

ROPS Design and Testing for Agricultural Tractors

Final Performance Report

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LIST OF ABBREVIATIONS

ASAE – American Society for Agricultural Engineers

LVDT – Linear Variable Differential Transformer

NIOSH – National Institute for Occupational Safety and Health

ROPS – Roll-over Protective Structure

SAE – Society for Automotive Engineers

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ABSTRACT

A roll-over protective structure (ROPS), as described in ASAE S519, is a protective structure designed to minimize the frequency and severity of operator injury resulting from accidental tractor upset (ASAE, 1996). ROPS utilization has shown to have dramatic impacts in reducing fatalities during tractor overturns. But some agricultural tractors do not have appropriate ROPS designs and ROPS are not available. This project investigates and evaluates roll-over protective structure (ROPS) designs for agricultural tractors in the United States to provide operator protection on tractors and in operating conditions not currently available.

Initially, an inventory of agricultural tractor ROPS availability (specifically for older tractors) was conducted. Classification of axle housings and determination of the population of tractors for which ROPS are not available was performed. The most popular pre-ROPS tractors were categorized into 4 major axle categories, with 4 tractors (Ford 8N, John Deere A, Farmall M and Allis Chalmers D17), representing each major axle category. As appropriate ROPS designs had previously been conducted for the Ford 8N and Farmall M, ROPS were designed, constructed and tested, according to ASAE S519 (SAE J2194) for the John Deere A and Allis Chalmers D17 tractors. Both static and field upset tests for side and rear rollover were conducted in accordance with ASAE S519 (SAE J2194). Measured deflection at the energy criteria and during field upset tests were less than the allowable deflection, indicating successful ROPS designs. Radio-controlled John Deere A and Allis Chalmers D17 tractors were utilized in the field upset tests. The axle housing strength tests were conducted on the John Deere A, Allis Chalmers D17 and Allis Chalmers WD 45 tractor models to evaluate the suitability of the axle housing to support a ROPS. All axle-housing strengths exceeded the stress applied during the static longitudinal tests, with a factor of safety greater than 1.6.

This report also presents the results of dynamic deflection of ROPS when John Deere A tractor equipped with radio controlled system was subjected to overturn and analyzes the effect of impulse loading on ROPS design and installation pattern. In order to measure the dynamic deflection of ROPS, a LVDT (Linear Variable Differential Transformer) was installed in same plane in which the deflection of ROPS occurred. The position of tractor was monitored by the MSTs (measuring system of tractor stability). Tractor position, ROPS rotation velocities and dynamic deflection of ROPS were recorded at a 40 Hz acquisition rate. This information can be useful for deployment times for the NIOSH auto-ROPS. The time from instability to the ROPS striking the ground ranged from 0.7 to 1.0 seconds during the field-upset tests. Drawing of the ROPS designs for the John Deere A and Allis Chalmers D17 tractors are presented. This project demonstrates the procedure and feasibility for designing and testing ROPS for pre-ROPS tractors.

SIGNIFICANT FINDINGS

Analysis was conducted that indicates of the 70 most popular tractor models in the United State (Myers and Snyder, 1995), 50.4% were pre-ROPS tractors. Of these tractors, 73% are included in this ROPS design study (includes previous R01 grant involving Ford and Farmall tractors). With the completion of this ROPS design research project, 89.6% of the Pre-ROPS tractors (in the top 70) will have a ROPS design.

ROPS can be successfully designed for the John Deere A and Allis Chalmers pre-ROPS tractors. These ROPS meet ASAE S519 (SAE J2194) standards. Axle housing tests conducted demonstrate the ability of the axle housings to attain the stresses produced during the static longitudinal tests without failure. Factors of safety of 1.6 were attained. The ROPS are able to withstand the forces produced during the field upset tests. The method of measuring ROPS dynamic deflection was developed by using a LVDT. Dynamic deflection occurred during about 0.155-0.2 seconds period. Body rotation velocity could be as high as 200-350 degrees/second when ROPS touched ground. The velocity of the deflection was 63 cm/s. The duration of tractor rollover is about 0.7 to 1.0 seconds.

Maximum dynamic deflection is less than the static deflection at the required energy. Longitudinal static deflection is 22 cm and longitudinal dynamic deflection is 11 cm; lateral static deflection is 25 cm; lateral dynamic deflection is 12 cm. Dynamic deflection provides more effective information for development of engineering control strategies for deployable ROPS.

USEFULNESS OF FINDINGS

The findings of this study reveal the opportunity and approach for mounting ROPS on agricultural tractors. Tractor ROPS manufacturers can understand the opportunities and problems associated with mounting ROPS on pre-ROPS tractors (John Deere A and Allis Chalmers D17). This study also reveals the ROPS designs used to successfully mount ROPS to pre-ROPS tractors.

SCIENTIFIC REPORT

A. Background

Agriculture is considered one of the nation's most hazardous occupations with an estimated death rate of 21 per 100,000 workers in 1996 (National Safety Council, 1997). The National Safety Council estimated 800 agricultural work deaths in 1995. Also in 1995, the National Safety-Council estimated 431 on-farm tractor-related deaths, of which 237 were due to tractor overturns. Although not all the tractor overturn fatalities are considered agricultural work deaths, it represents a considerable percentage. In fact, in 1994 agricultural work deaths were estimated at 890, while tractor overturns resulted in 188 on-farm fatalities. In these two years (1994 and 1995), the ratio of on-farm tractor overturn fatalities to agricultural work deaths rose from 20.6 percent to 29.6 percent.

In a review of the National Institute for Occupational Safety and Health (NIOSH) Fatality Assessment and Control Evaluation (FACE) program, 454 agricultural production fatalities were reported by the State FACE programs from 1990-1994 (Olenchok, 1997). Of these, 178 were tractor-related, with half resulting from tractor overturns. Here the ratio of tractor overturn fatalities to agricultural production fatalities is about 20 percent. A review of agricultural fatalities conducted by Myers and Snyder (1995) concluded, "tractor overturns (are) the leading cause of occupational traumatic death in the U.S. agricultural industry."

Tractor rollovers have been called an "occupational obscenity" by NIOSH (National Institute for Occupational Safety and Health) Director J. Donald Millar (NIOSH, 1993). NIOSH recommends National and community-based programs retrofit farm tractors with rollover protective structures (ROPS) and develop guidelines for the design of ROPS for tractors manufactured before 1971 (NIOSH, 1993).

A ROPS, as described in ASAE S519, is a protective structure designed to minimize the frequency and severity of operator injury resulting from accidental tractor upset (ASAE, 1996). ROPS are designed to absorb energy resulting from the impact of the vehicle (tractor) with the ground surface during an overturn. ROPS utilization has been shown to have dramatic impacts in reducing fatalities during vehicle overturns (Woodward and Swan, 1980; Lehtola and Marley, 1992).

In a study conducted in 1993, an estimated 4.8 million tractors were in use on U.S. farms, of which 2.98 million or 62 percent were not equipped with ROPS (Myers and Snyder, 1995). ROPS are not commercially available for a large percentage of these tractors. Myers and Snyder (1995) found that ROPS are still needed for 1.68 million of the 2.98 million tractors lacking ROPS.

In 1985, tractor manufacturers voluntarily installed ROPS on new tractors as standard equipment (Murphy, 1992). Also, retrofit ROPS are currently available for tractors that were manufactured with ROPS as an option (National Farm Medicine Center, 1997). Although some tractor manufacturers had ROPS-equipped tractors earlier, many tractors manufactured prior to 1970 did not have ROPS as an option and thus the axle mounts were not originally designed with the intent to structurally support a ROPS during an overturn. Such tractors will be referred to as pre-ROPS tractors. Although significant progress has been recently made to make ROPS available for pre-ROPS tractors (Ayers, 1997), there are still many tractors for which ROPS are not available. Prioritization of tractor models regarding ROPS design feasibility and population numbers needs to be evaluated.

Use of ROPS and seat belts can have a dramatically positive affect on the possibility of a tractor operator surviving a tractor overturn accident. Reports of axle casting failures during ROPS testing and actual overturns indicate the tractor structure and ROPS mounting area, and

not only the ROPS strength, may be an area of concern for pre-ROPS tractors. If ROPS can be successfully attached to the axles of pre-ROPS tractors, then this hazard can be reduced.

The Occupational Safety and Health Standards applicable to ROPS on agricultural tractor are described in regulation 1928.51 (Roll-over Protective structures (ROPS) for tractors used in Agricultural Operations), 1928.52 (Protective Frames for Wheel Type Agricultural Tractors - Test Procedures and Performance Requirements) and 1928.53 (Protective Enclosures for Wheel Type Agricultural Tractors - Test Procedures and Performance Requirements). The regulation states that agricultural tractors manufactured after October 25, 1976 (and used by an employee) shall be provided with a ROPS and seat belt. Several exemptions involving low-profile tractors working in orchards and low-buildings are stated. Until recently the legal incentive to retrofit agricultural tractors manufactured prior to October 25, 1976 with ROPS did not exist.

On May 5, 1995, Washington Industrial safety and Health Act (WISHA) Regional Directive 95-4A, addressing ROPS requirements for pre-1976 agricultural tractors became effective (Washington Department of Labor and Industries, 1995). The interpretation accompanying the directive indicates ROPS are required for employee-operated tractors manufactured prior to October 25, 1976. Not only does the directive cover tractors originally built and sold with ROPS or built with ROPS as an option, but also tractors that are structurally engineered in a manner so that the ROPS installation is feasible. The ROPS must also be commercially available for the tractor make and model. It appears this interpretation includes pre-ROPS tractors for which retrofit ROPS are available. Thus any pre-ROPS tractors would meet these regulations if they are appropriately structurally engineered and a commercial ROPS is available. Further clarification explains that the tractor's structure (frame and axle housing) must be engineered with sufficient strength to withstand a rollover with ROPS installed.

Another legislative effort that is currently underway is the result of the Tractor Risk Abatement and Control: The Policy Conference, which was held September 10-12, 1997 at The University of Iowa. The conference was sponsored by the Injury Prevention Research Center at The University of Iowa, Iowa's Center for Agricultural Safety and Health and the Great Plains Center for Agricultural Health, and received financial assistance from the Centers for Disease Control and the Occupational Safety and Health Administration. The purpose of the 3-day workshop was to produce policy options aimed at reducing or eliminating tractor-related injuries. Although still in draft form, the policy recommendations include a time step process requiring ROPS on tractors 1) operated by youth, 2) operated on public roads, 3) operated by employees, 4) resold and 5) eventually all tractors (including pre-ROPS tractors). The workshop participants are continuing to work on a legislative draft titled the Tractor Injury Prevention Act.

This type of legislative effort must be viewed as a ROPS **retrofit** initiative as opposed to a tractor **retire** program for the owners of pre-ROPS tractors for which ROPS are not commercially available. Recognized by the workshop participants as one of the consensus policy recommendations was to fund a research program for ROPS design for pre-ROPS tractors and

for special work environments (i.e., orchards).

Although some ROPS have been designed and are available for some pre-ROPS tractors, ROPS are not commercially available for a large percentage of these tractors. This research effort explores ROPS design and testing for Agricultural tractors without ROPS.

B. Specific Aims

The overall objective of this project is to investigate and evaluate rollover protective structure (ROPS) designs for agricultural tractors in the United States to provide operator protection on tractors and in operating conditions not currently available. The specific objectives include:

- 1) Continued examination and inventory of agricultural tractor ROPS availability (specifically for older tractors) to determine the population of tractors for which ROPS are not available,
- 2) Prioritizing the agricultural tractor population for ROPS design feasibility based on population numbers and ROPS design and mounting feasibility,
- 3) Design, construction and testing of ROPS for the two highest prioritized pre-ROPS tractors (tractors not originally designed with the intent to mount a ROPS) in accordance with ASAE S519 (Rollover Protective Structures (ROPS) for Wheeled Agricultural Tractors, ISO Compatible). This includes conducting both lateral and longitudinal tests in static and field upset conditions,
- 4) Conducting a minimum of four axle housing strength tests for each pre-ROPS tractor to evaluate the torsional strength and design margins,
- 5) Conducting, in accordance with ASAE S519, lateral and longitudinal field upset tests on the NIOSH auto-ROPS (frame only) to evaluate elastic and plastic deformations and dynamic stresses,
- 6) Conducting, in accordance with ASAE S519, lateral and longitudinal field upset tests on the NIOSH auto-ROPS (frame and deployment sensor) to evaluate deployment timing. Video technology will be used to evaluate timing and operator protection. A field-upset test will also be conducted in a high-speed hillside roll condition,
- 7) Evaluating false deployment possibilities in lateral and longitudinal conditions at 45 degree slopes and high speed hill-side test conditions, and

8) Presenting pre-ROPS tractor ROPS and auto-ROPS design and test results to commercial ROPS manufacturer for commercial construction and follow-up field testing.

C. Procedures, Results and Discussion and Conclusion (listed by Specific Aim)

1) Examine agricultural tractor ROPS availability (specifically for older tractors) to determine the population of tractors for which ROPS are not available.

A variety of sources have been used to examine the availability of tractor ROPS and populations. These include the 1998 version of A Guide to Agricultural Tractor Rollover Protective Structures (A Publication of the National Farm Medicine Center, Marshfield Wisconsin), communication with John Myers (NIOSH, Morgantown) and related paper, a recent survey conducted by Mac Legault at Penn State, and a review of ASAE tractor books. The results of this survey are presented in Appendix A. These results include tractor models, numbers made and currently used, ROPS availability, lineage (or similar axle housing categories). The lineage of popular pre-ROPS tractors without ROPS availability is also presented in Appendix A.

The initial effort included identifying and categorizing pre-ROPS tractors in order to determine axle mount designs appropriate for ROPS design and testing. Axle pictures and/or drawings for over 30 tractors were obtained. Based on the acquired pictures/drawing, review of the tractor survey conducted by Myers and Snyder (1995) and discussions with tractor and ROPS manufactures, four major tractor axle housing categories were identified. A tractor axle housing category consists of a group of tractor models with similar axle housing dimensions. Selecting axle housing groups allows one ROPS design to be more easily modified to fit several different tractor models. A representative tractor model for each axle housing groups was determined as the Ford 8N, John Deere A, Farmall M and Allis Chalmers D17.

The Ford 8N tractor axle housing category includes the Ford 8N/NAA/Jubilee/800 series tractors. The second major axle housing category (John Deere A) includes the axle design for the John Deere A, B, G, 50, 60, 70, 520, 620, 720, 530, 630, and 730 tractors. The third major axle housing category (Farmall M) covers the Farmall H, M, Super H, Super M, 300, 400, 350, 450, 460 model tractors. The fourth major axle housing category (Allis Chalmers D17) includes the WD, WD45, D10, D12, D14, D17, D19 and D21 tractors. The number of pre-ROPS tractors in each axle category that are still in use (based on the top 70 tractors listed in the Myers and Snyder, 1995 survey) is also shown in Appendix A. Axle housing drawings and model information for these four categories were obtained from the tractor manufacturers.

2) Prioritize agricultural tractor population for ROPS design feasibility based on population

numbers and ROPS design and mounting feasibility.

Based on the analysis conducted above, prioritization of the agricultural pre-ROPS tractor population was conducted. The list of tractors include 1) tractors for which ROPS are not available or adaptable from other models, 2) tractors for which ROPS are not available but have ROPS adaptable from other models, 3) tractors for which ROPS are available but is either cost prohibitive or is not commercially compatible. Previous research by the PI had produced successful ROPS designs for the Ford and Farmall models. Based on this review, the tractors selected for examination in this project are:

John Deere A (category 3) – A ROPS was designed and tested previously at Colorado State University, but the design is not commercially acceptable. The original design utilizes existing bolt hole in the axle housing (and not the acceptable compression mount). This bolt hole may not be available on the tractors due to bolt shear. So, the original design (relying on the bolt holes) needs modified to provide compression fit.

Allis Chalmers D17 (category 1) – This very popular tractor does not have a ROPS design. The cylindrical axle housing makes a compression fit difficult (but not impossible). A vertical fender mount flange is used in the final ROPS design.

Allis Chalmers WD-45 (category 1) – This is another very popular tractor with a similar axle-housing mount of the AC D17. Axle housing strengths tests were conducted on this model

3a) Design, construct and static test ROPS for the two highest prioritized pre-ROPS tractors.

ROPS designs were initiated for the John Deere A (compression fit) and the Allis Chalmers D17. The specific ROPS designs and drawings will be discussed in section 8. The static ROPS test involved mounting the ROPS/frame combination on a hydraulic ROPS test stand located at the Agricultural Engineering Research Center (AERC) at Colorado State University. The test procedure consists of applying a horizontal force at just less than 5 mm/sec and measuring the force and ROPS displacement. The ROPS testing apparatus utilizes a 10 cm diameter hydraulic cylinder to apply the force and a 90,000 N load cell to measure the force. The ROPS displacement is measured using an electronic potentiometer. Measurements are recorded every second and the test is stopped when the ROPS has met the energy requirement or has failed the deflection criteria. The allowable ROPS deflection is determined utilizing the intrusion/exposure model previously developed (Ayers et al., 1994).

