ROLL OVER PROTECTIVE STRUCTURE (ROPS) DESIGN, ANALYSIS AND TEST FOR THE MILITARY 6000-LB. ROUGH TERRAIN FORK-LIFT TRUCK

G. R. Gavan

Lockheed Propulsion Company

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Army Mobility Equipment Research and Development Center

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ROLL OVER PROTECTIVE STRUCTURE (ROPS)
DESIGN, ANALYSIS AND TEST FOR THE MILITARY 6000 LB ROUGH TERRAIN FORKLIFT TRUCK

FINAL REPORT
15 JANUARY 1974

Contract No. DAAK02-72-C-0574
U.S. Army Mobility Equipment Research and Development Center

Approved: 
G. R. Gavan
Project Engineer

Approved: 
S. A. De Martinis
Program Manager

Approved: 
J. Bonin
Technical Director

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1.0 INTRODUCTION

This document is the final technical report summarizing technical performance on Contract No. DAAK02-72-C-0574 for roll-over protective structure (ROPS) retrofit to the Military 6000-Pound Rough-Terrain Forklift Truck. A ROPS has been developed, which by utilizing a two-post design and a wire mesh roof, provides minimum obstruction to operator visibility. The structural capability has been demonstrated by compliance with SAE static load testing requirements and by a field roll-over test.

The program was structured as a two-phase effort to develop a ROPS for the forklift truck. The tasks of the development phase were as follows:

- Examine the vehicle chassis in the areas of ROPS attachment for structural adequacy and determine methods of reinforcement if required.
- Design and analyze structurally a ROPS which can be retrofitted to the forklift truck with a minimum of impairment to the functional requirements of the vehicle.
- Fabricate a development unit and conduct a test to applicable SAE Recommended Practices to obtain data required to verify the ROPS design.

The prototype phase of the program was conducted with the following tasks:

- Analyze the development test results, modify the development ROPS design and conduct additional structural analysis as required to establish a prototype design.
- Fabricate a prototype unit and perform a certification test to SAE Recommended Practices.
- Conduct a field roll-over test to verify the design under actual roll-over conditions.
- Fabricate two additional units to be delivered to USAMERDC. The first to be installed on a Type "A" vehicle while documenting installation procedure. The vehicle will then undergo performance testing at USAMERDC. The second ROPS is to be used as an installation trainer at USAMERDC.
- Prepare a complete technical data package for producing and installing ROPS and ROPS adapters for the forklift truck.

This is the first of three final technical reports due under this contract. The remaining two reports will be submitted following the completion of the respective technical efforts and will cover the following vehicles:

2. Military 10,000 pound rough-terrain forklift truck, Allis-Chalmers 645M military front-end loader, J. I. Case M924 military front-end loader and military 20-ton rough-terrain crane. The development of the non-linear computer program will be included.

This final report fulfills the requirements as specified in DD Form 1423 and contains a summary of information generated throughout the program and incorporated previously into the monthly progress reports, preliminary design review (PDR) and critical design review (CDR).
2.0 SUMMARY

A roll-over protective structure (ROPS) for the Military 6000 Pound Rough-Terrain Forklift Truck was developed and is shown in Figure 1. All objectives of the contract were met. In arriving at these objectives, development and prototype hardware were designed and analyzed structurally, four units were fabricated, and three tests were conducted including a field roll-over test. The design was certified to meet applicable SAE criteria. A complete technical data package capable of producing and installing ROPS and adapters to the vehicle was provided.

2.1 Design

The design effort included feasibility studies and complete drawing packages for the development and prototype hardware. The results of the feasibility studies indicated that a two-post configuration attached to the vehicle aft of the hydraulic reservoir would provide the best retrofit advantages. The ROPS is fabricated with square tubing with gusseted corners and provides overhead falling object protection (FOPS) with steel mesh while maintaining minimum obstruction to operator visibility. The ROPS fits into sockets and is attached by two cap screws. Since the forklift was not originally designed for ROPS installation, reinforcements were required to distribute loads into the chassis.

Although the development design met all structural requirements, the objectives of the prototype design phase were to solve two problems encountered with the development hardware. Fit checks to the Type "A" vehicle with wooden mock-ups showed inadequate clearance with the steering actuation system and the tires during some modes of operation. Also, lengthy installation time and chassis distortion were encountered during welding of reinforcements to the chassis. Modifications made to the post feet, sockets and chassis reinforcements provided adequate clearance in all areas. A bolt-on concept was developed which simplified the installation procedure and did not require welding to the chassis. Reinforcement of the axle housing was no longer required since a cross-over beam was provided to transmit loads between sockets.

2.2 Structural Analysis

Comprehensive structural analyses were conducted to assure structural integrity of the ROPS and vehicle to withstand roll-over loads. The applicable SAE standards and the anticipated roll-over conditions were used to establish the applied loads. The non-linear plastic computer program developed by LPC and classical techniques were used to perform the analyses. The analysis results indicated that all areas of the structure could withstand the applied loading environment with adequate safety factors. Deflection curve predictions for side and vertical loading were developed prior to each test and compared to measured results after the completion of each test.
2.3 Fabrication

Four ROPS units were fabricated during this contract. All of the units were built by Tube-Lok Products, Portland, Oregon following the solicitation of competitive bids by LPC. The following is a summary of the hardware procured and its usage:

1. Development test unit
2. Prototype test unit which was also used for the field roll-over test
3. Delivery unit which was mounted on Type "A" vehicle and shipped to USAMRDC for performance testing
4. Delivery unit which was shipped to USAMRDC for use as an installation trainer model.

