Implementing and Developing Industry Standards in the Design of Agricultural Safety Systems

E.A. McKenzie[1], Jr., Ph.D., P.E.
M. Ronaghi[1], MSME, MSAE, MBA
J.R. Powers[2], Jr., BSEE
NIOSH, Morgantown, WV

T.J. Lutz[1], BSME, P.E.
NIOSH, Pittsburgh, PA

Abstract

In 1993, approximately 132 agricultural tractor overturn fatalities occurred per year (Myers and Snyder, 1993). Ten years later, the number of fatalities is still in excess of 100 each year (Myers, 2003). The use of rollover protective structures (ROPS) on farm tractors, along with operator seat belt use, is the best known method for preventing these fatalities. One impediment to universal ROPS use, however, is low-clearance situations, such as orchards and animal confinement buildings. These agricultural low-clearance environments, involving "low-profile" tractors where traditional ROPS may not be feasible, are exempted from ROPS use as stated in OSHA 1928.51(b)(5)(i & ii). To address the need for ROPS that are easily adapted to low-clearance situations, the Division of Safety Research (DSR), National Institute for Occupational Safety and Health (NIOSH), developed a passive safety device to protect tractor operators in an overturn event. The automatically deploying, telescoping ROPS (AutoROPS) consists of two subsystems. The first is a retractable ROPS that is normally mounted to the tractor axle and latched in its lowered position for day-to-day use. The second subsystem is a sensor that monitors the operating angle and rate of roll on two axes of the tractor. If an overturn condition is detected by the sensor, the retracted ROPS will deploy and lock in the full upright position before ground contact. The AutoROPS has been tested under both field and laboratory conditions prescribed in the ROPS performance industry standard, SAE J2194.

The adoption of such a new agricultural safety device is based upon compliance with the existing industry standards and the development of new performance standards when necessary. This presentation will describe the process of: (a) determining the necessary standards for design and testing criteria, (b) interpretation of the chosen standards, (c) implementing the testing procedures described in the standard to new and existing agricultural safety devices or systems, and (d) developing new performance standards in conjunction with the American Society of Agricultural and Biological Engineers (ASABE).

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[1] Co-Author, Presenting
[2] Co-Author, Not Presenting

Introduction

Tractor overturns are the leading cause of fatalities in the agricultural industry. Approximately 132 fatalities occur per year (Myers and Snyder, 1993). The use of a rollover protective structure (ROPS), along with concurrent seat belt use, is a system with the potential of preventing these fatalities. Although ROPS use is increasing (Zwerling, et al., 1997), the number of overturn-related fatalities per year has not been declining significantly (National Safety Council, 1997).

One impediment to ROPS use is low-clearance situations, such as orchards and animal confinement buildings. Many smaller tractors are now equipped with manually extending or foldable ROPS for use in such situations. However, between 10% and 20% of new tractors are reported to be operating without ROPS (Myers and Snyder, 1993). Decreased use or non-use of manually extending or foldable ROPS may occur because of a need to operate these tractors in low-clearance situations. A ROPS will only provide protection if the operator chooses to properly deploy them.

Current data on injuries and fatalities due to the lack of manual deployment of adjustable ROPS is absent. To address the need for ROPS that are easily adapted to low-clearance situations, NIOSH has adopted the innovative technology used to protect drivers and passengers from overturn hazards when operating convertible automobiles (Mowry, 1999; Mercedes-Benz AG, 1995; U.S. Department of Transportation, 1989). NIOSH/DSR has developed a prototype telescoping ROPS system that automatically deploys (AutoROPS). The NIOSH AutoROPS is a passive device consisting of a retractable ROPS that is normally latched in its lowered position for day-to-day use, and a sensor that monitors the operating conditions of the tractor. If an overturn condition is detected by the sensor, the retracted ROPS deploys and locks in the full upright position before the overturning tractor contacts the ground.

Static load testing and field upset tests of the NIOSH AutoROPS have been conducted in accordance with SAE J2194. Additionally, timed trials of the AutoROPS deployment mechanism were performed. The NIOSH designed system has successfully completed each of the required tests, meeting or exceeding the industry standards.

General Description

The NIOSH AutoROPS is an electronically controlled deployable ROPS system consisting of the base (stationary) section containing the latching system, the crossbar (deployable) section, and the electronic control section (Powers, et al., 2000). The system is normally operated in its retracted position, at a height in the proximity of the operator’s shoulder and remains in this retracted position until the electronic rollover sensor initiates deployment of the AutoROPS. The deployed height of the structure is approximately equal to the height of a commercial fixed ROPS. The height of the NIOSH AutoROPS in the retracted position was established based upon the sitting mid-shoulder height for a 5th percentile female (NASA, 1978).