The John Deere A ROPS was mounted on the axle housing. During ROPS test, the force and deflection were recorded and stored in the 21X data logger (Figure 1), and the accumulation of the applied energy on the ROPS was calculated. The John Deere A has a mass (m) of 2467 kg. The equation of the required energy (E) for first longitudinal loading (rear loading) is:

$$E_{it.1} = 1.4m_i \text{ (joules)} \quad (1)$$

So, the termination of the test occurred when the accumulated energy was 3454 joules. The result of test is shown in Figure 2. The relevant deflection of the ROPS is 21 cm. This deflection is less than the intrusion/exposure criteria allowable rear deflection of 28 cm.

Traverse (side) or lateral static testing was also conducted. The required energy for side loading should meet the following threshold:

$$E_{is} = 1.75m_i \text{ (joules)} \quad (2)$$

Therefore, the required accumulated energy is 4318 joules (Figure 3). The relevant deflection of the ROPS is 26 cm, satisfying the 29.5 cm allowable deflection. After testing, neither the ROPS nor axle housing showed signs of cracking or weld separation.

Similar longitudinal and lateral static tests were conducted with the Allis Chalmers D17 ROPS mounted on the Allis Chalmers D17 axle housing. Figure 4 shows the force vs. deflection results for the longitudinal test. The Allis Chalmers D17 tractor has a mass of 2118 kg. The required energy (2965 J) was absorbed at a deflection of 23 cm (Figure 5). The allowable longitudinal deflection for this ROPS design is 41.5 cm. Figure 6 shows the force vs. deflection results for the lateral test. The required energy (3706 J) was absorbed at a deflection of 26 cm (Figure 7). The allowable lateral deflection for this ROPS design is 40.0 cm. The allowable deflections are determined using the intrusion/exposure criteria (Ayers et al., 1994), shown in Appendix B for the Allis Chalmers D17.

3b) Conduct radio control modification of the two highest prioritized pre-ROPS tractors.

After passing the static test, a new ROPS is constructed for the field upset testing. This also involves modifying the tractor operation for remote control. The pre-ROPS tractor is operated by remote control to allow a field upset without the operator being in danger of injury. The remote control system allows the nearest researcher (operator) to be more than 50 m from the tractor during the rollover.

Both the John Deere A and Allis Chalmers D17 tractors have been modified for radio control using the same procedure. The remote control system is based on two normally extended pneumatic cylinders (air power). These two cylinders release the clutch and brake when an electric solenoid is activated from the relay box, allowing the tractor to move forward. The cylinders are oriented such that if electrical power or air pressure is lost, the clutch and brake are automatically depressed, stopping the tractor. The system also incorporates a fuel shut-off and power shut-off into the control box. A 3.78 liter gas tank and sealed battery will also be installed on the tractors. The steering is controlled using a reversible gear motor attached to the steering wheel. The gear motor control is provided through the relay box. The relays are controlled using radio control.

3c) Conduct both lateral and longitudinal field upset conditions.

ASAE Standard S519 was used to design the rear overturn bank, which was used to conduct the longitudinal field upset tests. The bank has a front slope of 60 degrees, width 6.1 m and the height 3.0 m. The landing area is compacted soil with a cone index greater than 1500 kPa. To conduct the longitudinal tests, the tractors are driven at the overturn bank at a speed from 5 to 8 km/hr using the radio control system. The tractors climb the bank and roll over backwards (Figure 8). A sliding rod with friction collar configuration is used to determine the elastic and plastic deflections at the top of the ROPS (Figure 8). The measured deflections are compared to ASAE Standard requirements utilizing the intrusion/exposure model. An LVDT is also used to determine the dynamic deflection characteristics (Figure 8).

The side overturn test is conducted on the same tractors and ROPS. The side overturn bank (specified by ASAE S519) was approximately 1.5 m tall at a slope of 50 degrees. A steel ramp was placed at an angle of 12 degrees from the overturn bank. The tractors approach the ramp at a speed of 16 km/hr (or maximum vehicle velocity). As the right side of the tractor climbs the ramp, the left side descends down the overturn bank, and the tractor rolls over on its side. Side elastic and plastic deflections are measured (Figure 9) and acceptability of the ROPS is determined.

Field upset tests have been successfully conducted for the John Deere A. Rear overturn tests were repeated with one ROPS. Figure 8 shows the deflection of ROPS during John Deere A's rear overturn. The ROPS presented typical characteristics of an under damped response. After the tractor stayed on a rear overturn position, the ROPS' final deflection was about 6 cm. However, the maximum deflection of the ROPS was 11.0 cm when the ROPS hit ground the first time. This maximum deflection is less than the allowable 28 cm deflection, indicating operator protection.

Figures 11 and 12 show the dynamic deflection of the ROPS and the tractor moving status with time. In Figure 11, impact of the ROPS on the ground occurred for a very short time. During impact, roll velocity of the tractor changed from 40 degrees/s to -70 degrees/s, which means the variation of the velocity was 110 degrees/s. The kinetic energy of the tractor was absorbed by both the ROPS and ground. The maximum dynamic deflection of the ROPS was 11.0 cm. But it should be noted that the 11.0 cm of deflection occurred during a 0.075 second period. Therefore, the velocity of deflection was approximately 147 cm/s, which was a critical concern for the ROPS design and strength.

Figure 12 demonstrates the variation of stability index and ROPS' deflection for a second rear roll. The maximum deflection was 8 cm, quite similar to Figure 11. The calculation of stability index (Liu and Ayers, 1999) shows good prediction of the roll-over condition.

Side overturn shows a different dynamic deflection of the ROPS. When a tractor has a side overturn, it slides on a bank first and the whole body rotates around the tipping axle (Liu and Ayers, 1997, 1998, 1999), which may move on the ground. Then the rear wheel, ROPS, front frame and wheel follow a certain pattern to hit or touch ground. The purpose of the ROPS deflection is to absorb the kinetic and potential energy of the tractor (Chisholm, 1979). When the ROPS hit the ground, the roll velocity dramatically changed about 200 degrees/s.

Figures 13 and 14 show dynamic deflection of John Deere A ROPS during the two side overturns. The maximum deflections of the ROPS are 12 and 11 cm, respectively. Again, these deflections are less than the allowable 29 cm deflection indicating an appropriate ROPS design.

Static and dynamic (field upset) tests are based on the ASAE S519 (SAE J2194). It can be noted that longitudinal deflection is less than transverse loading for static tests and field upset tests (Figure 15). To meet the requirement of absorbed energy under static tests, the lateral deflection of the ROPS was 26 cm, and the longitudinal deflection was about 21 cm. However, the maximum deflections of the ROPS under field upset are about 11 cm for rear overturn and 12 cm for side overturn, respectively. But due to ROPS dynamic impact, the maximum impact force may be more for the field-upset tests, than the static test. No axle failures or ROPS weld separations were observe in any field-upset tests.

Field upset tests were also conducted with eh Allis Chalmers D17 ROPS design. The LVDT results from the longitudinal (rear) roll are shown in Appendix C. The maximum ROPS deflection measured of 8.6 cm is far below the allowable 41.4 cm deflection. Lateral (side) field upset tests were also conducted and produced ROPS deflections of 9.8 cm. This measured deflection is again below the 40.0 cm allowable lateral ROPS deflection. Both the John Deere A and Allis Chalmers D17 ROPS designs successfully passed the field upset tests.

4) Conduct four axle housing strength tests for each pre-ROPS tractor to evaluate the torsional strength and design margins.

Most tractors since 1970 have been manufactured with ROPS available, but many tractors produced prior to 1970 did not have ROPS as an option (pre-ROPS tractors) and their axle housings were not designed with the intent to structurally support ROPS during overturns. It is imperative that ROPS be properly designed and manufactured, and also that the entire tractor, including the axle housings successfully support ROPS. Some pre-ROPS tractor axle housings, which were not designed with the intent to support ROPS, may be subject to loading beyond the design range when tractors turn over. It is recognized that rear axle housing are not the only critical tractor chassis structural component that may be subjected to overloading.

ASAE Standard S519 is a standard to define the test procedure and performance criteria for ROPS (ASAE, 1996). However, the Standard does not require repetitive testing or determining the ultimate strength of the tractor chassis structural components. The structural

integrity of pre-ROPS tractor axle housings to support ROPS requires further investigation.

A study was conducted to evaluate longitudinal strength of pre-ROPS tractor axle housings to determine the design margin between longitudinal yield (or strength) torque of the axle housing and the maximum torque subjected during ASAE Standard S519 longitudinal static test. This design margin indicates how well pre-ROPS tractor axle housings can successfully support this ROPS loading.

One John Deere A, 6 Allis Chalmers D17 and 6 Allis Chalmers WD-45 axle housings were tested. The previous working conditions of these tractors were unknown, however these axle housings had seen considerable usage and were not new.

The testing apparatus for the axle housing strength tests included a base frame structure to mount the testing parts and a hydraulic cylinder to provide loads. A force sensor and a potentiometer were mounted on the cylinder to measure the loading force and displacement simultaneously during testing. A data logger was utilized to collect force and displacement measurement at one second intervals.

The axle housing strength test was similar to the longitudinal static test. The differential housing end of the pre-ROPS tractor axle housing was mounted to the testing frame to prevent movement of the housing relative to the apparatus. An I-beam was attached to the axle housing using typical ROPS mounting techniques, and the loading force was applied to the I-beam two meters above the housing using the hydraulic cylinder. The test was conducted by pushing the I-beam to twist the axle housing until it failed or the cylinder was fully extended. The displacement of the cylinder increased linearly with time during testing with the rate of about 0.35 centimeters per second.

The John Deere A axle housing exceeded the strength capacity of the loading apparatus (> than 95,000 N-m). This torsion strength would far exceed the longitudinal stresses applied during the static testing (approx 50,000 N-m). Design margins greater than 2.0 are expected.

Six axle housings were tested for both the AC D17 and AC WD-45 tractors (see Figures 16, 17, 18, and 19 for examples). No brittle fractures occurred. All axle housing strength tests were greater than 60,000 N-m. These axle-housing strengths exceed the maximum stress applied during the D17 longitudinal static test by 60 percent, providing a minimum design margin of 1.6.

5, 6, 7) Conduct lateral and longitudinal field upset tests on the NIOSH auto-ROPS (frame only) to evaluate elastic and plastic deformations.

Conversation with Dr. John Etherton (NIOSH, Morgantown) indicated the auto-ROPS design is near completion, but a complete prototype would not be available for testing for this

project. Efforts in this area to assist the NIOSH auto-ROPS efforts involve the testing of an LVDT to evaluate dynamic forces during a tractor rollover. Field upset testing with LVDT installed has been conducted on John Deere A longitudinal and lateral field upset testing.

From prevention effectiveness and control strategies point of view, the stability index and the ROPS impact indicate an important value with time line when the tractor rolled over. A zero of stability index indicates the tractor loses its stability (Liu and Ayers, 1999). Figures 12 and 14 can be used to derive time relationships between the stability index and the ROPS impact, which is the period of time between when the stability index is zero and when the ROPS hit the ground. This duration of time can be applied in the auto-ROPS development. According to Figures 12 and 14, the duration is about 0.7 and 1.0 seconds based on static stability index. The time is crucial for the design of the auto-ROPS deployment system.

8) Present ROPS design and test results to commercial ROPS manufacturer for commercial construction.

The design and construction of the modified (compression fit) ROPS for the John Deere A has been conducted (see Appendix D for the AutoCAD drawings and construction details). The static and dynamic (lateral and longitudinal) ROPS tests have been successfully conducted according to ASAE S519 (SAE J2194).

Figure 20 demonstrates an assembly diagram of ROPS design for John Deere A. Brackets are designed to compress the axle housing along its vertical planes because John Deere A has no a flat plane either on top or bottom of the axle housing. The front and rear vertical plates are designed with different dimensions of width to apply the maximum contact area on the axle housing. Two reinforcement pieces, which are parallel to the top and bottom surfaces of axle housing respectively, are added and welded to the rear plate in order to increase the rigidity and stability of the ROPS during tractor side overturn.

Because the Allis Chalmers D17 has a cylindrical axle housing, it was difficult to make a compression fit. An unusual mounting configuration was developed. Three vertical fender mount flanges with compression fit are shown in Figures 21, 22 and 23. The top mounting plate was designed with two extension wings (keys). With the compression fit of the top and bottom mounting plates, the two extension wings can fit into the space between two fender mount flanges incorporating a lobe interlock compression fit and resisting the rotation of ROPS rear overturn. The bottom part of mounting plates on the axle housing is designed into two pieces to decrease the pressure from compression fit on the surface of the axle housing and simplify the construction. Detailed auto-CAD drawings of the Allis Chalmers D17 axle housing mounts are shown in Appendix E. The ROPS post and crossbar dimension and orientation is shown in Figure 24.

ROPS designs for the John Deere A and Allis Chalmers D17 have been presented to two ROPS manufacturers (Saf-T-Cab and FEMCO). To date, commercial construction of these designs has not occurred. Although both of these ROPS designs meet the ASAE S519 (SAE J2194) performance criteria, the required tolerances and detailed machining has hindered its commercial acceptance. Innovative mounting techniques of ROPS to axle housings of older, pre-ROPS tractors need further research.

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Ayers, P. D. and J. Liu. 2001. ROPS design and testing for agricultural tractors. ASAE Paper No. 01-8034. ASAE, St. Joseph MI 49085.

Liu, J., P. D. Ayers, S. Legoza and A. Broner. 2000. Dynamic deflection of ROPS and prevention effectiveness evaluation. Proceedings of the NIFS Conference, Dubuque, IA.

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Pankonin, Luke Marriner, Travis Hertneky, Phillip Bacon, Ross Ballard, Ty Fickensher and Mike Olander.

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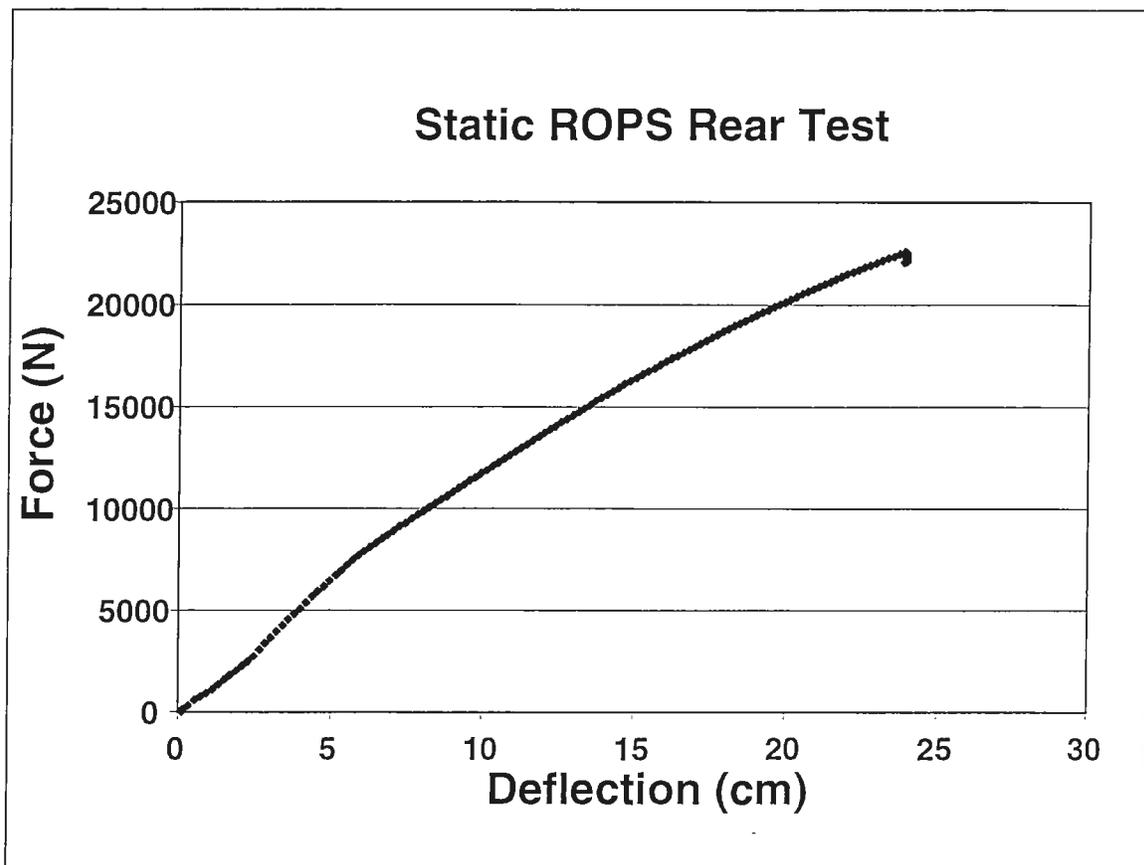


Figure 1. John Deere A static longitudinal ROPS test.