2.4 Testing

A series of three tests was performed at the Lockheed Potrero test facility to demonstrate that the unit could meet loading requirements. This series included a development, prototype and field roll-over test. The development and prototype tests were conducted in accordance with the following applicable SAE Recommended Practices:

- The 500-lb weight dropped 17 feet FOPS requirement of J231
- The 15,000-lb side load, 122,000 in-lb side load energy, 21,500 lb vertical load and 8 ft-lb Charpy V-notch strength requirements of J394a.
- The critical zone limitations of J397a which permit deflection of 13.5 and 14.5 inches in the horizontal and vertical directions, respectively.

The objective of the development test was to obtain data required to verify the ROPS design. The test results showed that the unit passed successfully all SAE requirements specified above. However, problems of lengthy installation time and vehicle chassis distortion were encountered during welding of reinforcements to the chassis.

The second test was conducted to certify the final prototype design would meet the requirements of the applicable SAE Recommended Practices. The tests of the bolt-on unit demonstrated compliance with requirements. The formal test report of certification to SAE standards is included as Appendix 6.6.

The field roll-over test was conducted with the ROPS used previously in the prototype certification test. The roll sequence included a side roll followed by a complete end-over-end roll. Figure 2 shows the vehicle during the test. The adequacy of the two-post was substantiated by the severe conditions imposed on the ROPS in the roll test.
3.0 CONCLUSIONS

A ROPS was developed for the Military 6000-Pound Forklift Truck and certified by test to meet the SAE Recommended Practices. In addition to fulfilling this primary objective, several other important conclusions were reached.

The structural integrity of the ROPS was verified by a field roll-over demonstration. The two-post design concept, with many functional advantages over the more conventional four-post configuration, was substantiated under severe roll-over conditions incurred during the test.

The feasibility of retrofitting a ROPS to the current forklift truck was established. The prototype unit was installed on a Type "A" vehicle and the vehicle reworked to original functional capacity.

Analytical advances were made for predicting ROPS deflection behavior in the elastic and plastic regions. Improvements were made to the non-linear computer program to predict ultimate plastic behavior of the structure. The critical parameters for accurately predicting elastic deflections were identified by resolving differences between analytical predictions and test results.
4.0 RECOMMENDATIONS

The drawings, specifications and installation procedures for the prototype ROPS are acceptable for use in procuring production quantities for the U.S. Army. Since the ROPS is a critical safety item, it is recommended that the units be procured from a manufacturer with a demonstrated capability for producing ROPS in production quantities.

Study of the test results, structural analyses and fabrication information developed in the program indicates that modification of the design approach would result in a ROPS system that is simpler and, therefore, of lower cost than the prototype design. If the number of units expected to be fitted with ROPS justifies the effort, it is recommended that work toward the lower cost design be considered.

It is also recommended that the material specifications included in Appendix 6.1.1 be revised to delete the requirements for ASTMA 516, Grade 65, or Grade 70 steel. The material specifications, EMSD103 and EMSD104, include all necessary material requirements. In addition, the Charpy impact test requirements of the proposed SAE combined ROPS code are an acceptable substitute for the requirements currently included in the specifications.
5.0 DISCUSSION

5.1 Development Phase

5.1.1 Design

5.1.1.1 Design Criteria

The criteria used for design of the ROPS for the 6000-lb rough terrain forklift truck was established to achieve the following goals:

- Provide adequate roll-over and falling object protection for the operator of the vehicle
- Minimize the restrictions to the functional characteristics of the vehicle

To meet these goals, it was necessary to develop a design which minimized construction to operator visibility, forklift performance degradation and vehicle modifications during retrofit. Since during military use the ROPS and vehicle will be shipped separately, it was desirable to provide for nesting capability and tolerance control to permit interchangeability. Simple and proven design/fabrication techniques were required to achieve a design which could be built for a low unit cost during production.

The load, energy and material requirements are derived from SAE Recommended Practice J394a which specifies the minimum performance criteria for roll-over protective structures for wheeled front-end loaders and wheeled dozers. The J394 practice was selected as the test criteria since the operation and usage characteristics of the rough terrain forklift resembles closely that of the wheeled front-end loaders. A summary of these requirements is presented in Figure 3, SAE Design Criteria.

The gross vehicle weight is 23,500 lb and corresponds to the vertical load requirement. The side load and side load energy requirements of 15,000 lb and 122,000 in-lbs respectively, are derived from the empirical equations specified in J394a. The current specification requires that for two-post designs the side load should be applied at a point 1/3 of the roof length from the vertical posts or 20.7 inches. However, since the distance to the critical zone is greater than 1/3 of the roof length, an alternate requirement seemed appropriate. On the recommendation of the SAE Ad Hoc Committee on 15 March 1973 the side load application point was established as the aft limit of the critical zone. This distance is 37.0 inches from the centerline of the vertical posts for this ROPS unit, and was the location used for the side load application.

The deflection limits were established from SAE Recommended Practice J397a which specifies the critical zone for laboratory evaluation of roll over protective structures and falling object protective structures of construction and industrial vehicles. As shown in Figure 4, the deflection limits at the aft edge of the critical zone are 13.5 and 14.5 inches in the horizontal and vertical directions, respectively. The horizontal deflection limit was established in accordance with Section 5.3.2 of J397a by determining a simulated ground plane (SGP), rotating this plane 15 degrees away from the critical zone.
FORKLIFT WEIGHT, W 23,500 LB

SIDE LOAD, F 15,000 LB

\[ F = 5300 \left( \frac{W}{10,000} \right)^{1.22} \]

SIDE LOAD ENERGY, U 122,000 IN-LBS

\[ U = 42000 \left( \frac{W}{10000} \right)^{1.25} \]

VERTICAL LOAD, W. 23,500 LB

MATERIAL IMPACT STRENGTH CHARPY V NOTCH STRENGTH OF 8 FT-LB AT -20°F

CRITICAL ZONE DEFLECTION LIMITS HORIZONTAL, 13.5 INCHES VERTICAL, 14.5 INCHES

FALLING OBJECT PROTECTION 500 LB WEIGHT DROPPED 17 FEET

Figure 3 - SAE Design Criteria

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Figure 4 - Critical Zone Criteria
and computing the allowable travel at the load application point.

