Static Load Test Performance of a Telescoping Structure for an Automatically Deployable ROPS

J. R. Etherton, R. G. Cutlip, J. R. Harris,
M. Ronaghi, K. H. Means, A. Gillispie

Abstract

The automatically deployable ROPS was developed as part of an innovative project to provide passive protection against overturn fatality to operators of new tractors used in both low–clearance and unrestricted–clearance tasks. The primary objective of this phase of the research was to build a telescoping structure that would prove that a ROPS can be built that will (1) reliably deploy on signal, (2) rise in a sufficiently short amount of time, (3) firmly latch in its deployed position, and (4) satisfy SAE J2194 testing requirements. The two–post structure had previously been found to meet deployment time criteria, and design analyses indicated that neither the slip–fit joint nor the latch pins would fail at test loading.

Four directions of static loading were applied to the structure to satisfy SAE requirements. For the series of static loading tests, the raised structure was found to maintain a protective clearance zone after all loads were applied. The structure is overly stiff and should be redesigned to increase its ability to absorb ground–impact energy. Results of dynamic tests and field upset tests are reported in companion articles. The next phase of development is to optimize the structure so that it will plastically deform and absorb energy that would otherwise be transferred to the tractor chassis.

Keywords. *ROPS, Passive protection, Automatic safeguard, Design, Testing.*

Tractor overturns are by far the leading cause of fatal injuries in the agricultural industry (Myers et al., 1998). Rollover protective structure (ROPS) use is increasing (Zwerling et al., 1997), but the number of overturn–related fatalities per year has not been declining significantly (NSC, 1997). There are still some tasks, such as orchard work and barn cleaning, that cannot be performed with a rigid ROPS mounted to the tractor. Innovation is needed to increase the use of lifesaving ROPS within this portion of the tractor population. Passive protection, with ROPS that can automatically move from a lowered to a raised configuration, is needed for tractor work that includes low–clearance operation.

Article was submitted for review in May 2001; approved for publication by the Journal of Agricultural Safety and Health of ASAE in September 2001.

The authors are **John R. Etherton, ASAE Member Engineer,** Safety Engineer, **Robert G. Cutlip**, Mechanical Engineer, **James R. Harris**, Safety Engineer, and **Mahmood Ronaghi**, Safety Engineer, National Institute for Occupational Safety and Health, Morgantown, West Virginia; and **Kenneth H. Means**, Professor of Mechanical Engineering, and **Adam Gillispie**, Mechanical Engineer, West Virginia University, Morgantown, West Virginia. **Corresponding author**: John R. Etherton, National Institute for Occupational Safety and Health, 1095 Willowdale Road, Morgantown, WV 26505; phone: 304–285–5985; fax: 304–285–6047; e–mail: jre1@cdc.gov.

An innovative concept to answer this need has been formulated at the Division of Safety Research, National Institute for Occupational Safety and Health (NIOSH). It is an automatically deployable, telescoping ROPS (AutoROPS) suitable for farm tractors (Powers et al., 2001). The newly conceived NIOSH AutoROPS is signaled to rise automatically to its protective position before the overturning tractor contacts the ground. The primary objective of this phase of the research was to build a telescoping structure that would prove that an automatically deployable ROPS can (1) reliably deploy on signal, (2) rise in a sufficiently short amount of time, (3) firmly latch in its deployed position, and (4) satisfy the SAE J2194 testing requirements (*SAE Standards*, 1997). Dynamic performance of the mechanism was confirmed first (Etherton et al., 2002). Of course, the protective clearance zone that the ROPS provides depends on the operator being held by a seatbelt within the protective clearance zone during an overturn. A tractor equipped with this device can be operated with the ROPS in its lowered configuration, either in low–overhead clearance areas where a rigid ROPS interferes with tractor movement or in open–terrain areas.

The signal that initiates the raising of the structure can be provided by an electrical, optical, mechanical, or other sensing device that can reliably detect tractor dynamic operating parameters indicating imminent tractor overturn. The complete system for the AutoROPS concept consists of: a telescoping two–post structure, two large compression springs, a release mechanism, a latch mechanism, and a sensor that detects when an overturn is about to happen. A self–contained hydraulic retract cylinder resets the device when the tractor use changes from unrestricted clearance tasks to low–clearance operation. Resetting can also be performed after periodic verifications of functionality, or after deployments in near–overturn events.