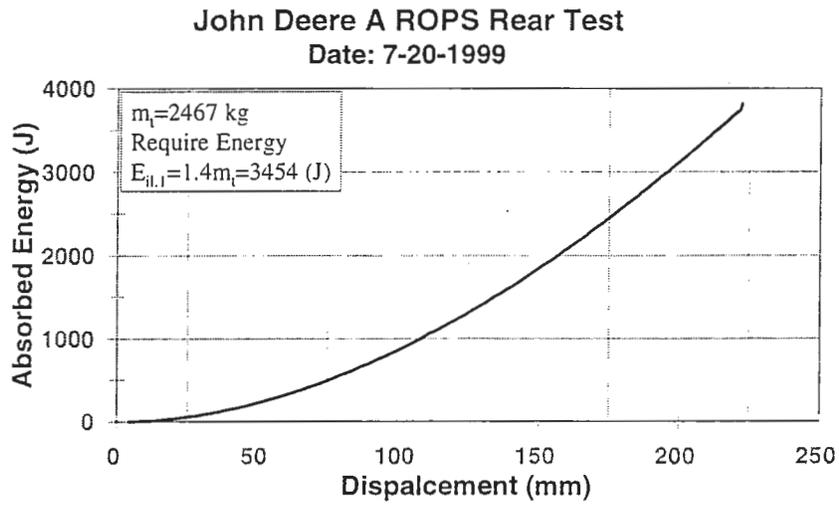


Figure 2. Absorbed energy vs. displacement during rear longitudinal test for the John Deere A ROPS.

John Deere A ROPS Lateral Test

Date: 7-20-1999

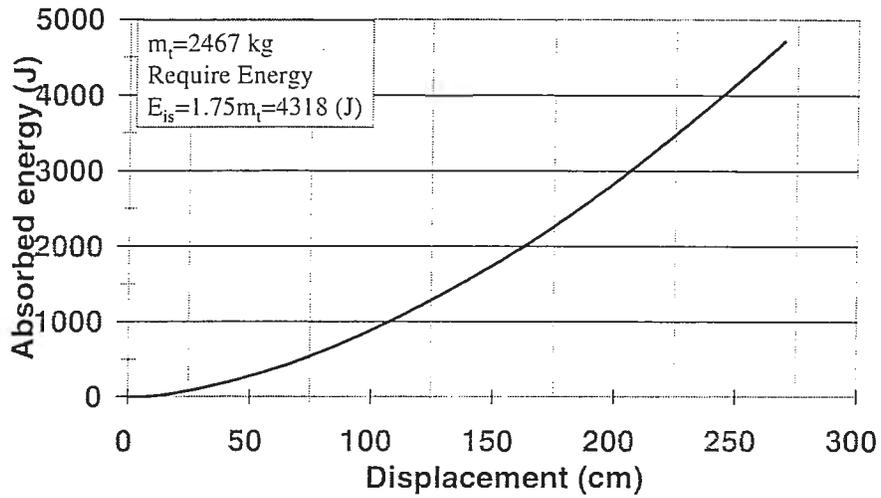


Figure 3. Absorbed energy vs. displacement during rear side transverse test for the John Deere A ROPS.

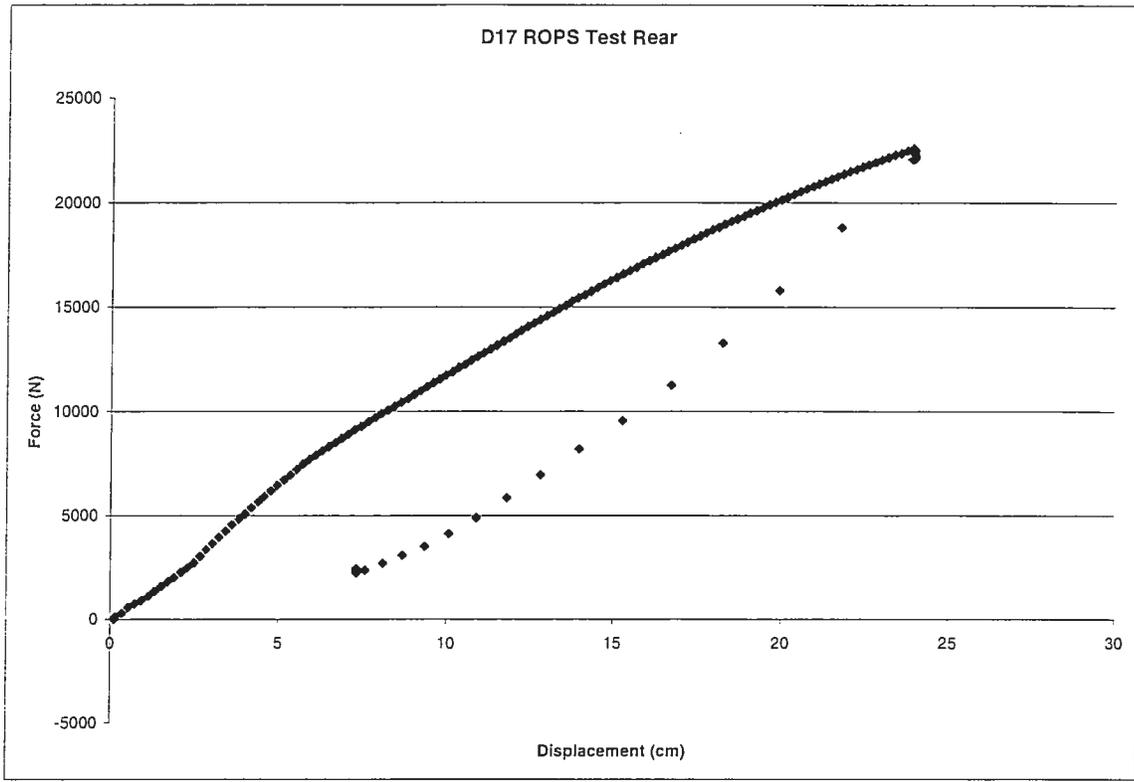


Figure 4. Allis Chalmers D17 static longitudinal ROPS test.

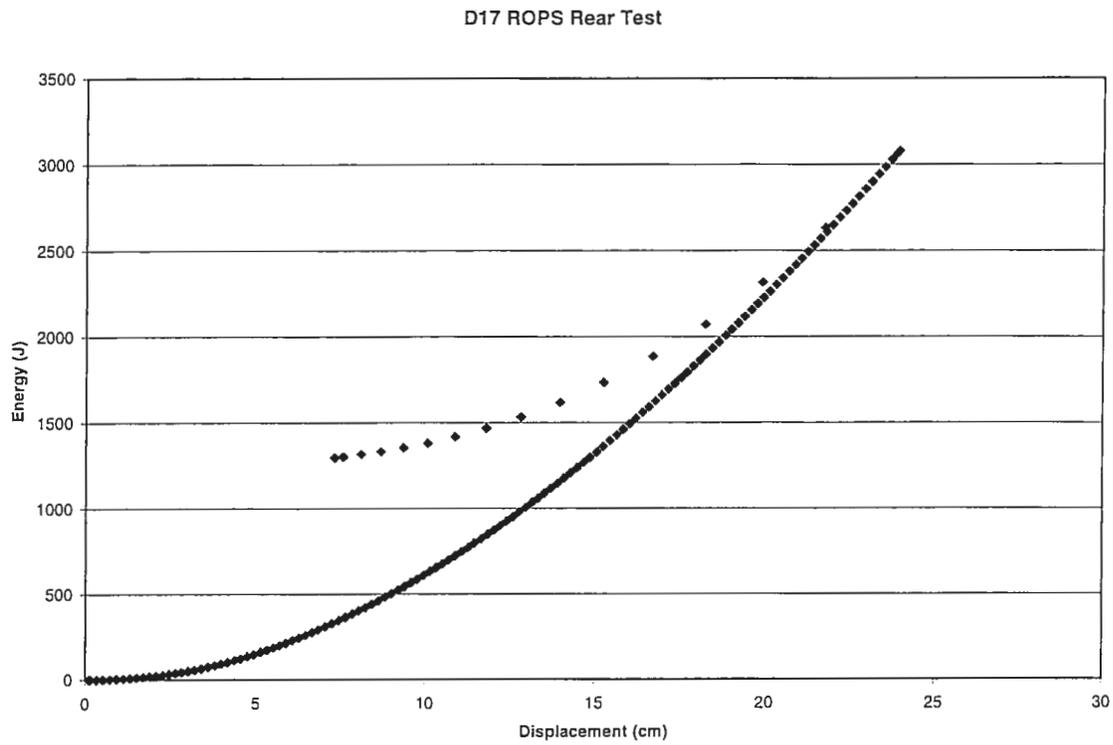


Figure 5. Absorbed energy vs. displacement during longitudinal static test for the Allis Chalmers D17 ROPS.

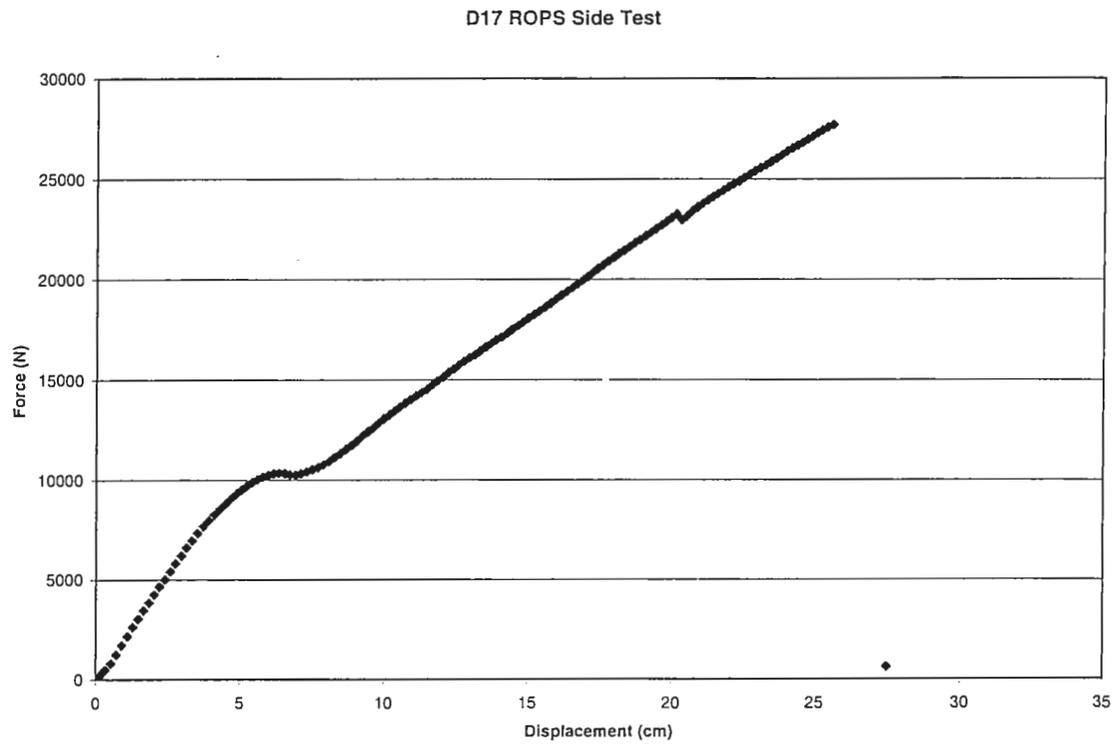


Figure 6. Allis Chalmers D17 static lateral ROPS test.

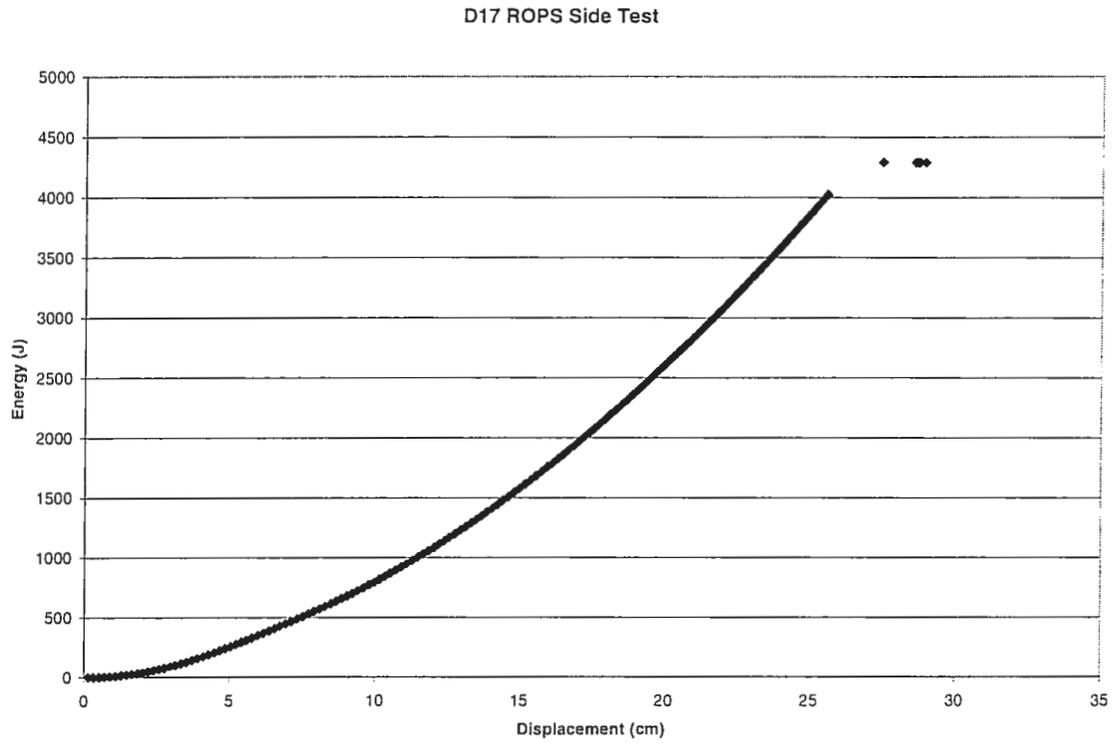


Figure 7. Absorbed energy vs. displacement during lateral static test for the Allis Chalmers D17 ROPS.

LVDT and Installation



LVDT Installation For Rear Overturn

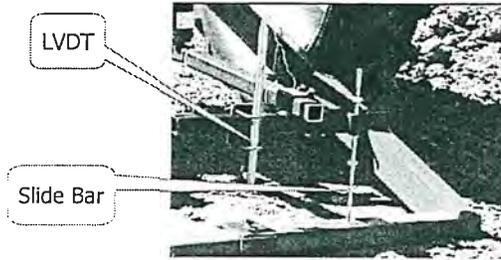


Figure 8. LVDT and slide bar installation on John Deere A.

LVDT Installation For Side Overturn

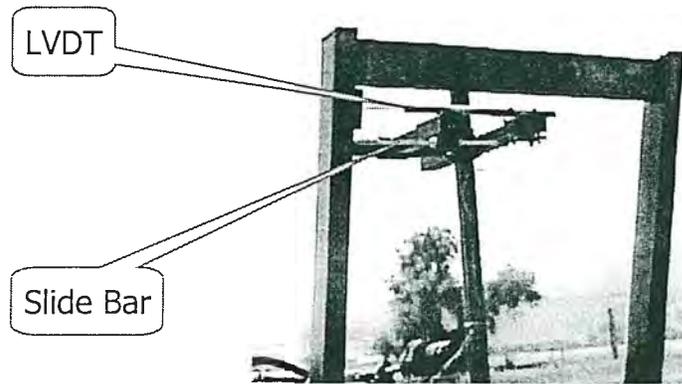


Figure 9. LVDT installation for side overturn.

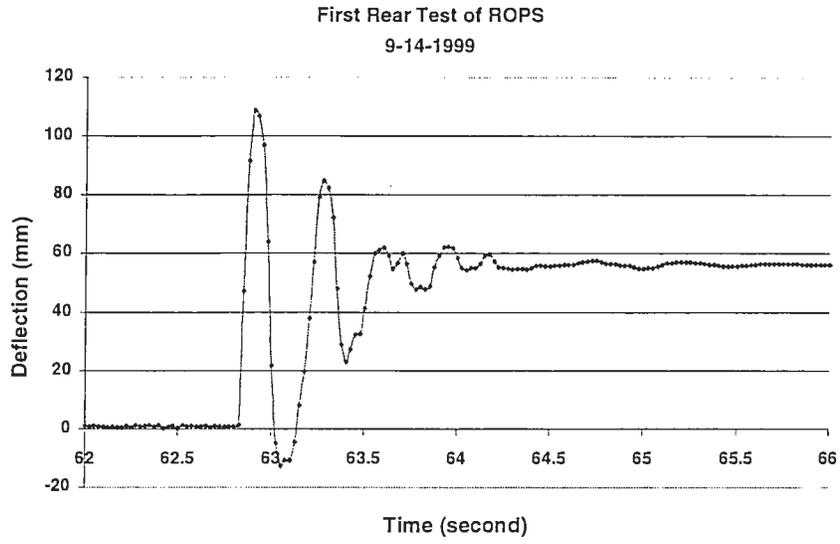


Figure 10. Dynamic deflection of ROPS during John Deere A tractor rear overturn.