The minimum performance criteria for the falling object protective structure is specified in SAE Recommended Practice J231. The important requirements are that a 500-lb weight with a 8.0-inch diameter dropped 17 feet over the critical zone does not permit the weight or ROPS structure to intrude into the critical zone.

5.1.1.2 Preliminary Design Feasibility Studies

The results of preliminary design studies showed that retrofitting a ROPS to the 6000-lb forklift was feasible. The 6K Forklift was examined during fabrication at the manufacturer's facility for available space and possible interferences with ROPS envelope by wheels or other operating parts of the Forklift Truck. This investigation indicated that several locations for ROPS installation were available behind the operator, but severe interference problems were encountered in areas ahead of the operator. Therefore, a two post concept seemed to be more feasible than a four-post.

Two positions were found to be favorable. The best choice appeared to be aft of the hydraulic reservoir. This location for ROPS installation offered advantages of accessibility, existing chassis rigidity due to axle mount structure, and low overall cost because of minimal vehicle modification. However, the extensive overhang due to the distance to the critical zone resulted in a heavier ROPS with greater loads induced into the chassis. The heavier ROPS was needed to meet the minimum side load requirements and to provide sufficient rigidity to achieve the required energy level. Also, the overturning moment during vertical loading produced higher bending stresses in the posts.

The second choice for locating the vertical posts was forward of the hydraulic reservoir. Advantages of this attachment location were a lighter ROPS with less overhang and lower loads to be transferred into the chassis structure. With this concept extensive modifications to the vehicle would be required. These modifications would consist of relocation of the hydraulic reservoir and associated hydraulic lines, and redesign of the steering mechanism. Another disadvantage of this location was inadequate clearance for the ROPS attachment structure.

Brief preliminary analyses were made of the two-post designs attached at these locations. Steel tubing 4 x 4 x 1/2 was adequate for the forward mount; while 5 x 5 x 3/8 was required for the posts attached behind the hydraulic reservoir. Structural design of the ROPS hardware was complicated by the SAE requirements which specify that a minimum amount of energy (area under the force-deflection curve) must be achieved while maintaining a minimum side load. In addition, the structure cannot deflect into the defined "critical zone". Therefore, the structure was carefully sized to reach the minimum side load and be flexible enough to absorb the required energy without intruding into the critical zone.

Although choice of the two-post design concept was dictated primarily by space availability, other advantages are also realized over the four-post design. These include better forward visibility, lower cost and weight, and a nestability capability for shipping with the ROPS detached from the vehicle. Potential advantages of a four-post design would be greater industry experience and correlation to SAE requirements, and a more stable configuration for fore-aft and vertical loads.
5.1.1.3 Design (Development Unit)

The final design configuration of the Development Unit is shown in the following figures:

- Drawing 299025, ROPS Assembly on Frame, 6K Forklift-Layout, Figure 5
- Drawing 299026, Roll Over Protective Structure, 6K Forklift, Figure 6
- Drawing 299027, ROPS Mounting Bracket and Axle Mount Support Cap, 6K Forklift, Figure 7
- Drawing 299030, Frame Reinforcement Details, 6K Forklift, Figure 8.

Design of the development unit was completed while meeting the following constraints imposed by USAMERDC:

1. The design must meet all applicable SAE criteria.
2. The ROPS must be interchangeable and removable.
3. Upward shift of the vertical center of gravity should be minimized.
4. Obstructions to upward visibility should be minimized.

In addition, the design was guided by the list of groundrules summarized in Figure 9.

The ROPS, Drawing 299026, is supported by two vertical posts and bus wire mesh to provide overhead protection for falling objects.

The top of the ROPS canopy is fabricated primarily from square tubing. The major support members are 5 x 5 x .375 inch square tubes. To achieve a low center of gravity, beams which are not heavily loaded are 5 x 3 x .25 inch square tubes. The front beam is 2.50 inch diameter tubing to permit good visibility of the fork load when in an "up" position. Lifting brackets welded to each side of the roof are designed to carry three times the ROPS weight. As a safety precaution, the welds are sized to fail under the combined weight of the ROPS and vehicle.