Automatic operation overcomes the major shortcoming of manually adjustable ROPS, namely that their deployment depends on the actions of the tractor operator. Human strength limitations or safe behavior errors could result in a manually adjustable ROPS not being deployed at a critical moment. The phase of the automatic ROPS (AutoROPS) development reported here is the design, fabrication, and proof–of–concept testing for the fully deployed structure. Subsequent field upset tests were conducted on the strength of the new structure and sensor sensitivity to imminent overturn.

Description

Telescoping Structure

Design of the two–post telescoping structure (fig. 1) was facilitated by use of finite element analysis (FEA) and computer–aided design (CAD) software. Plain carbon steel (AISI 1020 CD) seamless tube was the material selected for fabricating the structure. At the base of the sliding upper post is a cylindrical piston that contains engagement slots for the release pins. One portion of the FEA was modeling the reaction of the sliding–fit joint with respect to SAE J2194 (*SAE Standards*, 1997) test loading on the raised structure.

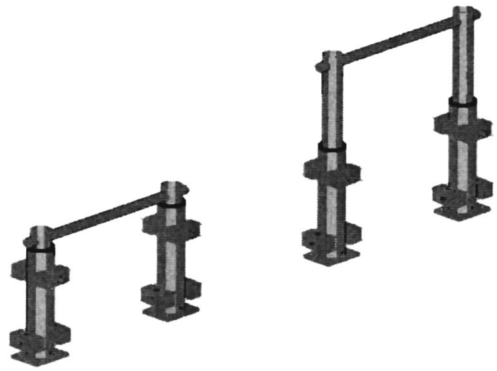

Figure 1. Lowered and raised configurations of the new ROPS design.

Analysis of Bending Stresses

Spring elements were used to model the surface–to–surface contact in the sliding–fit joint. The analysis indicated no plastic bending at the sliding–fit joint. The maximum bending stress in the structure was found to be at the bottom of the base post.

Latch pins on either side of each base post snap into place underneath the upper post to lock it into the deployed position (the latch pins are in the upper blocks in figure 1). These latch pins support the structure, especially for loading in–line with the posts. These pins were analyzed for shear loading in–line with the posts and their diameter (1.9 cm, 0.75 in) was chosen to provide an ample safety factor.

Laboratory Test Procedures

The purpose of SAE J2194 static testing is to simulate, with slowly applied loads, the variety of dynamic loads encountered in various types of overturns (90° rearward, 90° sideways, and 180° all wheels up). The laboratory test is designed so that the energy that the structure absorbs during slow loading will be equivalent to the energy that would be absorbed if the structure impacted the ground in an overturn. The manner in which loads are applied to the ROPS is crucial. Loading the ROPS requires the use of universal joints, or the equivalent, so that the ROPS is free to deflect in any direction while the direction of loading remains fixed. In the crush test, however, vertical forces must be carried entirely through the ROPS. This means that the tractor needs some type of direct support with the ROPS secured to the axle.

Loading Configurations

The first longitudinal load must be applied at one–sixth of the distance from the outermost width of the ROPS. The length of the loading fixture cannot be less than one–third of the width of the ROPS nor longer than 49 mm greater than the minimum, and the energy requirement is 1.4 times the tractor's mass.

The transverse loading application region of a two–post ROPS is at the uppermost side member. The load fixture can be as long as possible, up to 700 mm, and the energy requirement is 1.75 times the tractor's mass.

The second longitudinal loading follows the same loading fixture requirement as the first longitudinal loading. The load is applied in the opposite direction and on the opposite corner. The energy requirement is 0.35 times the tractor's mass.

The vertical crush force is the only load that is not applied according to an energy criterion. The vertical crushing force requirement is twenty times the tractor's mass. The application point is the uppermost structural member. To be conservative, the maximum mass of 3,728 kg, as reported in the Nebraska Tractor Test (1976) for a Ford 4600, was used. Table 1 summarizes the energy and force requirements.

After each load is applied, failure is determined when the deformed structure intrudes on the occupant clearance zone (OCZ) or when the three–point ground plane intrudes upon the zone. This makes the determination of the OCZ a relevant process. Each zone is uniquely determined for each class of tractor. The first step in creating the zone is dependent upon the seat reference point. The seat reference point can be determined by ISO standard 3462 (ISO, 1987) with the seat at its rearmost and uppermost position. The zone can be successfully represented after the seat reference point is known. The OCZ specifications are shown in figure 2.

Sixteen strain gauges (Micro–Measurements CEA–06–250UT–120) were attached to the base and upper post to assess the level of elastic and plastic deformation of the most–stressed side of the AutoROPS structure during the slow load application (5 mm/s). Rings of four gauges were placed at four levels: near the bottom of the base post, midway up the base post, on the upper post near the intersection between base and upper posts, and midway up the upper post. The gauge locations were on the planes of maximum tension and compression and on the neutral axis.

