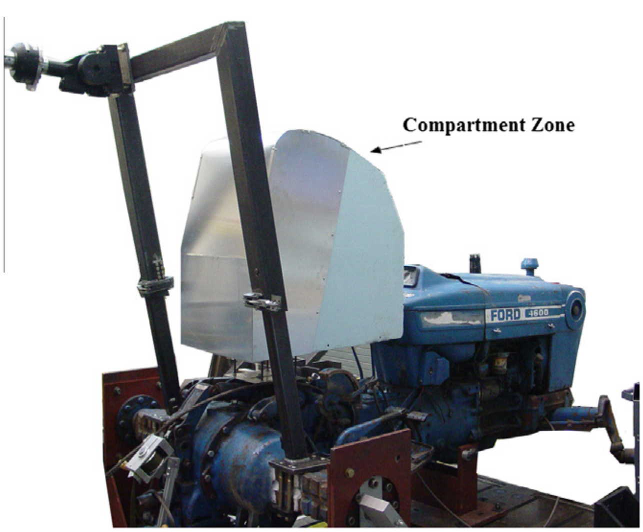

Fig. 3. Typical rear load application.

Fig. 4. Vertical crush application.

4.2.2. Vertical crush loadings

The second load was applied vertically on the 3rd generation AutoROPS. The beam was positioned across the rear uppermost

Fig. 5. Typical side load application.

structural member and the resultant crushing force was located in the vertical reference plane. The force was applied over that point of the AutoROPS, which would support the rear of the tractor when the tractor completely overturned. The force of 16,700 lbs was applied in this vertical crush test (see Fig. 4).

4.2.3. Side transverse loading

The third load applied on the AutoROPS was the side transverse load. This was similar to the first longitudinal load but was applied from a different direction (see Fig. 5). The point of loading was the one, which would touch the ground in case of sideways overturn. The load was applied until the required energy was met. The required energy was calculated as following:

$$E = 1.75m_t(\mathrm{J}) \quad (2)$$

which for this case resulted in E = 37,232 in lbs.

4.2.4. Second vertical crush loadings

The fourth load applied on the 3rd generation AutoROPS was vertical crushing test similar to the second vertical crushing load applied in the second test.

5. Results

Test results for the four different loads applied on the 3rd generation AutoROPS design came out as following:

5.1. Longitudinal loading

The load on the first longitudinal test was gradually increased until it reached 4797 lbs, with the maximum deflection being 9.1 in. The AutoROPS did withstand the applied load and absorbed a total energy of 29,880 in lbs. No intrusion was measured in the operator's clearance zone (see Fig. 6).

5.2. First vertical crush loadings

After applying a vertical crushing force of 16,700 lbs, test results came out positive showing that the internal mechanisms and the deployment bars worked and the chosen material did withstand the applied load. The Auto-ROPS absorbed the required amount of energy without intrusion into operator's clearance zone.

5.3. Side transverse loading

The second load applied on the 3rd generation AutoROPS was the side transverse load. The load on the Side transverse test was gradually increased until it reached 9520 lbs, with the maximum permanent deflection being 5.788 in. The AutoROPS did withstand the applied load and absorbed a total energy of 38,020 in lbs (see Fig. 7). No intrusion was measured in the operator's clearance zone.

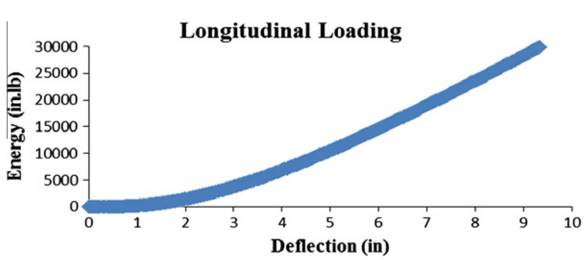

Fig. 6. Energy deflection curve for the longitudinal loading test.

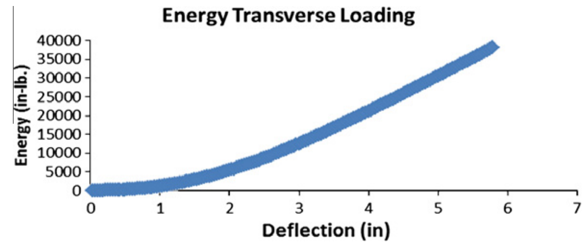

Fig. 7. Energy deflection curve for side transverse loading test.

5.4. Second vertical crush loadings

The second vertical crushing force of 16,700 lbs did not cause the AutoROPS to fail. The Auto-ROPS did absorb the required amount of energy without intrusion into the driver's compartment. The Test results for internal mechanisms in between the two over-lapping posts area for the 3rd generation AutoROPS design came out positive showing that the internal mechanisms and the deployment bars worked and the chosen material did withstand the applied load.

The base of the 3rd generation AutoROPS was observed visually during all loading tests. The Base did withstand all the applied loads with minor bending in the upper plate. The bending did not jeopardize the integrity of the base structure.

6. Discussions

This research has been a continuation of earlier research conducted by Alkhaledi on the 3rd generation AutoROPS. This research was conducted in coordination with NIOSH. The focus for the first part was on building, testing and analysis NIOSH 3rd generation AutoROPS to predict the behavior of the AutoROPS.