A wire mesh is provided in the region directly above the operator to permit good upward visibility at the same time as falling object protection (FOPS). The mesh is fabricated from 2 x 2 x 0.50 diameter 8620 hot-rolled steel wire. The remainder of the ROPS roof is covered with 0.50 inch steel bar stock spaced at 5.0 to 6.0 inches. This spacing is similar to the original rock guard and gives adequate protection of the equipment from objects falling from the forklift load.
NOTES:
1. ALL WELDING PER DL-4600.
2. REMOVE 1/2" SQUARE HEAD FIXTURE FOR FRAME SUPPORT.
3. MATERIALS DECORATED WITH "X" TO BE VERIFIED.
4. REPAIRS SHOWN ARE 1/4" SQUARE HALF PLATE.
5. SECTION E-10 SHOWN AS "X" IN FABRICATION DRAWING.
6. SECTION A-10 SHOWN AS "X" IN FABRICATION DRAWING.
7. USE WELDING ROD NO. 45 FOR SECTIONS.
8. WELD 24K05-00 TO FRAME HORN SUPPORT AND REPEAT ON OPPOSITE SIDE.
9. MATERIALS SHOWN WITH "X" MUST BE VERIFIED.
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139. MATERIALS SHOWN WITH "X" MUST BE VERIFIED.
- Make extensive use of "CAT-CLARK" ROPS test data
- Consider actual roll-over influence on design
- Design must provide roll-over protection with side load applied at either side of roof at any fore/aft location
- ROPS to be interchangeable—tolerance control required
- Use simple and proven design/fabrication techniques
- Use LPC and industry experience where possible
- Absorb energy in simple, analytically predictable areas of the structure and avoid local buckling failures
- Minimize stiffness while staying within load constraints to preclude tractor failure
- Minimize cost
- Minimize vehicle modifications
- Limit operator visibility restrictions
- Minimize tractor performance degradation
- Limit noise and vibration induced by ROPS
- Provide for nesting capability during shipping if possible
- Minimize interference with maintenance operation

Figure 9 - Design Groundrules
The roof is supported by two vertical posts fabricated with 5.0 inch square tubing with a 0.375 inch wall thickness. The posts are spaced 37.33 inches apart to straddle the main support channels of the forklift chassis. The junction of these members with the roof has reinforcements in all planes to achieve good load and moment transfer.

The corner gussets are built up with 0.375 inch thick plates. They are welded together and to the square tubes. This type of corner reinforcement has advantages of wide industry usage with proven structural capability and excellent load transfer. Although this configuration requires many parts and considerable welding, it does not require special forming or bending techniques during fabrication. The width of the gusset plates are tapered to assure a gradual transition of load and a weld joint removed from the area of maximum bending stress in the tube. A curved plate is welded to the free edge of the gusset to preclude local buckling failures. A threaded bar spanning the two posts is provided to facilitate lateral adjustment of the ROPS during installation.

The lower end of the ROPS vertical support members are attached with a foot-socket arrangement. Threaded eye-bolts engage the feet into the sockets and permit easy removal of the ROPS. The steel post feet extend 5.0 inches into the tubes and are attached with a weld joint around the entire tube end. The portion of the foot which extends into the socket is tapered to achieve rigid fixity and easy installation. The eye-bolt is held in the foot with a 1.0 inch diameter pin which is retained by the side walls of the socket after installation of the ROPS. Noise and vibration isolation is obtained by placing sheets of "Fabreeka", a rubber-cotton composite material, between the sidewalls of the socket and under the nut.

The sockets are fabricated with an assembly of plates joined with penetration welds. The receptacles for the feet are curved to distribute the bearing loads in a manner which will reduce the stresses in the welds. Loads are transmitted from the sockets to the axle housing through "U" shaped reinforcements which are welded to the sockets and axle housing. The top of the axle housing is reinforced with another "U" shaped member.

The basic frame members of the forklift chassis are reinforced to distribute the loads incurred during rollover. Two 1.0 inch plates extending 67.0 inches along the frame channels provide the primary structural support. In addition, plates are provided below the frame channels and attached to the forward and aft faces of the sockets to give further chassis reinforcement and load distribution.

5.1.1.4 Material and Weld Requirements

During the design phase, specifications were written to establish the requirements for the materials and welding to be used in the roll-over protective structures. These specifications meet the requirements of the applicable SAE recommended practice and are consistent with the design criteria.
The material requirements for the high strength carbon steel are given in Material Specification EMSD103, Appendix 6.1.1 and the carbon steel tubing requirements are specified in Material Specification EMSD104, Appendix 6.1.2. All of the steel used in the design of the ROPS and chassis reinforcements meets the SAE impact strength requirement of 8 ft-lb at -20°F with a 10 mm x 10 mm test specimen.

The material properties for the plate and tubing members used in the design and analysis are presented in Figures 10 and 11, respectively. These levels can be easily achieved with "ROPS charpy steel" commonly used throughout the industry. However, the tubing yield strength of 50,000 psi is above the level used commonly. This requirement is necessary to withstand the vertical loading with the two post design. ROPS fabricators have indicated that this strength level will be easily attainable during production.

The FOPS mesh is fabricated with 8620 hot rolled steel. The material passed the 8 ft-lb at -20°F Charpy Vee Notch Impact Test requirement with a full size (10 mm x 10 mm) specimen.

The welding requirements are given in Process Specification DPSF100, Appendix 6.1.3. This specification details the standards for qualifying welders, lists filler metals which will meet impact requirements, specifies acceptable equipment and outlines the quality assurance standards.

5.1.2 Structural Analysis

5.1.2.1 Analysis Approach

The method used for structural analysis was to determine the elastic curve of the ROPS, support structure, and vehicle by computer program and conventional analysis and to determine the ROPS ultimate capability with the non-linear computer program. Then, using structural internal loads for maximum ROPS side load and one 'g' vertical load, a detail structural analysis was performed on the ROPS, support structure, and vehicle. Factors of safety for the structure were obtained by comparing material yield strength to stresses obtained from the above loading conditions.