Hydraulic Actuator Control

All static loading tests, with the exception of the vertical crush test, were run via a QuickBASIC program and PC link to an MTS MicroProfiler under displacement control. The loading rate was kept at 5 mm/s. The program constantly computed the total energy applied, based on the area under the force–deflection plot. Loading was provided by 20 kip MTS hydraulic actuators. The vertical crush test was performed under manual displacement control to the required load level.

Results

During July 1999, the AutoROPS structure was successfully tested at the West Virginia University (WVU) Mechanical and Aerospace Engineering labs by the NIOSH/WVU project team. This was the first time that the structure had been load tested in its normally deployed position.

Table 1. SAE J2194 loading requirements (*SAE Standards*, 1997).

Load	Type	Equation
First longitudinal	Energy	$E = 1.4\ m_t$
Transverse	Energy	$E = 1.75\ m_t$
Second longitudinal	Energy	$E = 0.35\ m_t$
Vertical	Force	$F = 20\ m_t$

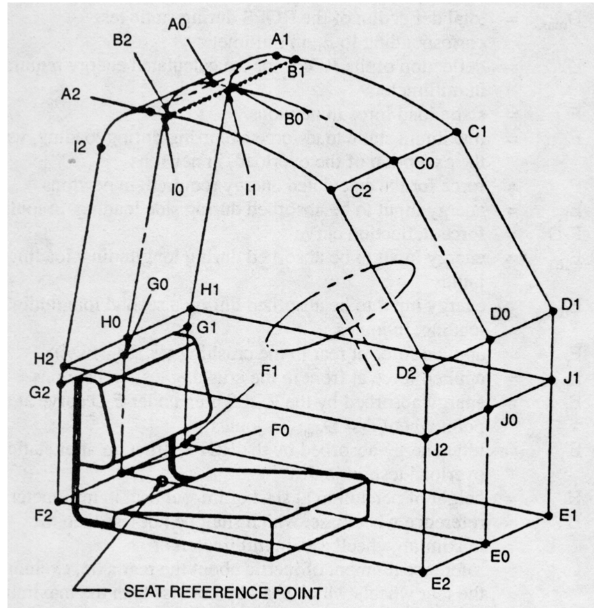

Figure 2. SAE J2194 occupant clearance zone (*SAE Standards*, 1997).

The first longitudinal and transverse tests were terminated when they reached load levels equal to those recorded for an approved standard ROPS on the same tractor (Brewer, 1996). Because of the stiffness of this structure, these load levels were achieved before the energy criterion of the standard was met. The second longitudinal load terminated when it met the energy criterion of the standard and before it reached a load level found for standard ROPS. Due to data collection difficulties, the first longitudinal load was performed twice.

The first longitudinal loading (fig. 3) resulted in 11.11 cm (4.373 in) deflection when 2,149 J (19,011 in–lb) of energy had been transferred. For the transverse loading (fig. 4), there was 5.672 cm (2.233 in) of deflection for 1,341 J (11,861 in–lb) of energy transfer. The vertical crush loading (fig. 5) was terminated when the vertical load reached 74,560 N (16,755 lb), while the second longitudinal loading (fig. 6) produced 8.298 cm (3.267 in) deflection for a 1,378 J (12,194 in–lb) energy transfer.

Strain Results

In general, the gauges near the bottom of the base post had the highest readings during any of the loading cycles. For the first longitudinal load, 1500 microstrain (10^{-6} in/in) in compression and tension was recorded on the peak stress surfaces during maximum loading. During the second longitudinal loading, 200 microstrain (10^{-6} in/in) in compression and tension was recorded at the peak stress surfaces at maximum loading. For the transverse loading, 400 microstrain (10^{-6} in/in) in compression and tension was recorded at the peak stress surfaces at maximum loading. For all cases, readings essentially returned to zero when the load was removed, indicating no plastic (permanent) deformation.

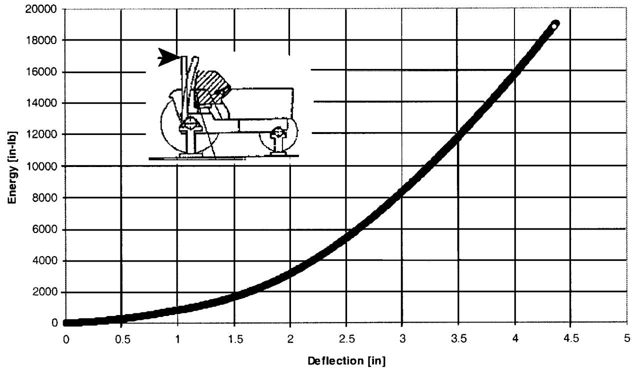

Figure 3. First longitudinal load test.