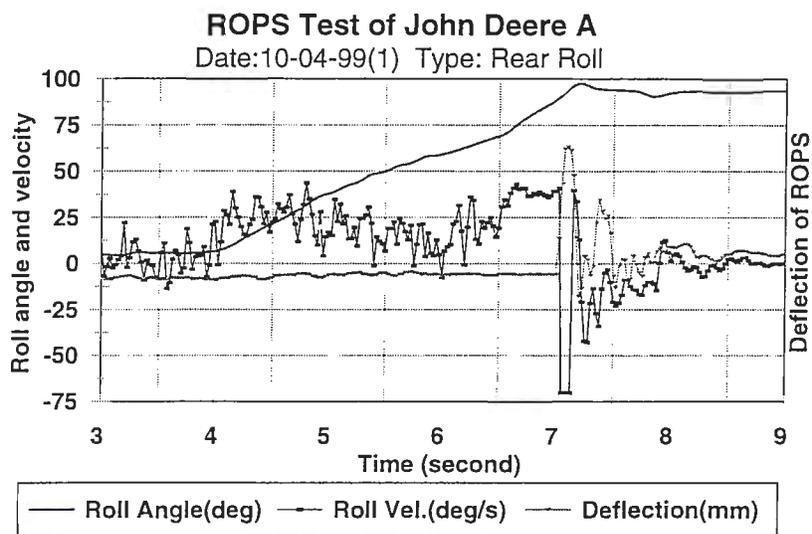


Figure 11. Dynamic deflection of ROPS and tractor rear overturn.

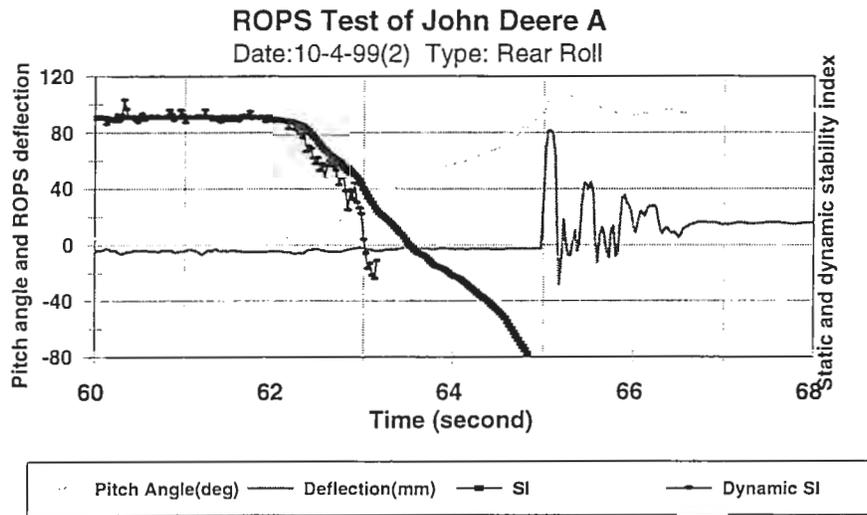


Figure 12. Dynamic deflection of ROPS and tractor stability index during second rear overturn.

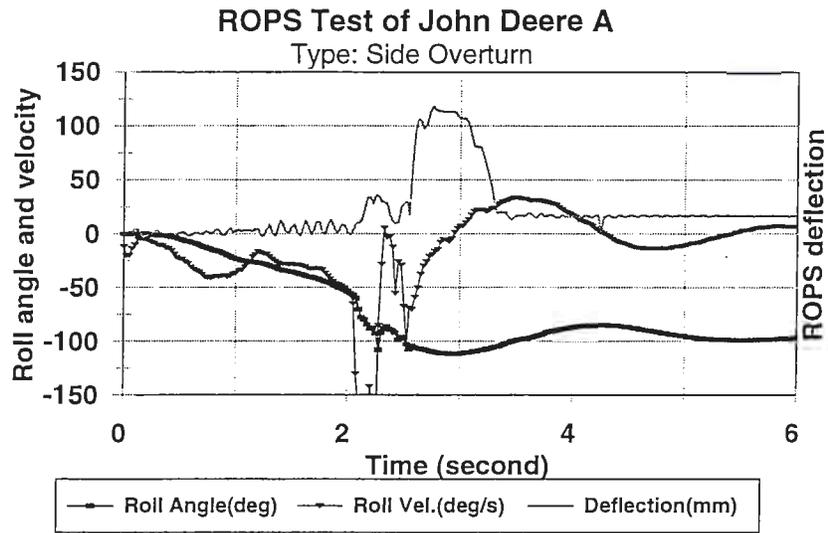


Figure 13. Dynamic deflection of ROPS and roll angle during first side overturn.

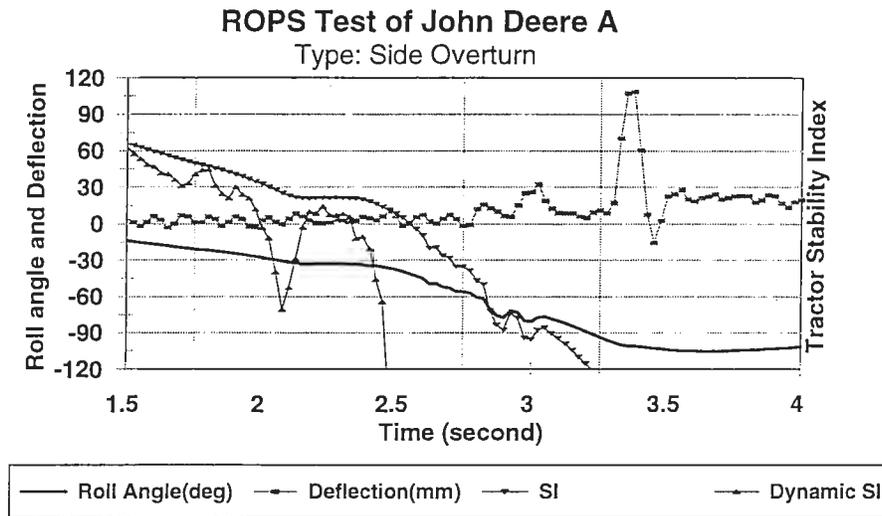


Figure 14. Dynamic deflection of ROPS and tractor stability index during second side overturn.

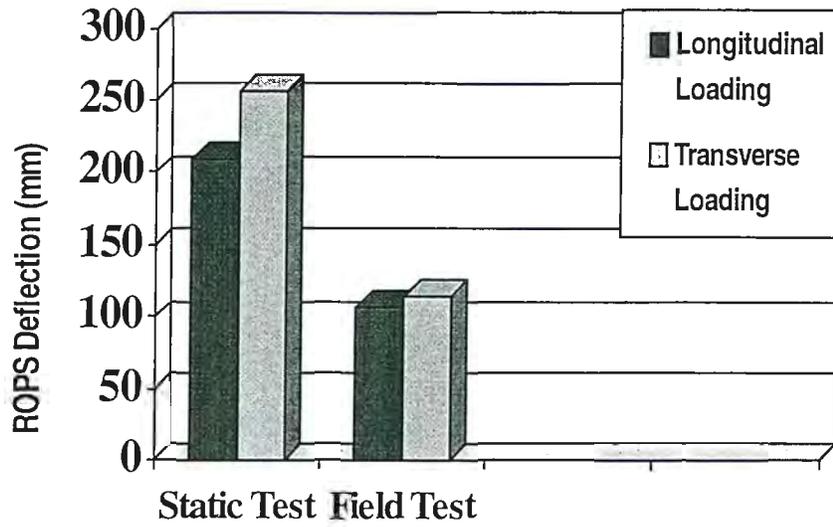


Figure 15. Deflection comparisons for static and field tests.

D-17 Torsion Shear Test

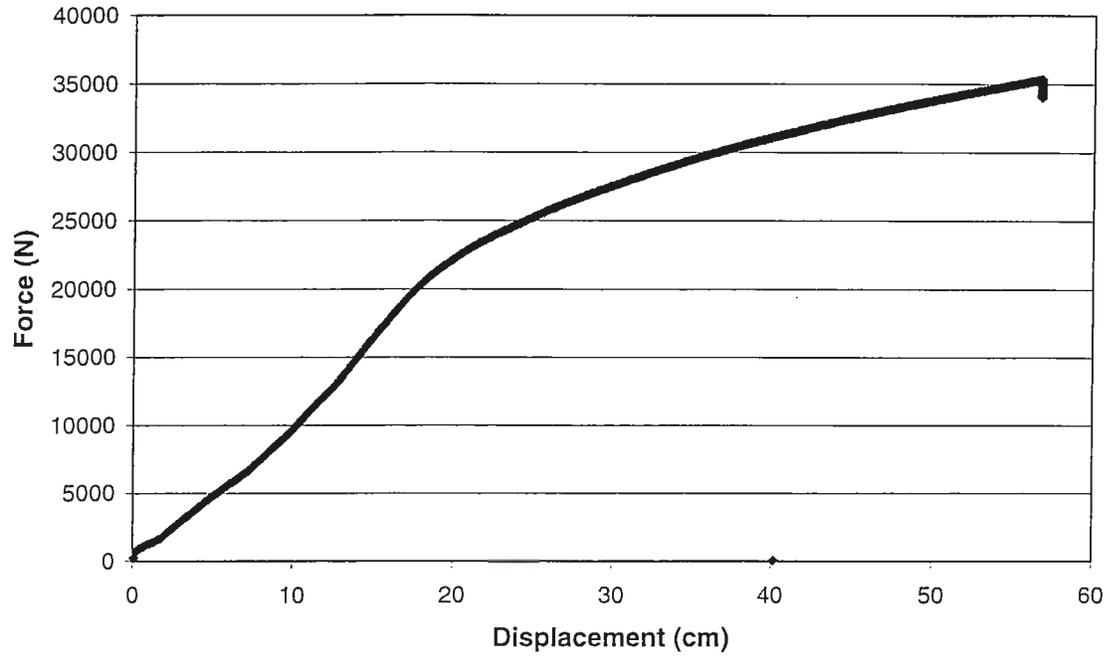


Figure 16. Allis Chalmers D17 first axle housing strength test.

D 17 Axle Strength Test, 02/13/02, Axle 5, AM-3835, 7-1-48

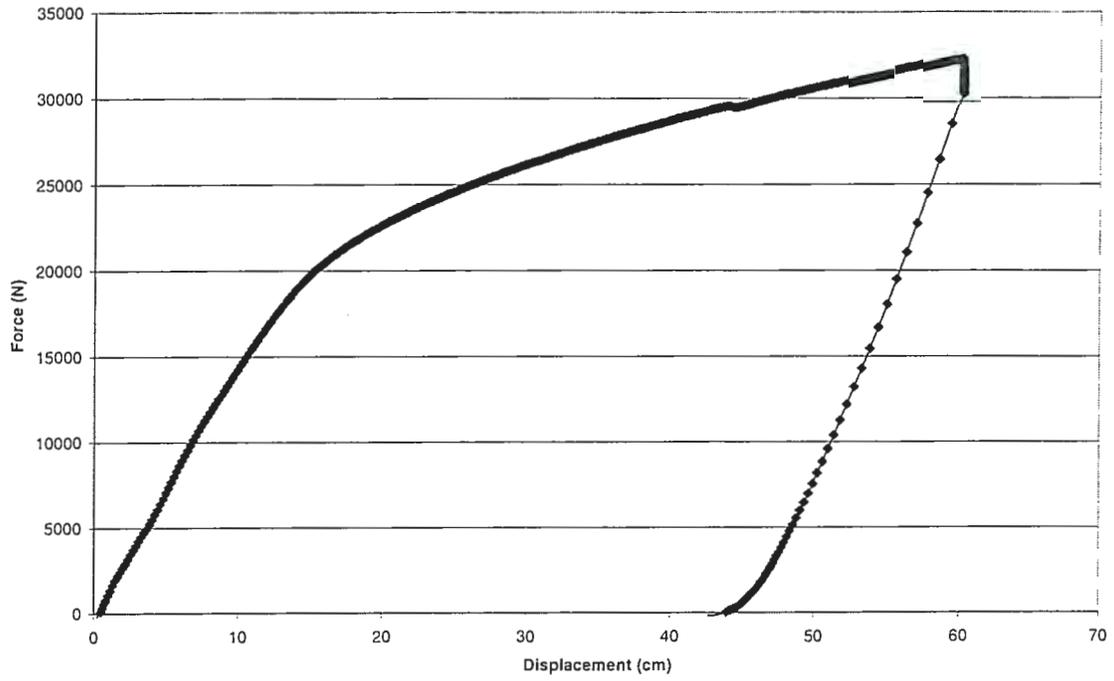


Figure 17. Allis Chalmers D17 second axle housing strength test.

WD-45 Axle Test 02/26/02 Axle 9

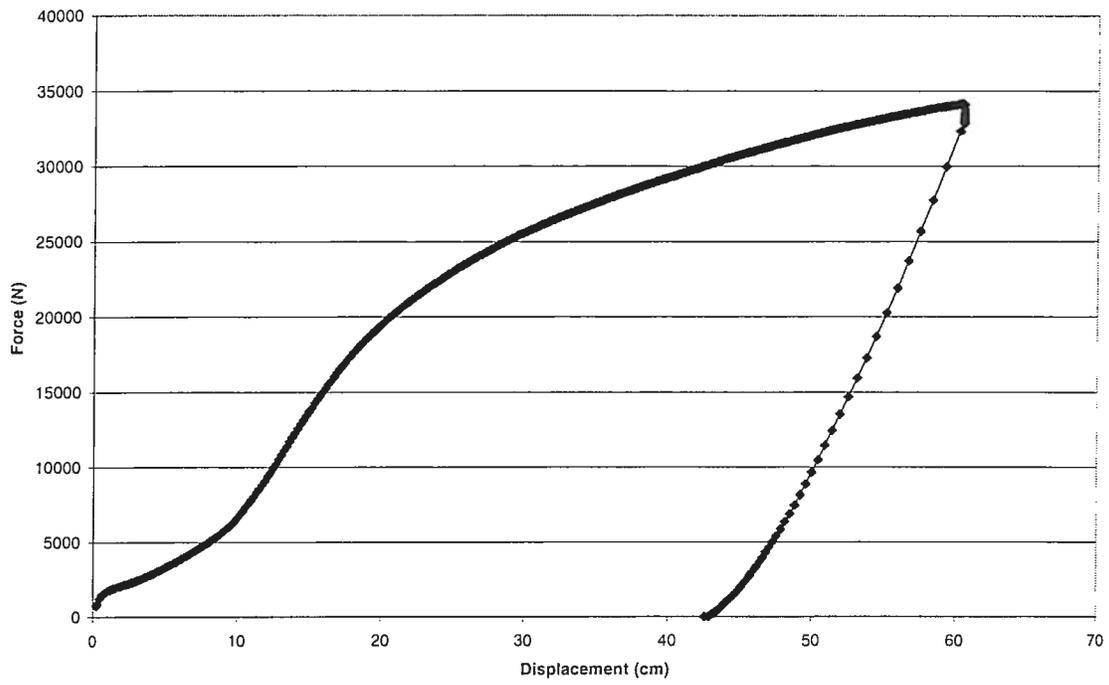


Figure 18. Allis Chalmers WD 45 first axle housing strength test.

Axle housing Test 03/15/02 WD 45 Axle 10

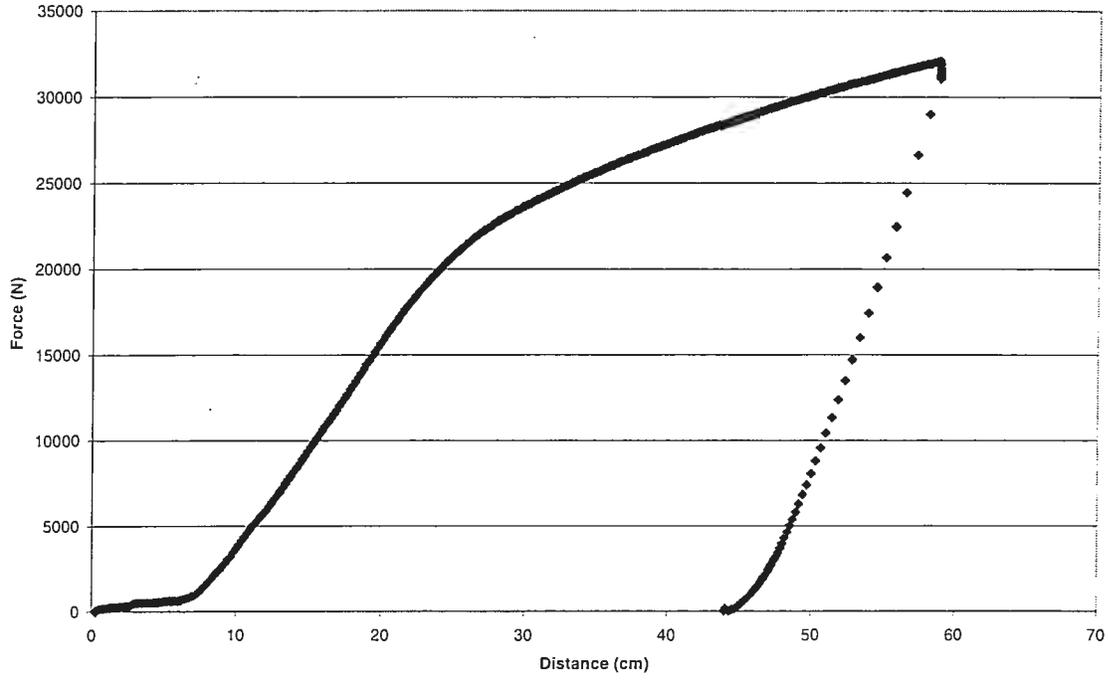


Figure 19. Allis Chalmers WD 45 second axle housing strength test.