An assumption made to simplify the computer model was the longitudinal vehicle frame does not have pitch rotation. This is completely true during the side load test because both sides of the frame are tied down at two locations. This assumption is felt to be accurate during actual rollover, also because numerous vehicle cross ties, axles, and engine prevent relative frame rotation. An additional modeling assumption used is that the ROPS foot is completely fixed in the socket. This assumption is true for large ROPS deflections and produces accurate results for ROPS ultimate capability. However, as shown by Figure 12, in the small deflection range considerable discrepancy is obtained. This is due to the ROPS feet rotating in the socket while absorbing socket clearance. Therefore, the elastic curve prediction was based on test data obtained from the caterpillar ROPS bedplate test.
* PLATE

- MATERIAL: ASTM-A-516 STEEL
- ULTIMATE TENSILE STRENGTH, $F_{tu}$: 70,000 to 90,000 PSI
- TENSILE YIELD STRENGTH, $F_{ty}$: 38,000 PSI
- SHEAR STRENGTH, $F_{su}$: 44,000 PSI
- ULTIMATE BEARING STRENGTH, $F_{bru}$: 115,000 PSI
- MODULUS OF ELASTICITY, $E$: $29.0 \times 10^6$ PSI
- MODULUS OF RIGIDITY, $G$: $11.2 \times 10^6$ PSI
- POISSON'S RATIO: 0.30
- CHARPY V-NOTCH IMPACT STRENGTH AT $-20^\circ F$: 8 FT-LB
- DENSITY, $\rho$: 0.283 LBS/IN$^3$

* LPC SPECIFICATION NO. EMSD104

Figure 10, ROFS Plate Material Properties
* ROPS TUBULAR MEMBERS

- **MATERIAL**
  - ASTM-A-500 STEEL

- **ULTIMATE TENSILE STRENGTH, $F_{tu}$**
  - 60,000 to 80,000 PSI

- **TENSILE YIELD STRENGTH, $F_{ty}$**
  - 50,000 PSI

- **COMPRESSIVE YIELD STRENGTH, $F_{cy}$**
  - 50,000 PSI

- **SHEAR STRENGTH, $F_{su}$**
  - 38,000 PSI

- **ULTIMATE BEARING STRENGTH, $F_{bru}$**
  - 98,000 PSI

- **MODULUS OF ELASTICITY, $E$**
  - $29.0 \times 10^6$ PSI

- **MODULUS OF RIGIDITY, $G$**
  - $11.2 \times 10^6$ PSI

- **POISSON'S RATIO, $\nu$**
  - 0.30

- **CHARPY V-NOTCH IMPACT STRENGTH AT -20°F**
  - 8 FT-LB

- **DENSITY, $W$**
  - 0.283 LBS/IN$^3$

* LPC Specification No. EMSD104

Figure 11 - ROPS Tube Material Properties
Figure 12 - Comparison of Caterpillar ROPS Bedplate Test and Computer Analysis Results
5.1.2.2 Analysis Results

The predicted ROPS side load vs. deflection curve is shown in Figure 13. The elastic and elastic-plastic transition section of the curve is based on test results from the caterpillar ROPS bedplate test and the ultimate capability value of 28,000 lbs is based on the non-linear computer program output. Figure 13 also shows the results from the non-linear program for a partially pinned (fixed for foot torsion) and fully fixed lower end ROPS. The pinned end curve cannot be used for prediction because its elastic slope is less than expected and, it develops about one-half of the ultimate capability. The fixed end curve cannot be totally used because its small deflection stiffness is excessive. These curves point out a non-linear fixity mechanism has to be developed for a computer model of ROPS with sockets to accurately predict load vs. deflection in a single run. A non-linear fixity mechanism is presently being developed to be incorporated in the ROPS computer procedure.

The computer predicted ROPS vertical load vs. deflection curve is shown in Figure 14. The effect of socket clearance was not included at this time.

A plot of the ROPS model is shown in Figure 15. This plot is a model of the pinned lower end ROPS; therefore, no frame influence is necessary. The computer program includes this model plotting capability to help check for model geometry errors and to provide a plot of the model deflected shape.

The structural analysis of the unit is given in Section 6.2 of the Appendix and a summary of the results is shown in Tables 1, 2 and 3. Table 1 is a summary of the ROPS factors of safety. Due to side load, P1, local buckling tends to occur at the point of load application. Location 1 is a check of this condition. Since upward visibility is required through this ROPS, roof panels cannot be used. As a result, side load applied forward of the ROPS vertical members have to be transferred by the roof members in bending. This bending causes excessive stresses on the roof mid joints requiring gussets to be added to the joints. Points 2 and 3 are a check of these gussets for the member bending moments. Point 4 is a check for foot bending stresses. Foot bending stresses were compared with ultimate bending stress as foot yielding was permitted. Location 5 is a check of ROPS tube bending stress due to the vertical load, P2. It is necessary to compare location 5 stress to an allowable yield stress as the roof deflection may become excessive and enter the critical zone at ultimate bending stress.

Table 2 is a summary of the frame stresses due to maximum ROPS side load. Location 1 is a check of weld tension stress due to a right hand side load. Due to a right hand side load, P3 puts a tension load on 1 and a couple due to -M3 at the top and bottom of the socket puts a tension load on 1. Locations 2 and 3 are a socket tension and shear check due to a right hand side load. The weld tension load at location 1 loads the frame one inch horizontal plate. This load has to be transferred as a shear force down to the axle casting through location 4 weld. Location 4 is a weld shear check for this loading. Location 5 is a weld shear check between the socket vertical structure and bottom plate. The welded axle and reinforcement reacts M3 in bending. This bending causes a weld tension stress at 6 for a right hand side load. Location 6 is a check of this tension stress.
Figure 15 - 6K ROPS Computer Model
Table 1 - ROPS Stress Summary