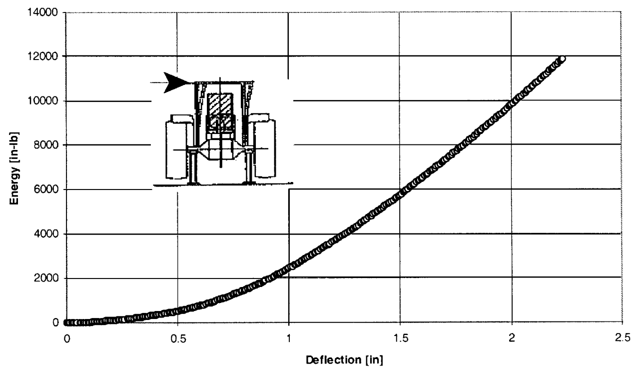

Figure 4. Transverse load test.

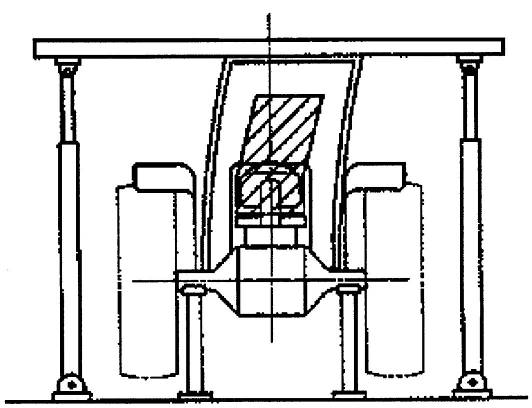

Figure 5. Vertical crush load test.

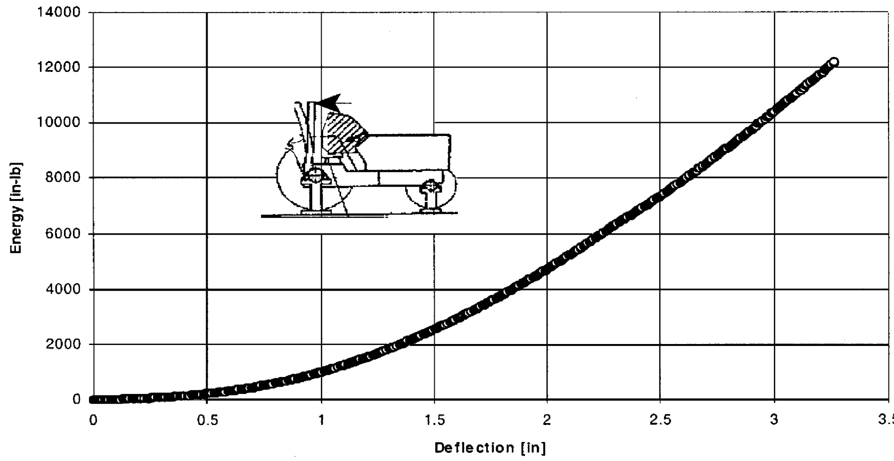

Figure 6. Second longitudinal load test.

Discussion and Conclusions

During laboratory testing, the structure of the new AutoROPS was found to maintain a protective clearance zone as intended. Field testing following the SAE J2194 upset test requirements has been conducted, and the structure performed its protective function in a fully satisfactory manner.

Only limited effort was made in the initial studies to build a structure that optimized the design of components for ease of use and lower cost. The steel tubing selected for this prototype structure was of commonly stocked diameters (17.78 cm, 7 in, and 13.33 cm, 5.25 in) and wall thickness (0.64 cm, 0.25 in). These conveniently chosen dimensions proved satisfactory in the FEA models that were run prior to conducting the static load tests. In the laboratory tests, these dimensions were also shown to provide a safe structure that maintained the required protective clearance zone for the operator and that experienced very little deformation under the required test loads. However, in addition to providing a protective clearance zone, it is desirable for the structure to absorb energy rather than transfer it to the tractor frame. High energy transferred to the frame can result in damage to the tractor. The next phase of development is to optimize the structure so that it will plastically deform and absorb energy that would otherwise be transferred to the tractor chassis.

Acknowledgements

The authors recognize the valuable assistance of John Powers with strain gauge instrumenting and of Rick Current and Brad Newbraugh with strain gauge application.

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