Initial Concept/Design

The concept for an automatically deployable rollover protective structure (AutoROPS) was to have a passive device that could be constantly in the retracted (or armed) position until a rollover was detected and then would be deployed into the protective position. At the time of initial (1995) concept no other agricultural device as described existed, but some automakers had similar devices. Acceptance by the agricultural manufacturers required that applicable industry safety standards must be satisfied. The most applicable standard was for wheeled agricultural equipment, SAE J2194. This standard allows three methods for acceptance: (a) static laboratory testing, (b) field upset testing, or (c) dynamic laboratory testing. The nature of the AutoROPS required that two parts of SAE J2194 be utilized. The static laboratory test would be used to satisfy the strength and energy absorption of the AutoROPS and the field upset test would be used to satisfy the functionality and performance of the AutoROPS.

The laboratory testing design was awarded to West Virginia University (WVU) under a government contract, while the initial design of the 1st generation AutoROPS was performed at NIOSH. The field upset testing site was located at NIOSH's Pittsburgh Research Laboratory (PRL) because of the availability of space for the two required test pits: one for the rear upset test and the second for the side upset test. A Ford 4600 tractor was chosen for the prototype AutoROPS design. Two tractors were purchased: one for laboratory testing and one for field testing. The field testing tractor had to be modified for remote control operation, as well as protecting the tractor from structural damage so that it could be used in repeated upset tests. It took nearly two years to prepare the tractor before the first upset test was conducted in the spring of 1999. Figure 1 shows the tractor at the time of purchase and Figure 2 shows the tractor after the refurbishing with the remote controls, first generation AutoROPS, and the protective structure.

Figure 1. Ford 4600 When Initially Purchased - 1998

Figure 2. Ford 4600 after Remote Control with First Generation AutoROPS - 1999

AutoROPS Development

The NIOSH AutoROPS has had 3 major design changes in the past 10 years. These will be briefly discussed in the following sections that will highlight the obvious changes and the design philosophy for each.

First Generation AutoROPS

The first AutoROPS design was designed to prove a concept and most of the effort was put towards having a successful detection of an overturn event and a successful deployment of the AutoROPS. The first generation was constructed of telescoping round steel tubes with a deployable crossbar tube (inside tube) and a stationary base (outside tube). The deployment energy was supplied by stored energy of compressed springs inside the tubes. The AutoROPS was retracted using internal hydraulic cylinders and deployed by means of a pyrotechnic squib system. The first generation system is shown in figure 3. The AutoROPS is shown in the deployed position on the Ford 4600 in figure 2.

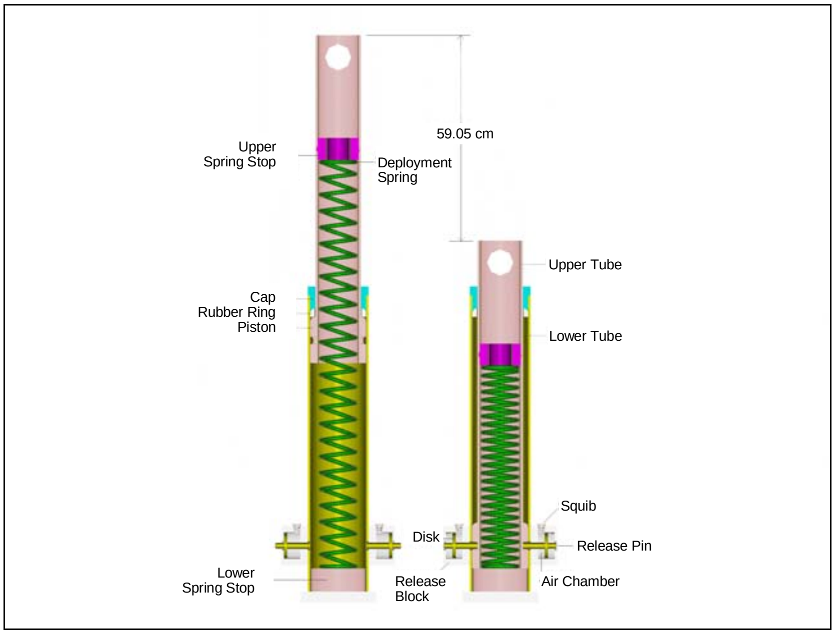

Figure 3. NIOSH First Generation AutoROPS in Deployed Position and Retracted Position