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>STRESS</th>
<th>ALLOWABLE</th>
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<tbody>
<tr>
<td>DUE TO P₁ =</td>
<td>31,500</td>
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<tr>
<td>1</td>
<td>15,700 lbs (col)</td>
<td>38,000 col.</td>
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<tr>
<td>2</td>
<td>15,300 psi</td>
<td>38,000 $F_{ty}$</td>
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<td>3</td>
<td>6,750 psi</td>
<td>38,000 $F_{ty}$</td>
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<td>4</td>
<td>71,600 psi</td>
<td>105,000 $F_{bu}$</td>
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<tr>
<td>DUE TO P₂ =</td>
<td>23,500 LBS</td>
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<tr>
<td>5</td>
<td>47,000 psi</td>
<td>61,000 $F_{by}$</td>
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DUE TO ROPS LOAD = 31,500 LBS;

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<tr>
<td>1</td>
<td>$f_b = 24,000$ psi</td>
<td>$38$ ksi $F_{ty}$</td>
<td>1.58</td>
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<tr>
<td>2</td>
<td>$f_t = 6,900$ psi</td>
<td>$38$ ksi $F_{ty}$</td>
<td>1.87</td>
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<td>3</td>
<td>$f_t = 27,000$ psi</td>
<td>$38$ ksi $F_{ty}$</td>
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<td>4</td>
<td>$f_s = 24,200$ psi</td>
<td>$54.5$ ksi $F_{su}$</td>
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<td>$f_s = 22,000$ psi</td>
<td>$45$ ksi $F_{su}$</td>
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<td>6</td>
<td>$f_t = 19,200$ psi</td>
<td>$36$ ksi $F_{ty}$</td>
<td>2.48</td>
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Table 2 - Frame Stress Summary
### Frame Loads

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<td>1</td>
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<td>36,000 $F_{ty}$</td>
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<tr>
<td>2</td>
<td>$f_s = 16,000 \text{ PSI}$</td>
<td>37,000 $F_{su}$</td>
<td>2.32</td>
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<tr>
<td>3</td>
<td>$f_t = 15,000 \text{ PSI}$</td>
<td>36,000 $F_{ty}$</td>
<td>2.40</td>
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$P_x = 25,000 \text{ LB}$
$P_y = 15,000 \text{ LB}$
$P_z = 67,200 \text{ LB}$
$M_y = 625,000 \text{ IN-LB}$
$M_z = 229,000 \text{ IN-LB}$
$M_x$ (Carried by Axle Mount)

### Diagram

- **Mz**
- **Px**
- **My**
- ROPS Socket Loads
- Counterweight

---

Table 3 - Frame Stress Summary (Cont'd)
Location 1 on Table 3 shows the expected frame stress for the side load test.

Location 2 and 3 are tie down stresses.

A possible increase in rear axle stress level due to additional ROPS weight was considered. When contacted by the USAMERDC representative, Clark, the axle manufacturer could see no difficulty in the additional axle loading. No additional analysis was conducted since inadequate definition of structural detail and load factors was available.

5.1.2.3 Comparison With Test Results

A comparison of the predicted side load to the measured test side load is shown in Figure 16.

Figure 16 shows more stiffness was obtained during the test in the elastic part of the side load deflection curve than predicted by the adjusted frame socket prediction curve. This occurred because the development 6K ROPS conical socket developed more fixity than obtained from the caterpillar ROPS rectangular socket which the method for the predicted elastic curve was based upon.

The reduced ultimate capability obtained from the test compared to predicted is discussed in Section 6.4 of the Appendix, "Analysis of Development Test Results". In summary, it shows the reduced ultimate capability was largely due to an unexpected influence of actuator rotation on the side load test. Normal rotation of the ROPS roof causes the side load actuator to deflect forward at the point where it attaches to the roof. With the other end of the actuator pivoting about a fixed point, the actuator rotates and develops a forward component load relative to the vehicle. This forward actuator load causes an additional bending moment at the lower end of the ROPS vertical legs. As a result, the ROPS plastic hinge bending moment is developed at a side load which is lower than would be obtained without actuator rotation. Only a 2% additional reduction in side load capability was due to material strength.

A comparison of the predicted vertical load to the measured test vertical load is shown in Figure 17. Except for a slight initial sag in the test vertical load deflection curve, the elastic curve matches the predicted curve very closely. The initial sag is due to socket clearance which permits rotation of the foot within the socket. The reduction in strength obtained in the vertical load test at large deflections is attributable to actuator rotation. Actuator rotation causes a significant increase in moment arm distance between the actuator line of action and the bottom of the ROPS tube. This test data will be studied in detail for the 10,000 lb forklift application where more vertical load capability is required.

Maximum frame reinforcements stress obtained from strain gage data is at gage No. 29. This is located at location 1, Table 3. Expected stress was $f_r = 22,000$ psi at 31,500 lb side load. Actual stress obtained was 13,300 psi at 24,000 lb side load. Extending this stress to 31,500 lb side load would produce 17,500 psi stress or predicted stress level was 25% conservative.
Figure 16 - Comparison of ROPS Side Load Deflection to Prediction
Figure 17 - Comparison of ROPS Vertical Load Deflection To Prediction
5.1.3 Fabrication

The Preliminary Design Review (PDP) for the 6K Development ROPS was held at LPC on April 4 and 5 with Mr. Bill Stewart, Contracting Officer's Representative, USAMERDC. Authority to proceed with fabrication of the Development ROPS and reinforcement hardware was granted at this time. Bids were received and the fabrication contract awarded to Tube-Lok Products, Portland, Oregon on April 9, 1973. Fabrication was completed on 4 May. Figures 18, 19 and 20 are photographs of the ROPS, foot, and socket-reinforcement details as they were received at the Potrero Test Facility.