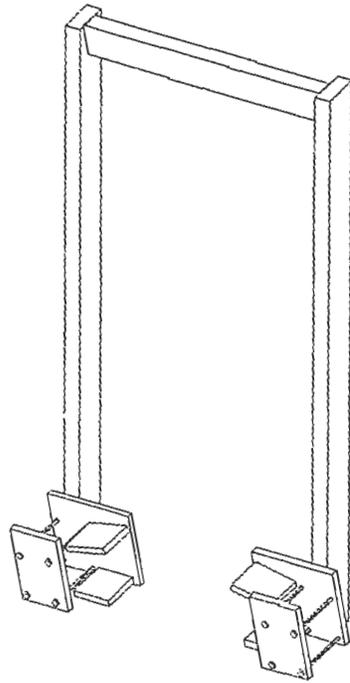


Figure 20. Assembly diagram of ROPS for John Deere A.

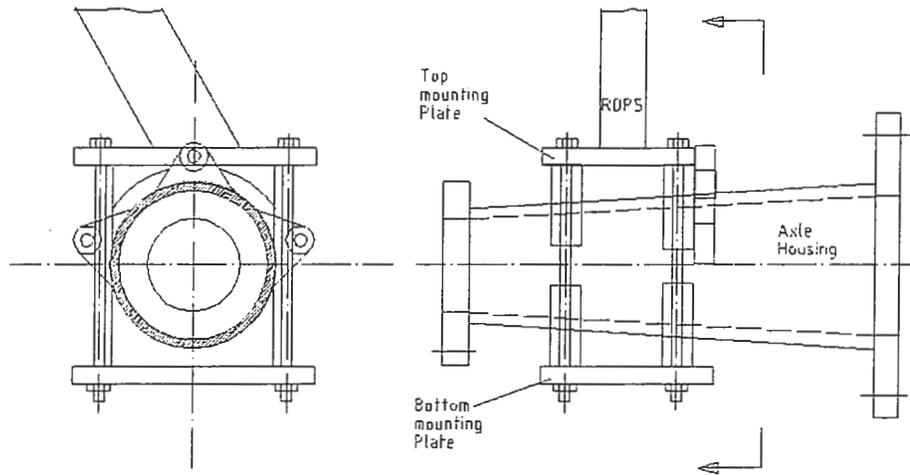


Figure 21. Assembly diagram of ROPS mounting configuration for Allis Chalmers D17.

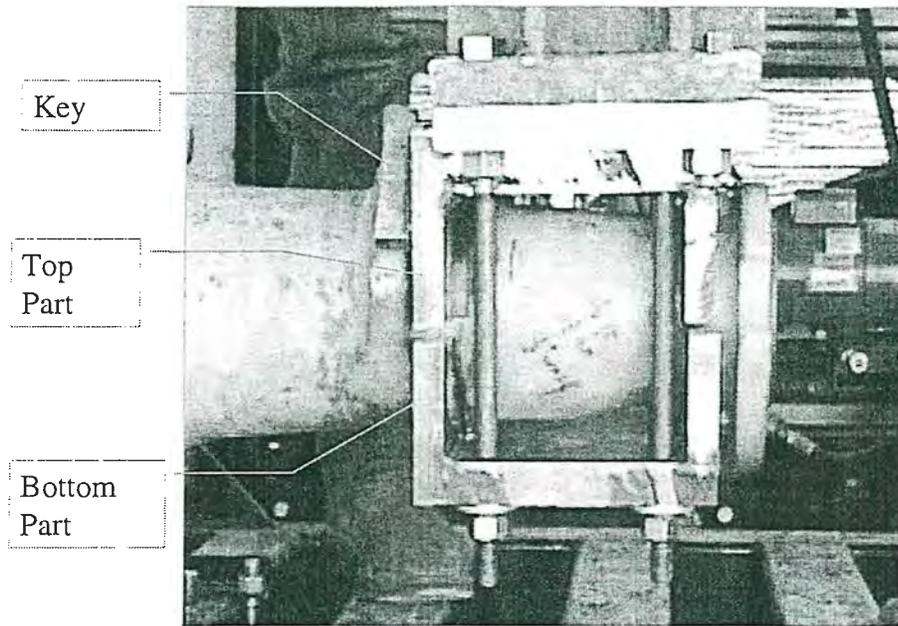


Figure 22. ROPS axle housing mount with ROPS attached for Allis Chalmers D17.

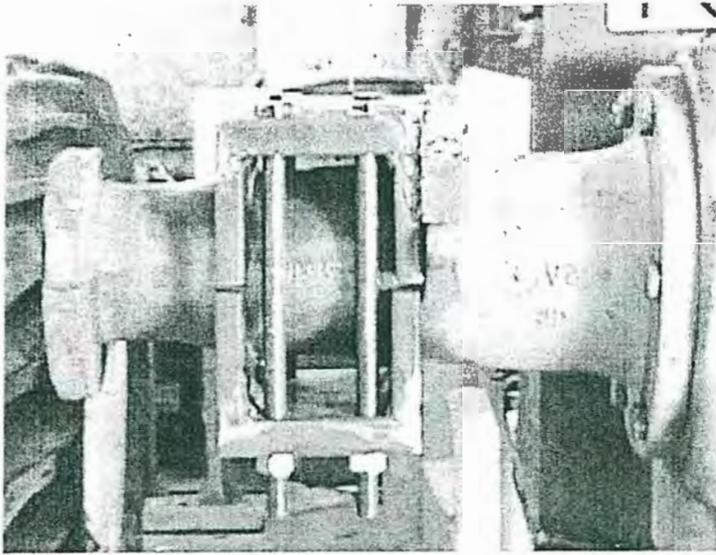


Figure 23. ROPS axle housing mount for Allis Chalmers D17.

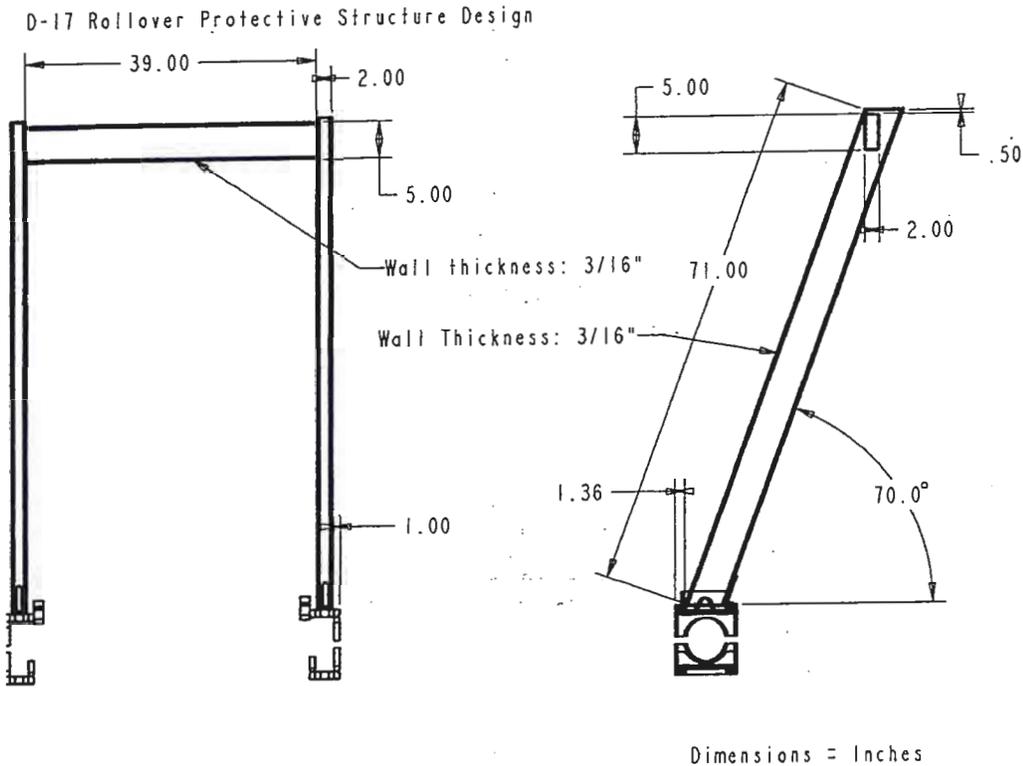


Figure 24. Assembly drawing for the Allis Chalmers D17 ROPS.

**Appendix A. Pre-ROPS tractor survey database and axle
classifications.**

Database of Possible Pre-ROPS Tractors

1998

Model	#of Tractors	Years Produced	Number Made	Weight	Fuel	Nebraska Tractor Test			Is ROPS Available (yes or no)				
						Test #	Date	Weight	1997	1993	1990	Manuf. Cost	
Farmall-M	76,798.15	1939-1952	290,422	6,770.00	gas	328	Sep-39	6770	no	yes	yes	no	\$ 1,075.00
Ford-8N	67,724.85	1947-1952	442,034		gas	385	Sep-47	2714	yes	yes	yes	yes	\$ 490.00
Farmall-H	65,875.42	1939-1953	389,999	5,550.00	gas	333	Oct-39	5,550	no	yes	yes	no	\$ 1,215.00
Ford-3000	43,052.28	1965-1968			gas	1051	Oct-70	4140	yes	yes	yes	yes	\$ 975.00
X AC D17	41,407.94	1958-1967	62867		dsl	1052	Oct-70	4220					
					gas	635	Nov-57	4659	no	no	no	no	
					dsl	636	Nov-57	4867					
Ford-4000	39,883.08	1963-1967			lp	644	Apr-58	4751					
					gas	999	Nov-68	4790	yes	yes	yes	yes	\$ 975.00
					dsl	995	Nov-68	4885					
MF-135	38,643.12	1964-1975			gas	899	May-65	3565	yes	yes	yes	yes	\$ 1,022.00
					dsl	895	May-65	3645					
Farmall-560	34,968.55	1958-1963	59777		gas	671	Sep-58	6563	no	no	no	no	
					dsl	669	Sep-58	6785					
					lp	675	Oct-58	6670					
IH-706	34,436.73	1963-1967	38020		gas	957	Nov-66	8700	no	yes	no	no	\$ 1,393.00
					dsl	955	Nov-66	9160					
					lp	956	Nov-56	8840					
Farmall-656	33,526.83	1965-1972	39450		gas	909	Sep-65	6935	yes	yes	yes	yes	\$ 447.00
					dsl	912	Sep-65	7230					
X AC-WD45	31,812.36	1953-1957	83688		gas	499	Aug-53	3955	no	no	no	no	
					dsl	563	Oct-55	4285					
					lp	512	Oct-53	4149					
Farmall-SuperA	26,381.77	1947-1953	86879		no test				no	yes	yes	no	\$ 879.00
Farmall-SuperM	24,845.55	1952-1954			gas	475	Jul-52	5603	no	yes	yes	no	\$ 1,075.00
Ford-2000	24588.5	1962-1984			gas	1054	Oct-70	4050	yes	yes	yes	yes	\$ 975.00
					dsl	1053	Oct-70	4100					
X AC-WD	22,179.78	1948-1953	160000		gas	440	Jun-50	3721	no	no	no	no	

				dist	Feb-01	Jul-48	3388						
JD-A	21,820.16	1940-1952	201880	Dist	222	Apr-34	4059	no	no	no	no		
JD-B	21,645.06	1940-1952	217575	4058 Dist	232	Apr-35	3275	no	no	no	no		
MF-35	21,353.09	1960-1963	30942	dsl	744	May-60	5909	yes	yes	yes	no	\$ 1,685.00	
Farmall-806	20,325.30	1963-1967	34442	gas	859	Nov-63	8650	yes	yes	yes	no	\$ 1,393.00	
				dsl	857	Oct-63	9290						
				lp	861	Nov-63	8815						
MF-65	19,023.01	1958-1964	51056	gas	659	Jun-58	9045	yes	yes	yes	no	\$ 1,538.00	
				lp	657	Jun-58	9115						
Farmall-400	17,715.04	1954-1956	28564	dsl	534	Apr-55	6898	yes	yes	yes	no	\$ 879.00	
Ford-800	16,793.03	1954-1957		no test				yes	yes	yes	no	\$ 1,318.00	
Ford-9N	16,217.40	1939-1943	105411	gas	339	Apr-40	3375	yes	no	no	yes	\$ 490.00	
Farmall-460	15,932.72	1958-1963	31051	gas	670	Sep-58	5835	yes	yes	yes	no	\$ 1,225.00	
				dsl	672	Oct-58	6055						
				lp	676	Oct-58	5910						
Ford-3600	15,842.32	1965-1984		gas	1208		4235	yes	yes	yes	yes	\$ 533.00	
				dsl	1203		4415						
Farmall-350	15,811.64	1956-1958		gas	611	Apr-57	5331	yes	yes	yes	no	\$ 879.00	
				dsl	609	Apr-57	5365						
				lp	622	May-57	5475						
Farmall-300	15,771.52	1954-1956	22723	5361 gas	538	Apr-55	5361	yes	yes	yes	no	\$ 879.00	
Case-930	15,328.95	1960-1969		dsl	741	May-60	8845	yes	no	no	no	\$ 656.00	
JD-730	15,301.49	1958-1960	22,075	gas	605	Nov-56	8945	no	no	no	no		
				dsl	594	Sep-56	9241						
				lp	593	Sep-56	9055						
JD-60	15,058.65	1952-1956		gas	472	Jun-52	5911	no	no	no	no		
Farmall-1066	13,857.37	1971-1976		dsl	1081	Oct-71	12145	yes	yes	yes	yes	\$ 597.00	
Ford-Gold.Jub.	12,639.71	1952-1954		gas	494	May-53	2841	yes	yes	yes	yes	\$ 490.00	
Farmall-856	12,473.91	1967-1971		dsl	970	Apr-68	10290	yes	yes	yes	yes	\$ 597.00	
AC-190	11,997.48	1964-1973	30117	gas	928	Nov-65	7665	yes	yes	yes	no	\$ 1,251.00	
				dsl	886	Apr-65	7845						
Oliver-1650	11,901.17	1964-1969		gas	874	Nov-64	7575	no	no	no	no		
				dsl	873	Nov-64	7815						
Farmall-504	11,642.13	1961-1968		gas	819	May-62	5285	yes	yes	yes	no	\$ 1,512.00	
				dsl	816	May-62	5606						
				lp	820	May-62	5385						
Oliver-77	11,545.05	1953-1954		gas	542	May-55	5131	yes	yes	yes	no	\$ 2,148.00	



Memorandum

Date: October 28, 2003

From: Michael J. Galvin, Ph.D., Program Official 
Office of Extramural Programs, NIOSH, E-74

Subject: Final Report Submitted for Entry into NTIS for Grant 5 R01 OH003612-03.

To: William D. Bennett
Data Systems Team, Information Resources Branch, EID, NIOSH, P03/C18

The attached final report has been received from the principal investigator on the subject NIOSH grant. If this document is forwarded to the National Technical Information Service, please let us know when a document number is known so that we can inform anyone who inquires about this final report.

Any publications that are included with this report are highlighted on the list below.

Attachment

cc: Sherri Diana, EID, P03/C13

List of Publications

Liu J, Ayers PD: Off-Road Vehicle Rollover and Field-Testing of Stability Index. *Journal of Agricultural Safety and Health* 5(1):59-71, 1999

Liu J, Ayers PD: Applications of Tractor Stability Index in Development of Control Strategies for Protective Structures. *Journal of Agricultural Safety and Health, Special Issue* (1):171-181, 1998

NIOSH Closeout Summary with Publications

Title: ROPS Design and Testing for Agricultural Tractors
Investigator: Paul D. Ayers, Ph.D.
Affiliation: Colorado State University
City & State: CO
Telephone: (970) 491-0584
Award Number: 5 R01 OH003612-03
Start & End Date: 9/30/1998–9/29/2002
Total Project Cost: \$462,107
Program Area: Control Technology
Key Words:

Final Report Abstract:

A roll-over protective structure (ROPS), as described in ASAE S519, is a protective structure designed to minimize the frequency and severity of operator injury resulting from accidental tractor upset (ASAE, 1996). ROPS utilization has shown to have dramatic impacts in reducing fatalities during tractor overturns. But some agricultural tractors do not have appropriate ROPS designs and ROPS are not available. This project investigates and evaluates roll-over protective structure (ROPS) designs for agricultural tractors in the United States to provide operator protection on tractors and in operating conditions not currently available.

Initially, an inventory of agricultural tractor ROPS availability (specifically for older tractors) was conducted. Classification of axle housings and determination of the population of tractors for which ROPS are not available was performed. The most popular pre-ROPS tractors were categorized into 4 major axle categories, with 4 tractors (Ford 8N, John Deere A, Farmall M and Allis Chalmers D17), representing each major axle category. As appropriate ROPS designs had previously been conducted for the Ford 8N and Farmall M, ROPS were designed, constructed and tested, according to ASAE S519 (SAE J2194) for the John Deere A and Allis Chalmers D17 tractors. Both static and field upset tests for side and rear rollover were conducted in accordance with ASAE S519 (SAE J2194). Measured deflection at the energy criteria and during field upset tests were less than the allowable deflection, indicating successful ROPS designs. Radio-controlled John Deere A and Allis Chalmers D17 tractors were utilized in the field upset tests. The axle housing strength tests were conducted on the John Deere A, Allis Chalmers D17 and Allis Chalmers WD 45 tractor models to evaluate the suitability of the axle housing to support a ROPS. All axle-housing strengths exceeded the stress applied during the static longitudinal tests, with a factor of safety greater than 1.6.