<u>Second Generation AutoROPS</u>

To latch the first generation AutoROPS in the retracted position or to release it to the deployed position was a labor intensive process. The intent of the second generation design was to reduce the labor required to prepare the AutoROPS for service. The other area of emphasis was to eliminate using "one-time use" pyrotechnic squibs. The goal of the second generation design was to eliminate the cost and danger related to the use of squibs (McKenzie and Etherton, 2002). To do this, the system had to have a reusable latch and release mechanism. The rest of the system remained virtually unchanged. The second generation design is shown in the retracted position (Figure 4) on a Ford 4600 in the laboratory setting.

Figure 4. Second Generation AutoROPS on Ford 4600 in Lab

Third Generation AutoROPS

The previous two designs were effective but did not resemble an actual commercial ROPS. The major emphasis of the third design was to produce an AutoROPS that represented a finished product in lieu of a prototype design. This was accomplished by eliminating the hydraulic cylinders, reducing the weight, using square tubing, switching the deployable crossbar tube (outside tube) and the stationary base (inside tube), and allowing the latch and release mechanism to be on the deployed section rather than the fixed section. This design (Figure 5) is dramatically different in looks, material, and fabrication from the proof-of-concept predecessor shown in Figures 2 and 4 (McKenzie et al., 2003).

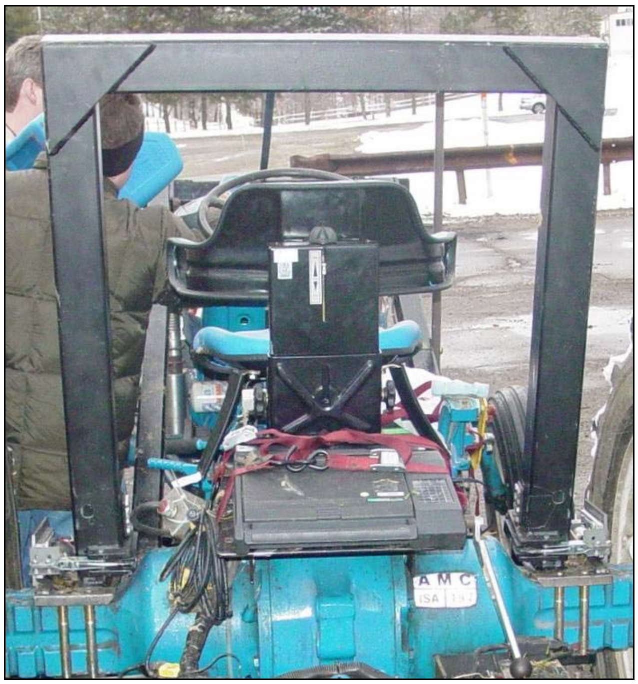

Figure 5. NIOSH AutoROPS Third Generation Design

This same design was adapted for use on a Scag zero-turn commercial lawn mower shown in Figure 6.