5.1.4 Testing

The development testing for the 6,000 lb forklift ROPS consisted of a series of tests to characterize FOPS mesh and tests of the development unit to SAE requirements. Overload tests were also conducted in the side and vertical directions.

5.1.4.1 Falling Object Protective Structure (FOPS) Tests

The design selection of steel mesh to provide FOPS protection was based on the need for good overhead visibility, a requirement for forklift operation. Since steel mesh had not been used previously in this application, test results were not available. Also, analytical predictions were not considered to be reliable since the mesh weave complicates the geometry and makes stiffness predictions difficult.

A test set-up was built to characterize the wire mesh to meet SAE J231 FOPS requirements. The test stand was made with 4 x 4 x 1/4 square tubes spaced to stimulate the support members of the ROPS roof.

Five drop tests were conducted, and the results are summarized in Table 4. Tests #2 and #3 demonstrated adequate penetration resistance by passing the 17 feet drop, but neither of the steels met the 3 ft-lb Charpy Vee Notch Impact test requirement. Figure 21 is a photograph of the Test #3 mesh after the 17 feet drop. Hot rolled 8620, a steel which exhibits strength and elongation properties similar to C1018, was used for the development ROPS test.
<table>
<thead>
<tr>
<th>TEST NO.</th>
<th>MESH SIZE</th>
<th>MATERIAL</th>
<th>DROP HEIGHT</th>
<th>TEST RESULTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>2 x 2 x 5/16</td>
<td>Spring Steel</td>
<td>17</td>
<td>Weight penetrated mesh</td>
</tr>
<tr>
<td>#2</td>
<td>2 x 2 x 1/2</td>
<td></td>
<td>17</td>
<td>No penetration</td>
</tr>
<tr>
<td>#2A</td>
<td>2 x 2 x 1/2</td>
<td></td>
<td>23</td>
<td>Weight penetrated mesh</td>
</tr>
<tr>
<td>#3</td>
<td>2 x 2 x 1/2</td>
<td>C1018</td>
<td>17</td>
<td>No penetration</td>
</tr>
<tr>
<td>#3A</td>
<td>2 x 2 x 1/2</td>
<td></td>
<td>20</td>
<td>Weight penetrated mesh</td>
</tr>
</tbody>
</table>

Table 4, FOPS Test Results
5.1.4.2 ROPS Installation for Development Test

The ROPS, mounting brackets and frame reinforcement details were installed to the forklift chassis in preparation for static testing. A problem with welding vehicle frame reinforcement was uncovered during reinforcement installation associated both with a lengthy installation time and frame distortion.

Reinforcements were welded to the chassis by a certified welder. Approximately 72 manhours were required to complete the welding specified in the installation assembly, Drawing No. 299025. 79 lbs of weld material were deposited, one quarter of which was required to weld reinforcement to the axle mount as shown in Figure 22 to permit this member to carry loads across the vehicle. The remainder of the welds were used to join reinforcement members and to attach them to the 9-inch channel section of the vehicle frame as shown in Figure 23. The installation time and weld material can be reduced slightly by modifying the weld preparation chamfers, but the concept of reinforcing frame members will require considerable welding.

A problem with controlling distortion in the chassis was encountered during reinforcement attachment. At the location of the mounting brackets the 9.0 inch chassis side channels had warped approximately 0.5 inch outward at the top flange. Distortion was due primarily to rotation of the channel caused by weld shrinkage of the large weld near the channel base. Some channel distortion was also noted in areas forward and aft of the mounting brackets.

The weld distortion of the channels caused cracking of the engine support brackets and interference with ROPS installation. Attempts to straighten the chassis were unsuccessful, therefore grinding approximately 0.25 inch from the side plate reinforcements was required to permit installation of the ROPS. Removal of this material was considered to have negligible effect on test results.

5.1.4.3 ROPS Development Test

Static development testing was performed with the ROPS and reinforcements installed on the Type "H" 6K Forklift on May 29. The tests were witnessed by W. Stewart and S. Newman of USAMERDC. The unit passed successfully all SAE requirements. The testing (in sequence conducted) with significant requirements and results is summarized as follows:

1. A 500-lb weight was dropped 17 feet onto the steel mesh on top of the ROPS in compliance with the FOPS requirements of SAE recommended practice J231. The weight did not penetrate the top of the critical zone (SAE Recommended Practice J397a) 14.5 inches below the mesh. The maximum deflection measured from high speed movies was six inches. Permanent deformation of 1.38 inches was recorded after the test. Figures 24 and 25 show the pretest and post-test condition of the mesh and supporting structure. It should be noted that prior to this test, the 8620 steel mesh passed the 8 ft-lb at -20°F Charpy Vee Notch Test
Figure 24 - Development ROPS Structure Before FOPS Test
requirement with a full size (10 mm x 10 mm) specimen.

2. The 15,000 lb side load and 122,000 in-lb side load energy requirements of SAE recommended practice J394a were met. Figure 26 shows that a load of 23,000 lb was reached at the required energy level and a deflection of 8.0 inches. Figures 27 and 28 show the pretest and post-test condition of the structure.

3. A vertical load of 23,500 lb, equal to the vehicle weight, was imposed at the geometric center of the ROPS roof as required by SAE recommended practice J394a. The deflections associated with this loading are shown in Figure 29. The structure under maximum loading is pictured in Figure 30.

4. The ROPS was then subjected to a side load overtest. The results showing a side load capability of 24,000 lb corresponding to a deflection of 12.5 inches is presented in Figure 31.