This report also presents the results of dynamic deflection of ROPS when John Deere A tractor equipped with radio controlled system was subjected to overturn and analyzes the effect of impulse loading on ROPS design and installation pattern. In order to measure the dynamic deflection of ROPS, a LVDT (Linear Variable Differential Transformer) was installed in same plane in which the deflection of ROPS occurred. The position of tractor was monitored by the MSTs (measuring system of tractor stability). Tractor position, ROPS rotation velocities and dynamic deflection of ROPS were recorded at a 40 Hz acquisition rate. This information can be useful for deployment times for the NIOSH

NIOSH Closeout Summary with Publications

auto-ROPS. The time from instability to the ROPS striking the ground ranged from 0.7 to 1.0 seconds during the field-upset tests. Drawing of the ROPS designs for the John Deere A and Allis Chalmers D17 tractors are presented. This project demonstrates the procedure and feasibility for designing and testing ROPS for pre-ROPS tractors.

Publications:

Liu J, Ayers PD: Off-Road Vehicle Rollover and Field-Testing of Stability Index. Journal of Agricultural Safety and Health 5(1):59-71, 1999

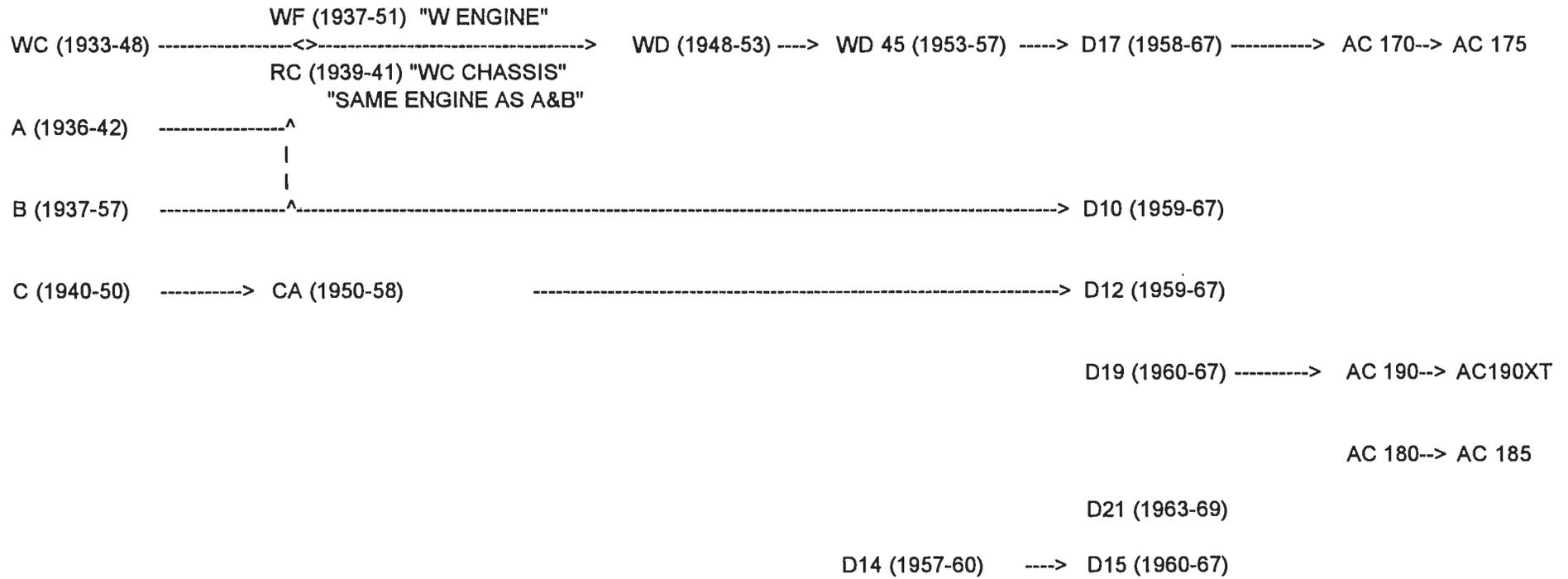
Liu J, Ayers PD: Applications of Tractor Stability Index in Development of Control Strategies for Protective Structures. Journal of Agricultural Safety and Health, Special Issue (1):171-181, 1998

JD-520	11,317.48	1956-1958	dsl	543	May-55	5253					
			gas	597	Oct-56	5809	no	no	no	no	
			lp	590	Sep-56	5895					
Farmall-140	10,804.10	1958-1979	gas	666	Sep-58	3000	yes	yes	yes	yes	\$ 879.00
Farmall-C	10,757.05	1948-1951	gas	395	Jun-48	2845	no	no	no	no	
AC-180	10,597.07	1968-1973	gas	1005	Apr-69	6420	yes	yes	yes	no	\$ 1,416.00
			dsl	964	Oct-67	6510					
JD-630	10,548.68	1958-1960	gas	598	Oct-56	8655	no	no	no	no	
			lp	591	Sep-56	8769					
Ford-801	10,497.11	1957-1961	no test				yes	no	no	yes	\$ 490.00
Oliver-550	10,253.66	1958-1975	gas	697	May-59	3655	yes	yes	yes	no	\$ 1,613.00
			dsl	698	May-59	3730					
JD-720	10,242.93	1956-1958	gas	605	Nov-56	8945	no	no	no	no	
			dsl	594	Sep-56	9241					
			lp	593	Sep-56	9055					

Allis-Chalmers Tractor Lineage

U (1929-52)

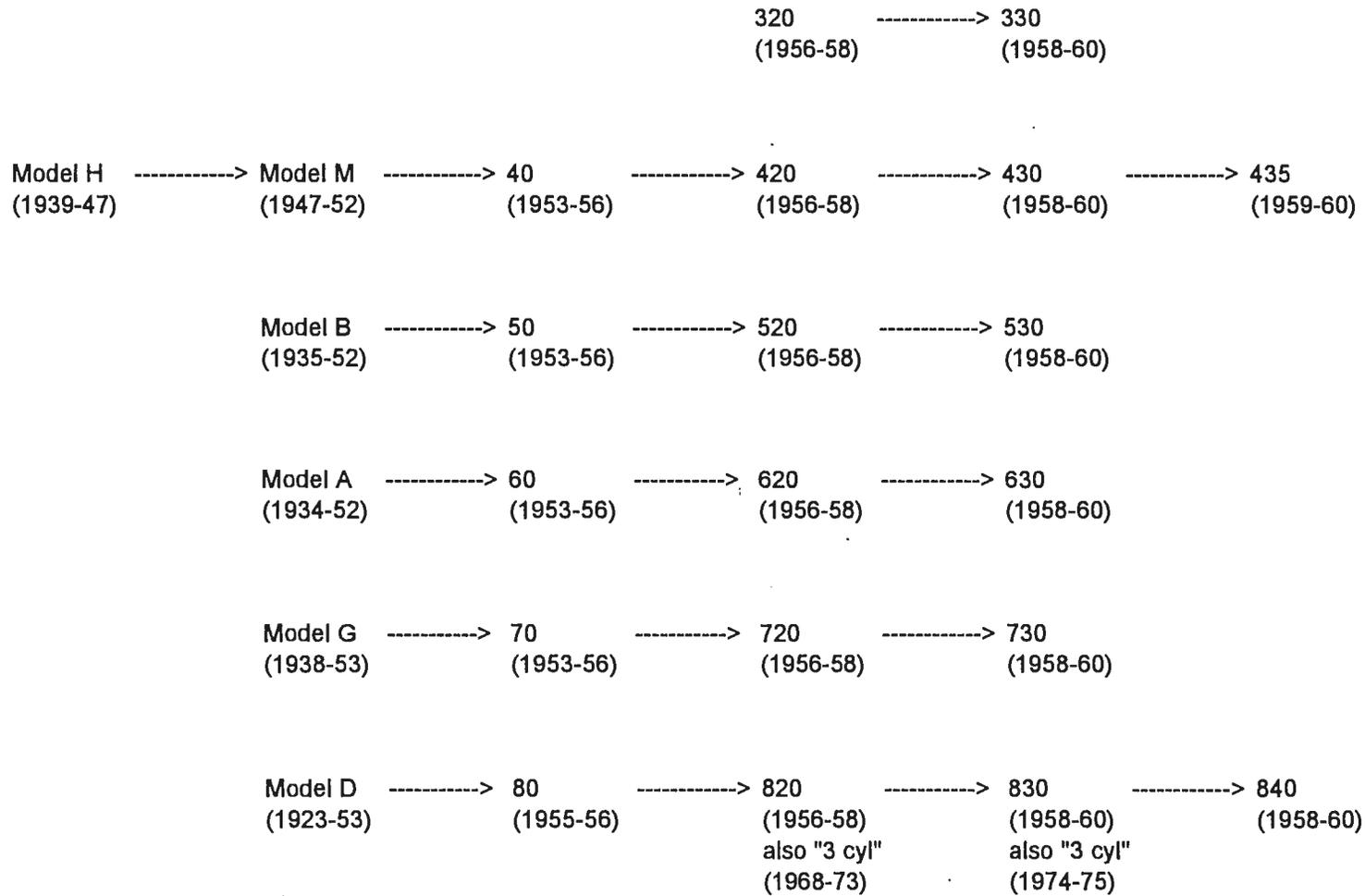
UC (1930-41)



Allis-Chalmers Tractors

Model	Years	No. Made	Weight	HP
U	1929-52	19,009	4821	25.63
UC	1930-41	6,188	6115	28.85
WC	1933-48	178,336	4535	29.93
A	1936-42	1,225	no test	44
B	1937-57	120,783	2620	13.17
C	1940-50	84,020	3025	18.43
WF	1937-51	8,350	no test	
RC	1939-41	5,516	4005	15.25
CA	1950-58	39,437	2763	22.04
WD	1948-53	146,380	3721	36
WD45	1953-57	84,030	3955	45
D10	1959-67	5,304	3001	29.97
D12	1959-67	4,070	3051	29.90
D14	1957-60	22,292	3620	30.27
D15	1960-67	19,525	3985	35.94
D17	1958-67	63,882	4659	45.37
D19	1960-67	10,581	6645	63.05
D21	1963-69	3,457	10,745	94.05

John Deere Tractor Lineage



John Deere Tractors

Model	Years	No. Made	Weight	HP
Model H	1939-47	60,000	3035	12.48
Model M	1947-52	40,580	2721	18.15
Model B	1935-52	300,000	3275	11.84
Model A	1934-52	300,000	4059	18.72
Model G	1938-53	64,000	5160	27.63
Model D	1923-53	160,000	4917	28.59
40	1953-56	33,000	3219	21.71
50	1953-56	33,000	4855	27.07
60	1953-56	57,300	5911	35.18
70	1953-56	43,000	6617	42.24
80	1955-56		7900	68
320	1956-58	3,000	2750	22.4
420	1956-58	55,000	3250	27.1
520	1956-58	13,000	4960	34.3
620	1956-58	22,600	5900	44.2
720	1956-58	29,000	6790	53
820	1956-58		8300	76
330	1958-60	1,000	2750	22.4
430	1958-60	12,680	3250	27.1
530	1958-60	9,800	4960	34.3
630	1958-60	18,000	5900	44.2
730	1958-60	30,000	6790	53
830	1958-60		8140	81
435	1959-60	4,500	4000	27.6
840	1958-60			

Ford Tractor Lineage

9N (1939-43) -----> 2N (1943-47) -----> 8N (1947-52) -----> NAA JUBILEE (1952-54)

600 (1954-57) -----> 601 (1957-61)

700 (1954-57) -----> 701 (1957-61)

800 (1954-57) -----> 801 (1957-61)

900 (1954-57) -----> 901 (1957-61)

FORDSON Power/Major Series (1953-61) -----> FORDSON Super/Major Series (1961-64)

DEXTA Series (1958-64)

Ford Tractors

Model	Years	No. Made	Weight	HP
9N	1939-43		3375	16.31
2N	1943-47			24
8N	1947-52		2714	17.06
NAA JUBILEE	1952-54		2841	25.3
600 Series	1954-57		2700	33
700 Series	1954-57			
800 Series	1954-57		2950	46
900 Series	1954-57		3350	46.5
FORDSON	1953-61		5515/5425	48/41
power/major				
601 Series	1957-61		3000	34
701 Series	1957-61		3175	35
801 Series	1957-61		3330	45
901 Series	1957-61		3345	50
FORDSON	1961-64		4609	
super/major				
DEXTA	1958-64		3030	31

Farmall Tractor Lineage

A & B (1937-47) -----> Super A (1947-53) -----> F 100 (1954-56) -----> F130 (1956-58) -----> F 140 (1958-79)

B --> C (1948-51) -----> Super C (1951-54) -----> F 200 (1954-56) -----> F 230 (1956-58) -----> F 240 (1958-62)

H (1939-53) -----> Super H (1952-54) -----> F 300 (1954-56) -----> F 350 (1956-58) -----> F 330 (1957-58)
-----> F 340 (1958-63)

M (1939-52) -----> Super M (1952-54) -----> F 400 (1954-56) -----> F 450 (1956-58) -----> F 460 (1958-63)
-----> F 560 (1958-63)

F 600 (1956) -----> F 650 (1956-58) -----> F 660 (1959-63)

Table 1. Pre-ROPS Tractors (in study) (after Myers and Snyder, 1995)

(Tractor Make/Model)	Number In Use
Ford 8N	67725
Ford 9N	16217
Ford Gold Jub	12639
Ford 800	16793
Ford 801	10497
Farmall M	76798
Farmall H	65875
Farmall 560	34968
Farmall Super M	24846
Farmall 300	15771
Farmall 350	15811
Farmall 400	17715
Farmall 460	15932
JD A	21820
JD B	21645
JD 60	15059
JD 520	11317
JD 630	10549
JD 720	10242
JD 730	15301
AC D17	41407
AC WD	21180
AC WD 45	31812
Total Pre-ROPS (in study)	591919

Appendix B. Allis Chalmers D17 allowable deflection calculations.

Allis Chalmers D17

update 10/01/00

Basic Parameters

# of Tractor	Made during Years	Total Number	Tractor Weight(kg)
41,407.94	1958-1967	81761	2157~4419

ROPS Dimensions

No:	Item Name	Unit in inch	Unit in cm
1	Rear tire diameter	55	139.7
2	Rear tire width	16.9	42.926
3	Tread width	78	198.12
4	Front tire diameter	26.5	67.31
5	Horizontal distance to seat reference point (SRP) from center of rear axle	-9.75	-24.765
6	Vertical distance to SRP from ground	53.25	135.255
7	Horizontal distance from SRP to point 40 mm past the forward upper edge of the steering wheel	35.6	90.424
8	Vertical distance from SRP to top of steering wheel	11	27.94
9	Steering wheel diameter	17.5	44.45
10	Vertical distance from SRP to top of seat back rest	9	22.86
11	Thickness of seat back rest	3	7.62
12	Horizontal distance from rear axle to front hood corner point	98.5	250.19
13	Vertical distance from ground to front hood corner point	58.5	148.59
14	Horizontal distance from tractor center line to front hood corner point	9.5	24.13
15	Tractor wheel base	93	236.22
16	Horizontal distance from front tire point to center line	28	71.12
17	Horizontal distance from rear tire point to center line	39	99.06
<u>Dimensions to be designed</u>			
18	Width of ROPS	45	114.3
19	Height of ROPS	67	170.18
20	ROPS base plate thickness	1	2.54
21	ROPS slant angle	60 degree 70 degree(modified on 3/28/2000)	

Clearance Zone Check of D17 During Side Rollover

The check points on the clearance zone
in millimeters with the origin at the SRP

	X	Y	Z
point 1	-76.	229.	-250.
point 2	-10	780	-130
point 3	-6	810	-123
point 4	5	839	-116
point 5	24.5570412	864.393555	-108.901611
point 6	49.1202316	883.488525	-104.127869
point 7	77.7667999	895.626953	-101.093262

Point	Deflection (mm)	Distance(mm)
1	400	-436.278351
2	400	-118.213104
8	400	-32.4744148
9	400	-25.3068333
10	400	-25.33992
11	400	-13.7612219
12	400	-6.35011816
13	400	-1.10642087
14	400	0.858825684

clearance zone exposed at point 14
Maximum side deflection is 400 mm

Clearance Zone Check of D17 During Rear Rollover

The check points on the clearance zone
in millimeters with the origin at the SRP

	X	Y	Z
point 1	-76.	229.	-250.
point 2	-10	780	-130
point 3	-6	810	-123
point 4	5	839	-116
point 5	24.5570412	864.393555	-108.901611
point 6	49.1202316	883.488525	-104.127869
point 7	77.7667999	895.626953	-101.093262

Point	Deflection (mm)	Distance (mm)
1	415	-80.7098083
2	415	-3.46365881
3	415	0.349132121

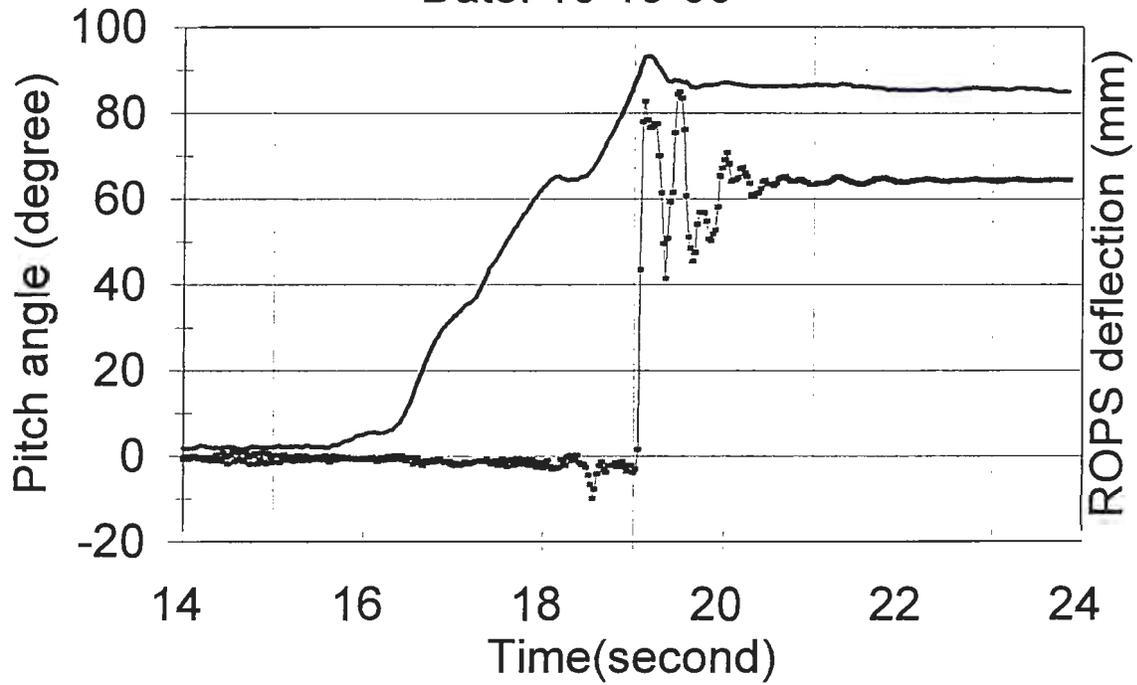
clearance zone exposed at point 3
Maximum rear deflection is 415 mm

Based on the dimension of ROPS and point 3 allowable deflection, the calculated allowable deflection on the top of ROPS could be 482 mm.