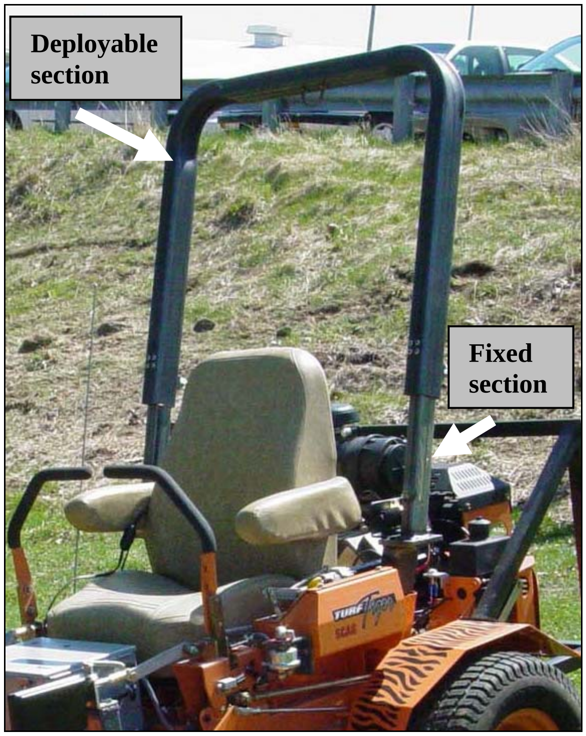

Figure 6. AutoROPS on a Scag Commercial Mower

Composite Materials Use in the AutoROPS

The proper use of ROPS effectively reduces the danger inherent to tractor overturns. Reducing the cost of ROPS, while maintaining their protective performance, is a meaningful approach to increasing the use of ROPS (Kelsey and Jenkins, 1991). Composite materials that have excellent mechanical properties and that can be more efficiently fabricated offer such an avenue. NASA has reported that composite materials are ideal for structural applications where high strength-to-weight and stiffness-to-weight ratios are required. The fabrication methods for making ROPS from composite materials present strong possibilities for off-setting somewhat higher material costs with lower-cost fabrication methods. By replacing steel with a composite material, strength, stiffness, corrosion resistance, wear resistance, weight, and fatigue life of the NIOSH AutoROPS could be greatly improved.

NIOSH researchers conducted a study to evaluate the use of composite materials for ROPS construction. The main advantage of using composite materials is that it would reduce the overall weight of the ROPS. This weight reduction would make adjustable ROPS (manual or automatic) easier to operate and increase their acceptability. The reduction in weight would also lower the tractor's center of gravity and increase its stability. The scope of this research involved identifying candidate materials for the deployable AutoROPS, performing computer model tests of these materials, conducting laboratory tests, and identifying a low-cost method for fabricating a prototype composite ROPS.

Static Testing

The static testing requirements, dictated in SAE J2194 for testing ROPS, were followed and applied to the composite ROPS. Testing to the ultimate load, a normal practice with composite structures was implemented. Load pads were used to prevent local crushing. Testing composite elements differs from testing isotropic material (metal) beam elements in that shear stresses (or strains) and deformations which depend on fiber orientation must be taken into consideration. An adequately slow rate of loading must be used for static tests and the composite joint must be cured and properly bonded prior to testing. The static test was applied to a single post composite and compared with the results from a computer model. The results were very comparable and validated the modeling effort as shown in Figure 7.

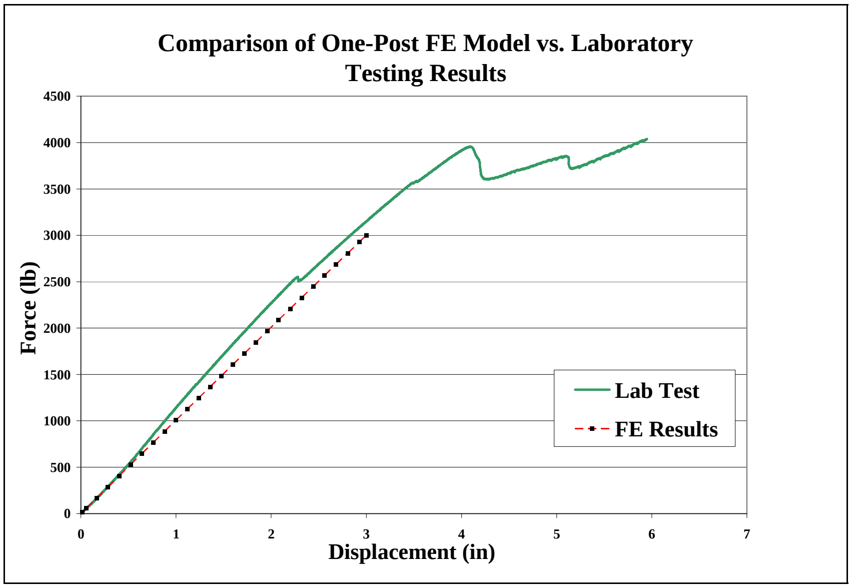

Figure 7. Composite Lab and FE Comparison

With this information a full fixed ROPS was built and tested. The composite structure did not deflect and hence did not absorb the required energy as stated in SAE J2194. The loads for this test exceeded nearly twice the weight of the tractor, and the force applied to a steel ROPS for the same tractor. The results from this test indicated that the static test was not an option for the composite ROPS and would require dynamic testing for SAE J2194 compliance. The composite ROPS before application of the test load is shown in Figure 8. The composite ROPS after the applied load is shown in Figure 9.