The fixed lower posts were shorter and smaller than upper tube ad that was chosen to make the weight lighter but this design created a concern that the lower posts may not be able to pass the load testing, but the lower posts did withstand all sequences of load in all cases. The structure of the base of the 3rd generation AutoROPS was a concern in this study because failure of the base in any rollover incident could lead to failure of the AutoROPS and that may cause injuries and even deaths. The base results were positive. The base did take the entire sequences of loads being applied to it as required by the SAE J2194 standard. The base of the 3rd generation AutoROPS did not fail during loads testing. The base design was light at the same time of the base was strong enough to absorb the required impact energy during a tractor rollover.

The focus for the second part was on building, testing and analysis NIOSH 3rd generation AutoROPS to predict the behavior of the AutoROPS. All the four loads were applied in sequence on the built model of the 3rd generation AutoROPS, and the results met the expectations of SAE J2194 standard. The 3rd generation AutoROPS absorbed the required energy and the AutoROPS did not intrude into the operator's clearance zone.

The overlap room between the AutoROPS was 10 in, which meets the design criteria and gives room for the spring to fit. This design also allows the deployable post to retract all the way down to the base of AutoROPS and to have a height of 39 in only. The latching mechanisms did take the loads and showed no signs of load or stress failure. The size of the overlap between the deployable and fixed post was one of the important results in this part of the study, because the overlap between posts had to be large enough to hold the latching mechanisms inside and still be able to hold the two posts together during any case of loading being applied at the AutoROPS.

When the loads where applied the entire AutoROPS posts did bend, and this was good sign because when the entire post bends

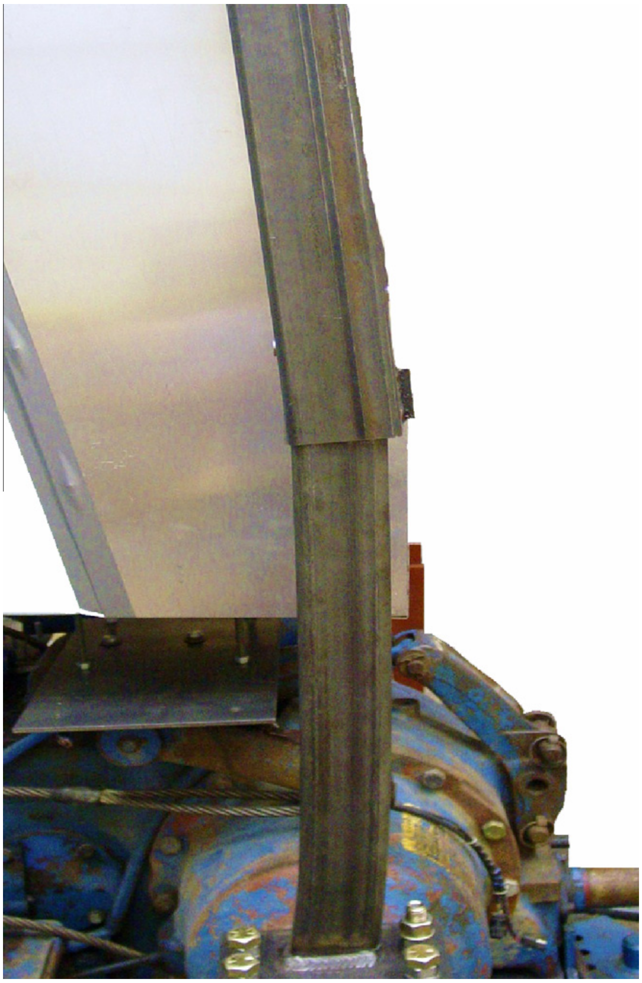

Fig. 8. The post bending during longitudinal loading.

it showed that the load was distributed over the entire posts, but if only the lower part of the vertical posts did bend it shows that the force was concentrated only in the bended portion of the AutoROPS posts and that will cause the AutoROPS to fail faster (see Fig. 8).

Reducing the 3rd generation AutoROPS weight played a major role in this design; because tractors consume less fuel with less weight and reduce make the cost of manufacturing AutoROPS with more acceptable price range.

7. Conclusion

In closing, the deployable AutoROPS is a novel idea to protect the tractor operator and to meet his need of having a low clearance. This study has shown that AutoROPS do the intended job of offering an option to the fixed ROPS and providing sufficient operator protection, and also could minimize the injuries in the case of a tractor rollover. Although the AutoROPS has proven effective in this research, it is necessary to continue research on future improvements of the AutoROPS. The possibility of saving even more lives makes the continued research worth looking at.

8. Recommendation and general safety tips

Since the 3rd generation AutoROPS does not guarantee the safety of the tractor operator by itself, it is necessary to be familiar with useful safety instructions. AutoROPS cannot be expected to protect a tractor operator in the event of a rollover without a seatbelt to hold the operator in the protected compartment (clearance zone).

Employers should provide safety training to his workers, including information regarding potential hazards and safe operation of equipment. Instructions for operating equipment safely, such as downshifting and reducing speed when descending a hill, can help workers to avoid injury. Never try to construct your own AutoROPS – there are too many variables in mounting and metal strength to design a rollover protection system which can protect you.

Disclaimer

The findings and conclusions in this report are those of the authors and do not represent the views of NIOSH. Mention of company names does not imply endorsement by NIOSH.

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