Appendix C. Allis Chalmers D17 Longitudinal Upset Tests.

D17 ROPS Rear Roll Test

Date: 10-19-00



— Pitch angle(deg) — Deflection(mm)

Appendix D. John Deere A ROPS drawings and design notes.

John Deere A ROPS Design Notes

Brackets (figure 1): The brackets are designed to compress the axle housing along its vertical planes (figure 2). The rear plate is made of 1-in. thick steel, while the front plate is made of 3/4-inch thick steel. The plates were cut slightly larger than their intended dimensions so that the edges could be ground to have a smoother finish. All holes in the bracket are 5/8-in. The bolts and nuts used to hold the brackets are 5/8-in. grade 8.

ROPS (figure 3): The ROPS was made from 5x2.5 square tube. The tubing came in 20-ft long bar, so two lengths of 80-in. for the sides and then one length of 40.625-in. was cut for the cross member, with the horizontal band saw. After the lengths were cut the angles were cut for the sides of the ROPS (figure 4) with a band saw since the horizontal band saw could not cut such sharp angles.

Gussets (figure 5): Gussets were added to the ROPS to improve strength and rigidity. The Gussets were made of the same material as the ROPS support (5x2.5 square tube). The gussets were welded with a MIG welder.

Future Improvements (figure 6): In the future the ROPS will be cut so that the full length of the brackets are used for attachment. This will increase the contact are of the weld increasing the strength of the ROPS greatly. Other improvements may include placement of the bolts so that they rest more in the valley where the greaser fitting is, decreasing the chance of slippage of the brackets, and the chance of the ROPS intruding into the driver safety area.