Figure 8 Composite ROPS before Static Testing

Figure 9 Composite ROPS after Static Testing

Dynamic Testing

A study on graphite composite laminates indicated that due to rate sensitivity issues, the dynamic testing generated better results than quasi-static (static) testing (Aymerich et al, 1999). This information supported the choice for dynamic testing. A dynamic testing system was designed by a WVU graduate student under a government contract. It was constructed and placed into service at PRL. Initial testing on a fixed steel ROPS indicated that this system was constructed in accordance with SAE J2194 and would give an acceptable level of evaluation of the composite ROPS when tested. Figure 10 shows the dynamic testing structure at PRL.

Figure 10. Dynamic Testing Structure at PRL

Intellectual Property

NIOSH researchers are encouraged to have intellectual property (IP) patented. IP can be very valuable to a company as it can be sold for licensing rights and gives the company leverage if someone tries to copy their product(s). The AutoROPS technology was believed at its inception to have patentable IP; however, the patent process was a very long and expensive process that in the end resulted in the abandonment of the patent application. The following paragraph briefly describes the history of the AutoROPS patent process. The AutoROPS project began in 1995 with the approval of two separate projects: one to design a structure and the second to design a sensor. The two projects developed independently for several years until both were ready to be tested as a complete system. An unsuccessful attempt to patent the AutoROPS technology was initiated within the Institute in 1996. At this time, the technology was not at an acceptable level of the maturity required to pursue a patent, and had to wait until 1999 after further research and development was completed. The U.S. provisional patent application was filed on July 7, 2000, and the Patent Cooperation Treaty (PCT) International Application was filed on June 25, 2001. In December of 2002, the Institute decided to abandon the case, and on January 7, 2003, the patent application lapsed. This process lasted just over four years. During the four-year period, disclosure of the AutoROPS technology had to be done in such a manner that would not jeopardize the on-going patent process.

Partnerships

When the patent process was abandoned, the search for partners began. To date NIOSH has partnered with three organizations on the development of the AutoROPS.

The first partnership (2003) came as a letter of agreement (LOA) with FEMCO, a well-established ROPS manufacturer located in McPherson, KS. They offered engineering expertise, cost evaluations, and manufactured parts for the AutoROPS.

The second partnership (2003) was with Scag Power Equipment of Maysville, WI. Scag is a leading manufacturer of lawn and turf care equipment, including walk-behind zero-turn and riding zero-turn commercial mowers. This company was identified by FEMCO because Scag is considered an industry leader with a progressive design philosophy. They offered manufacturing expertise and a zero-turn commercial lawn mower for design and testing.

The third partnership (2004) was a funding partnership with the Office of Technology Transfer and Commercialization (OTTC) at California State University at San Bernardino (CSUSB). The NIOSH AutoROPS team competed for and was awarded a prototype development, testing, and evaluation (PDTE) grant and a marketing study grant to commercialize the AutoROPS and ultimately bring the technology to the market sector. The PDTE efforts were done by NIOSH and its partners, and the marketing study was contracted to EMERGING GROWTH Enterprises™, LLC (EGE), a partner with OTTC. EGE has been awarded follow-on support for 2005-2007 from OTTC at CSUSB to assist the NIOSH researchers in the completion of the AutoROPS project. Much of the effort of EGE and NIOSH were in identifying potential partners to integrate the AutoROPS into the commercial arena. The main focus area identified in these efforts was the need to have an industry standard for the deployment requirements of the AutoROPS.

Standards Activities

The sponsoring organization for agricultural standards is the American Society of Agricultural and Biological Engineers (ASABE). In 2006, a proposal was filed with the ASABE standards committee to evaluate the need and relevance of a proposed AutoROPS standard. It was decided that a working group would look into the need and draft a standard if necessary. The working group voted in favor of the standard and it was assigned to the PM-52 (Power Machinery) committee for lawn and turf. The proposed standard was designated X-599 and the proposed title was "Standardized Deployment Performance of an Automatic Deployable ROPS for Agricultural and Turf & Landscape Equipment". The majority of the standard was written by NIOSH researchers and EGE staff. The standard is in the final stages and will be voted on by the PM-52 and PM-23 (ROPS for wheeled agricultural tractors) committees in the fall of 2007.

Conclusions

The NIOSH AutoROPS efforts for the past 12 years (1995-2007) have raised the awareness in ROPS usage through dissemination of research efforts. With the expected acceptance of the X-

599 standard by the ASABE governing committees, this technology will be available for manufacturers to implement into new and existing safety products.

Disclaimer

"*The findings and conclusions in this report are those of the author(s) and do not represent the views of the National Institute for Occupational Safety and Health.*"

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