Front plate is 3/4" thick
Rear plate is 1" thick

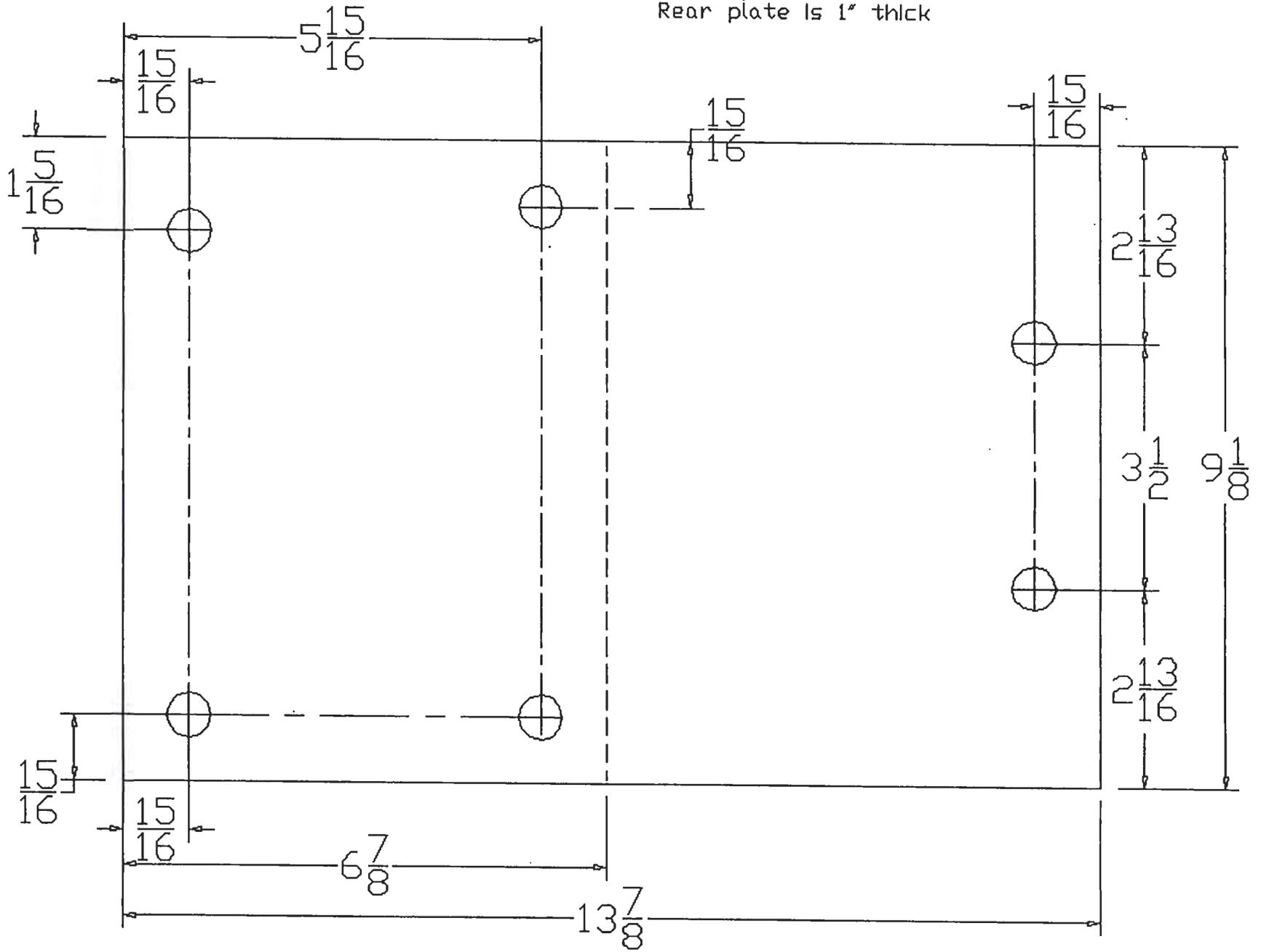


Figure 1

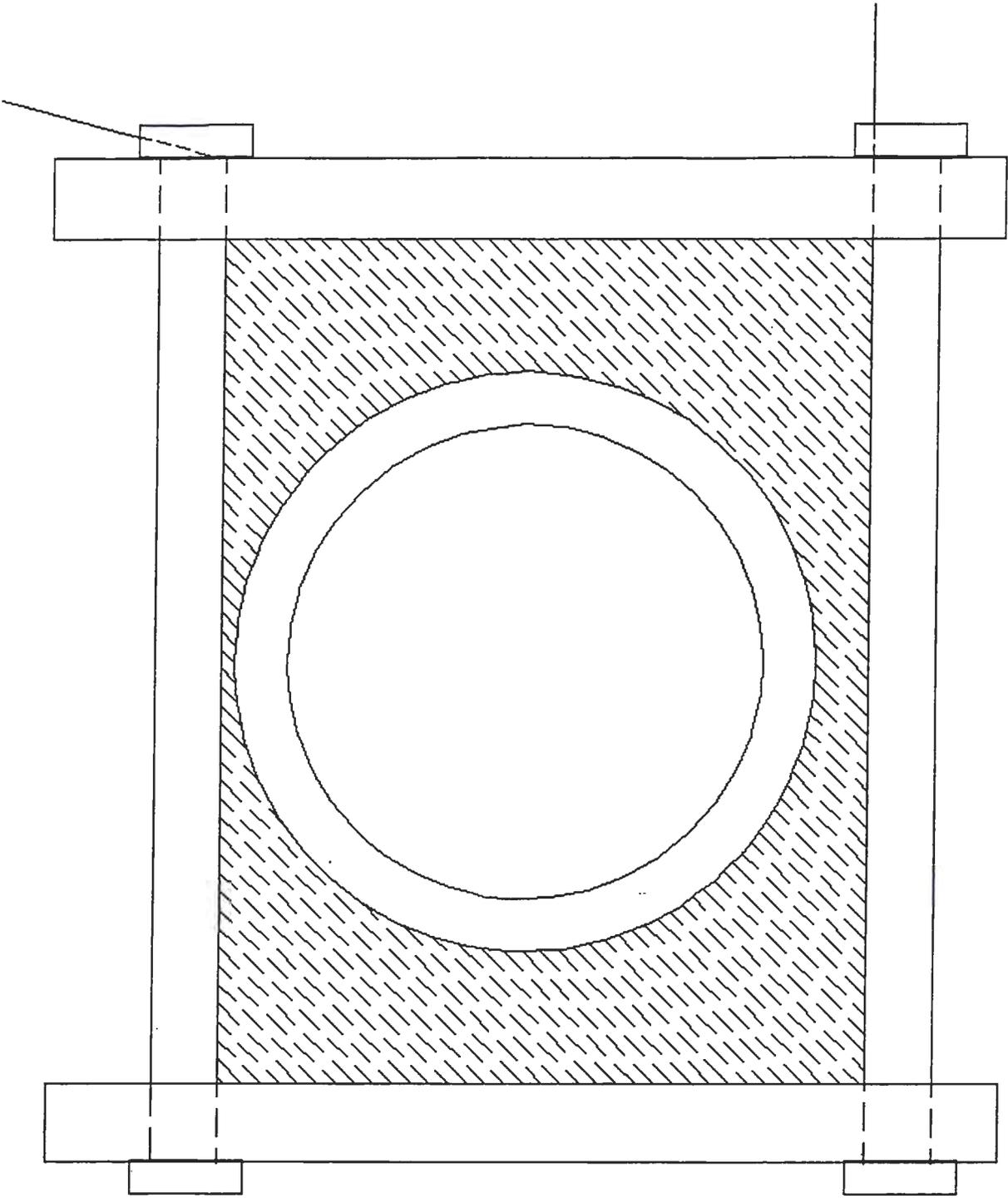


Figure 2

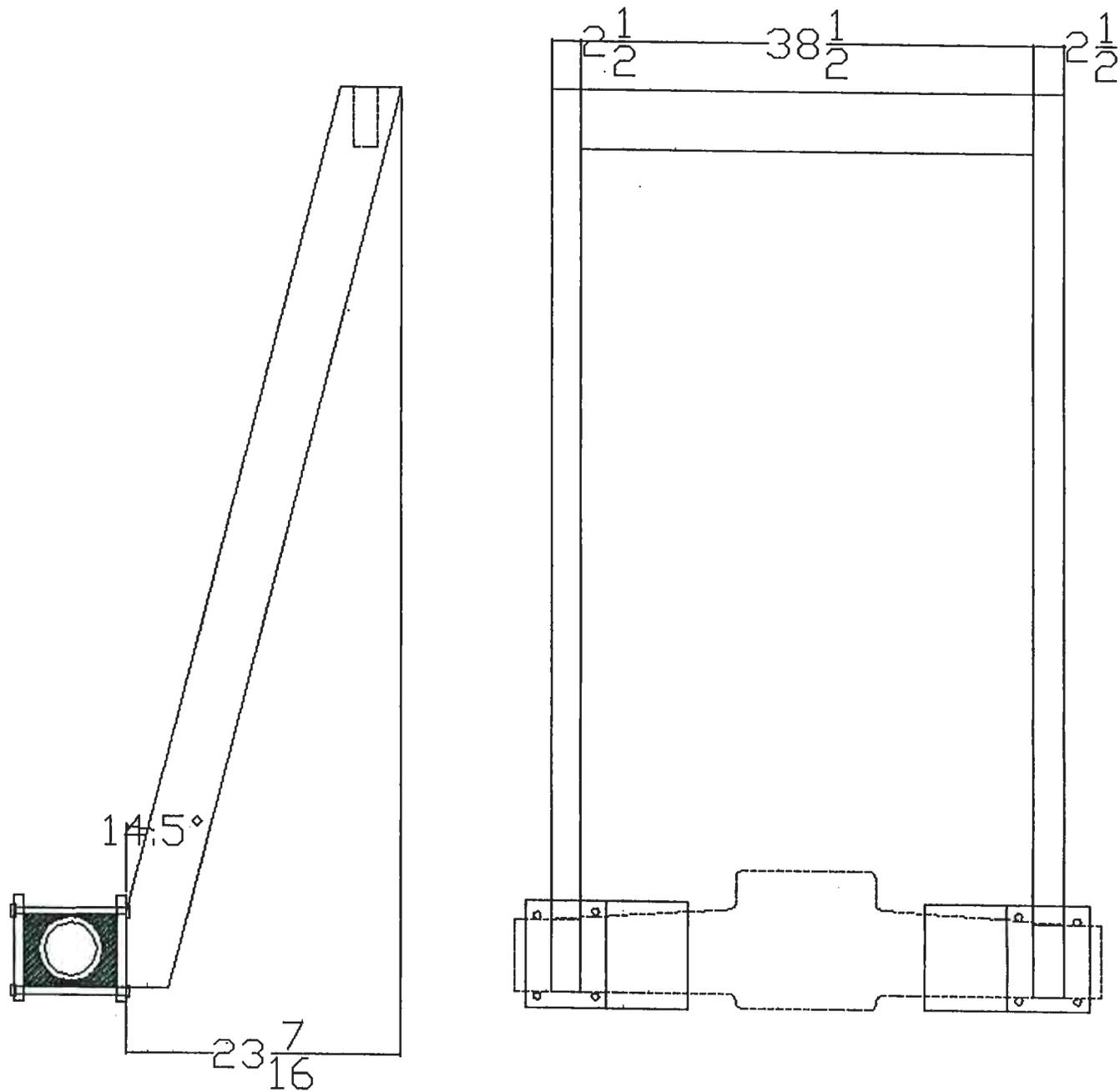


Figure 3

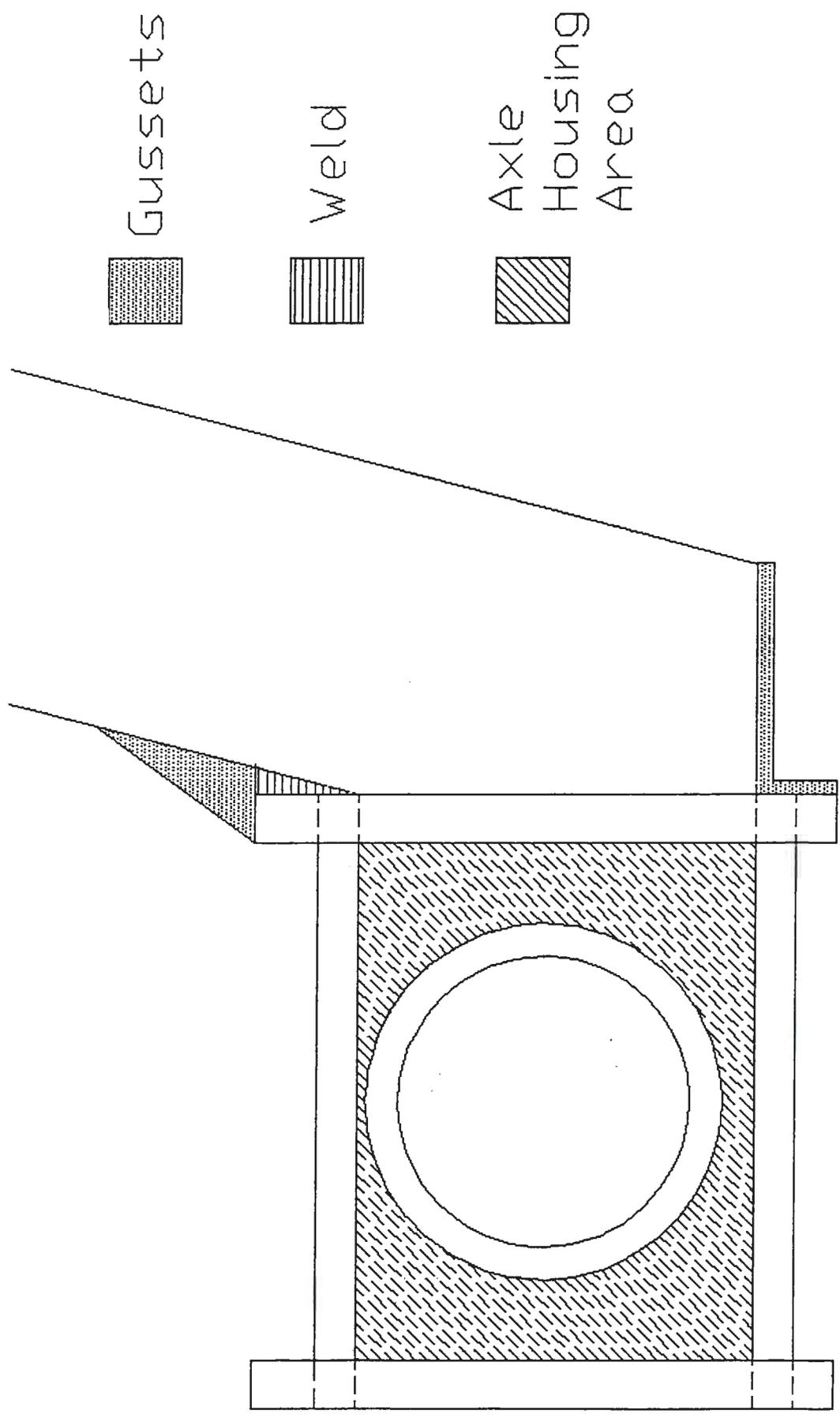


Figure 4

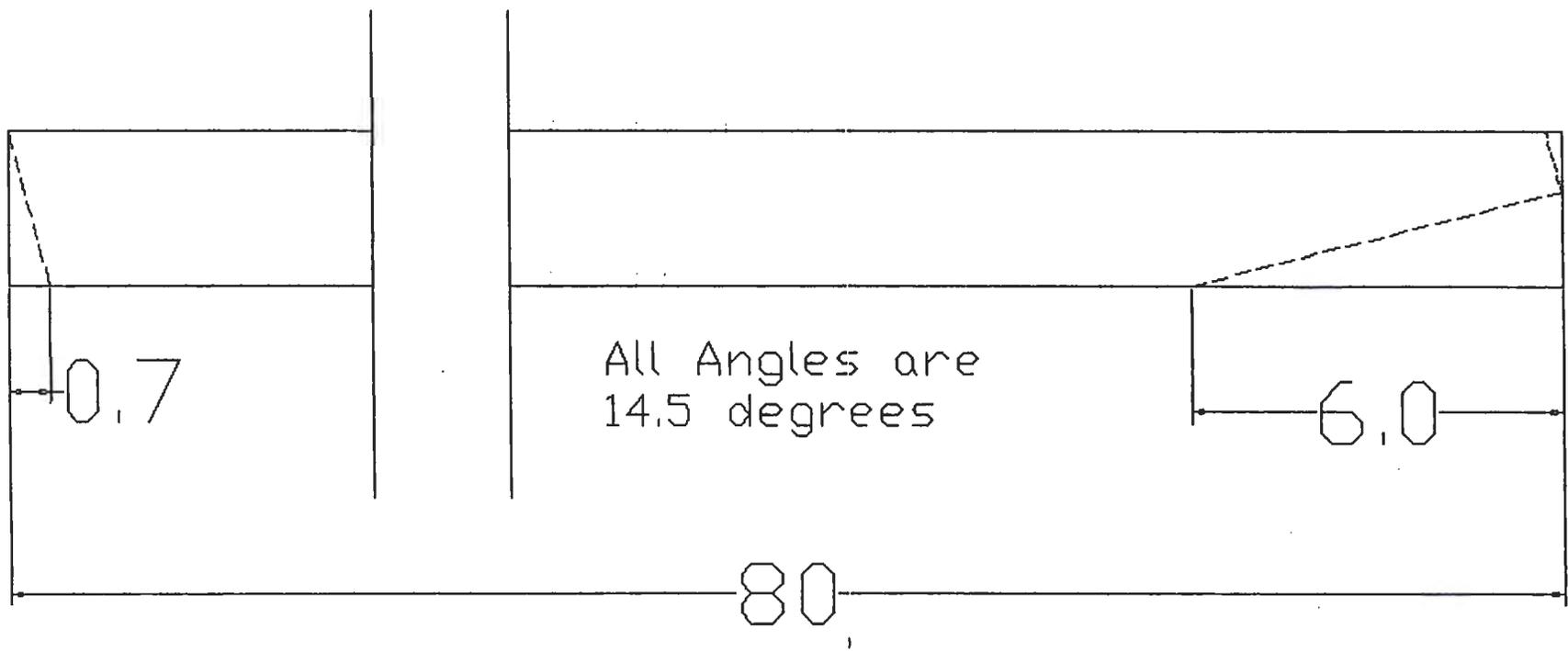


Figure 5

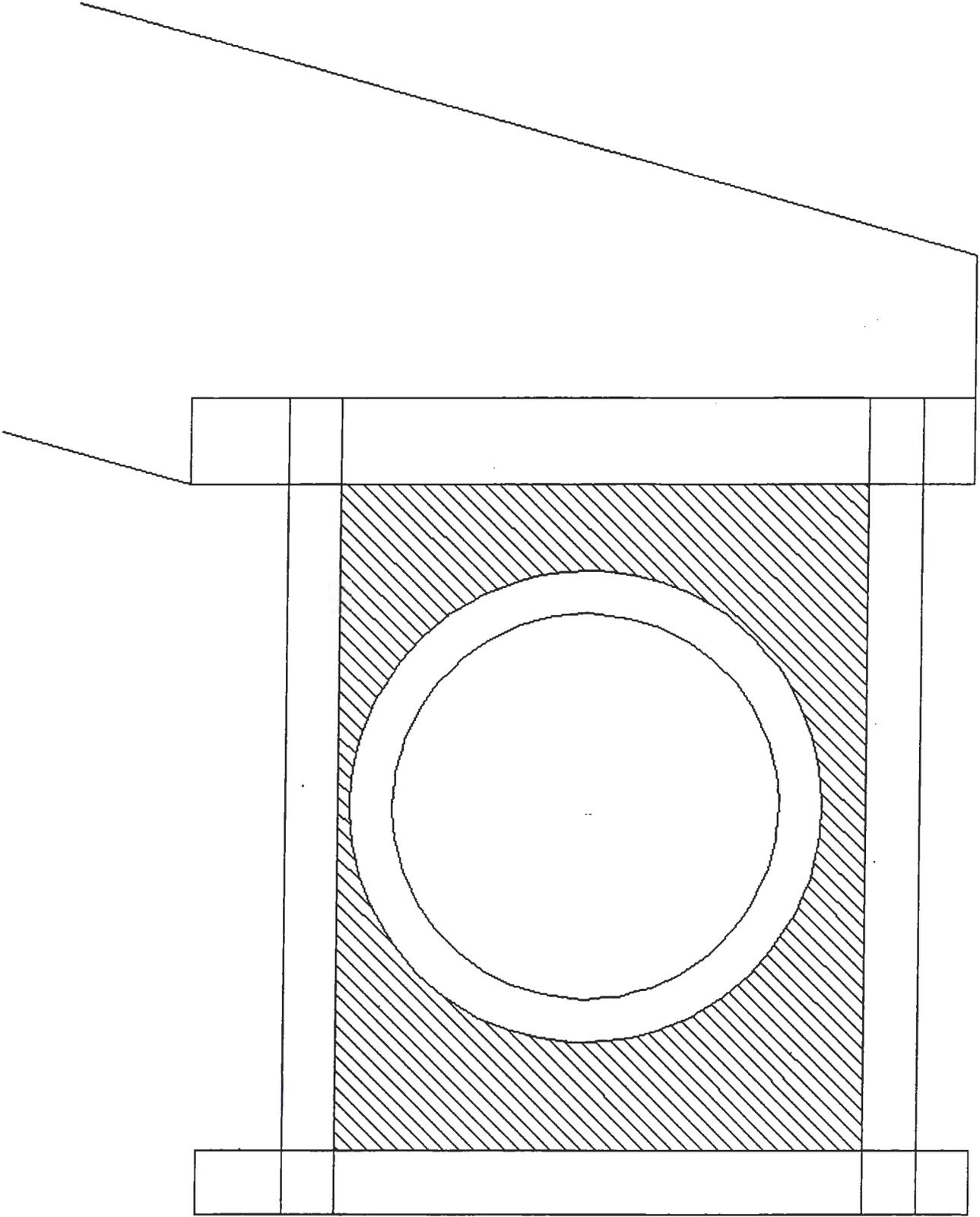
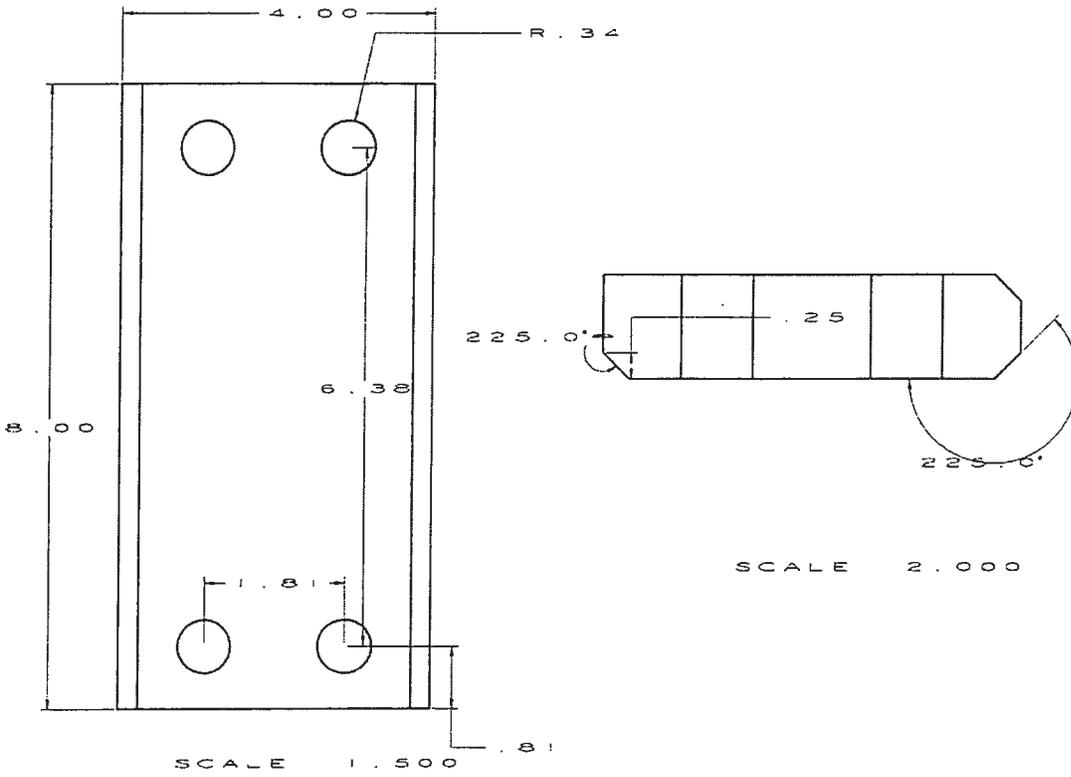


Figure 6

Appendix E. Allis Chalmers D17 ROPS drawings.

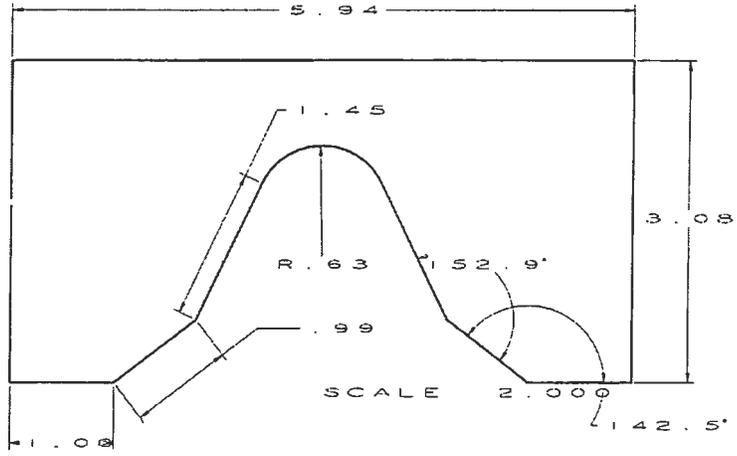
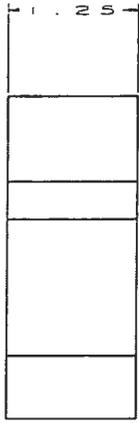
TOP Plate



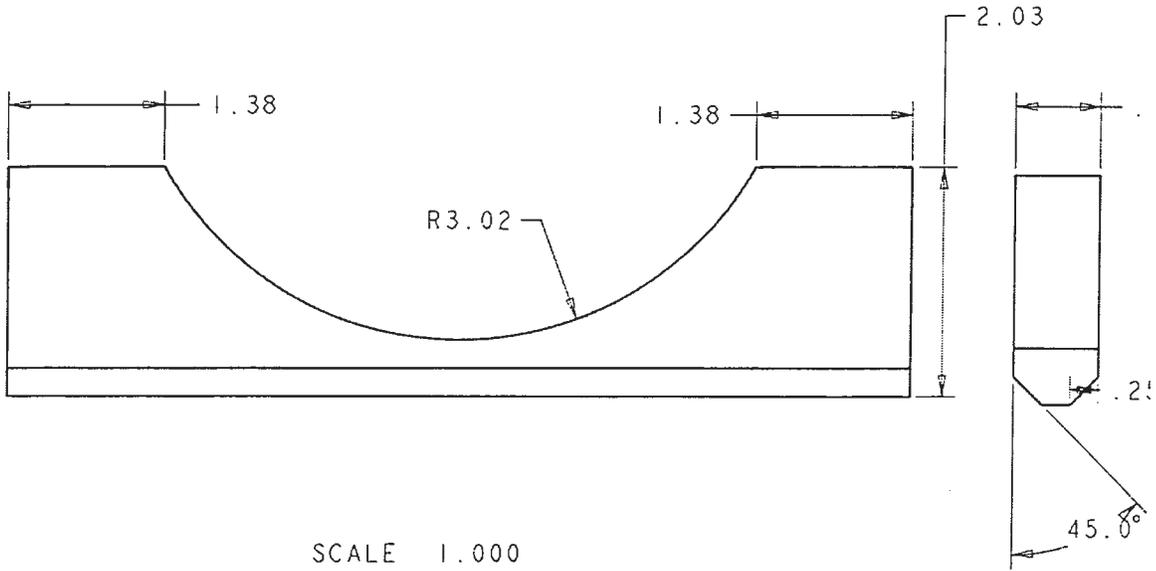
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SCALE 2.000

X M Y



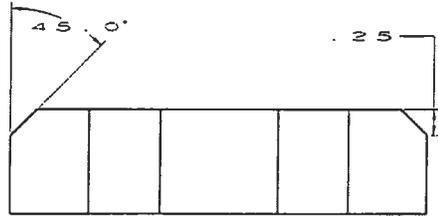
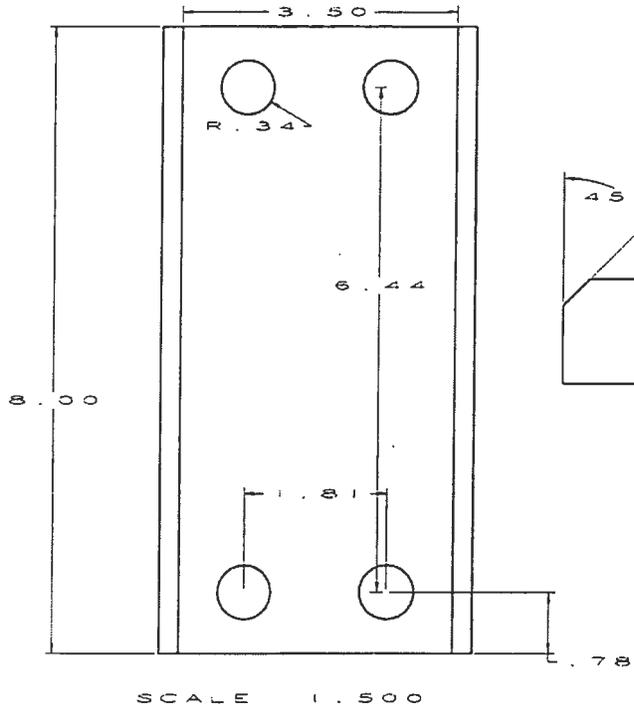
Bottom Inside side



SCALE 1.000

SCALE 1.00

Bottom Plate



SCALE 2.000