5. The ROPS was then subjected to a vertical load overtest to determine the load capability of the unit before the critical zone was invaded. Due to excessive rotation of the roof under load and the attendant variation in the load direction, data obtained in the test must be analyzed to accurately establish the load capability. This analysis will be conducted during the contract to retrofit a ROPS to the 10,000 lb forklift since a greater vertical load capability is required for this vehicle.

The complete Test Report is presented in Appendix 6.3, "Development Test Results". The results of all strain and deflection measurements are contained in this report.

5.2 Prototype Phase

5.2.1 Design

The design of the prototype hardware utilizes the development ROPS, but the ROPS attachment structure and chassis reinforcements are modified to permit bolting to the vehicle. The decision to use the development ROPS design was based on the development test results which showed that the unit passed successfully all of the applicable SAE criteria. Although the attachment structure to the chassis was changed significantly to accommodate the bolt-on concept the basic design features of the development unit were retained. This modification was needed to eliminate chassis distortion and reduce weld time incurred during installation of the development hardware.

5.2.1.1 Roll Over Protective Structure

The prototype ROPS is shown in LPC Drawing No. 299024, Revision D, Roll Over Protective Structure for 6K Forklift, Figure 32. As previously discussed, only minor changes were made to the canopy structure used for the development test.
Figure 26 - Side Load Test Results

SIDEB LOAD, 10 ksi

REQUIRED SIDE LOAD 15,000 LBS
REQUIRED ENERG, 122,000 ft- 1bs

u = 75,793 IN-1BS

DEFLECTION, INCHES

13.5

10.0

5.0

0.0

0

10

20

30

TEST CURVE

CRITICAL ZONE = 13.5 IN.
Figure 27 - Development ROPS Side Load Test Setup
Figure 28 - Development ROPS After Side Load Test
Figure 30 - Development ROPS Under Vertical Loading Requirement of 23,500 pounds
Figure 31 - Development ROPS at Maximum Side Load
Overtest Condition
The lifting lugs, located previously on the outboard surfaces of the main roof members, were moved to the inboard side of the same support members. The new position decreases the overall width to 75.205 inch from 83.375 inch. With this change the overall width of the vehicle was not increased by the ROPS retrofit. The lifting lugs are attached to the square tubing with welds on the top and bottom surfaces. These small welds will withstand the weight of the ROPS with a safety factor of three, but are sized to fail under the combined weight of the ROPS and vehicle. Therefore, the potential safety hazard of lifting the entire vehicle with the ROPS is avoided.

The configuration and material of the ROPS feet were changed to resolve clearance problems encountered during vehicle operation. During a fit-up check with a wooden mock-up critical areas of clearance were identified as follows:

1. The steering drag link located on the left side of the vehicle and the 299239-509 side plate reinforcements.
2. The steering cylinder located on the right side of the vehicle and the forward side of the socket.
3. The tire and 299239-105 top of socket at the outboard edge.
4. The tire and the outboard face of the 299024-137 post feet.

Each of these items was checked under various combinations of steering position and articulation of the vehicle. The design guidelines were to provide 0.5 inch clearance between vehicle components and the ROPS/reinforcement structure. An exception to this groundrule is the tire clearance which must be 1.0 inch to provide for the addition of tire chains. Actual clearances obtained are as follows:

1. An 0.5-inch clearance is provided for the steering drag link
2. The steering cylinder has 1.0 inch clearance
3. The tire clears the socket and post foot by 1.25 inch

The cross-section of the post feet was reduced to achieve a smaller socket. The width was reduced to 2.600 inch from 3.660 inch. The length of the feet was increased to 31.75 inch from 18.0 inch to permit shortening the square tubing to provide clearance with the tire.

A higher strength allowable was needed for the post feet to accommodate the higher applied stresses due to the reduced cross-section. The material was changed to AISI 4340 steel heat treated to 125,000 psi minimum ultimate tensile strength. To preclude weld cracking, special requirements for welding were specified in Note 12 of Drawing No. 2990240. This note added preheat, postheat and stress relieving requirements to the Welding Specification DPSF100.
A threaded hole was provided in the base of the post foot of the prototype unit to accept a cap screw to retain the foot in the socket. This concept offered several design simplifications to the development unit. The cap screw replaced the machined eye bolt and nut. The machined slot in the foot of the development unit was deleted. The tapped hole utilizes fabrication techniques more commonly used by ROPS manufacturers.

5.2.1.2 Attachment Structure

The ROPS attachment structure for the prototype unit is shown in LPC Drawing No. 299239, Revision E, 6K Forklift ROPS Bolt-on System Attachment Structure, Figure 33.

In the development unit, the frame and rear axle mount were strengthened by welding reinforcing elements to provide an adequate load path from the vehicle into the ROPS and to develop sufficient strength and stiffness to withstand the loads imposed on the ROPS. While making maximum use of the vehicle structure, this approach required considerable welding at the time of ROPS installation and the attachment of the long frame reinforcement member caused the 9-inch channel comprising the frame to deform. Because of the installation time and distortion, alternate approaches were investigated even prior to the development test. At the same time, modifications to reduce cost developed from the experience of fabricating the development unit were taken into account. The concept developed utilizes the forklift structure primarily as a load path between the vehicle and the ROPS. The axle housing is not utilized to transmit loads across the frame as in the development design. The attachment structure consists of integral mounting brackets and cross-over beam and frame reinforcement and attach plates.

The attach plates on one side are fabricated as part of the mounting bracket-beam unit. The other attach plate is assembled to the structure at the time of ROPS installation in order to accommodate vehicle frame width tolerances. At installation, the attach plate is welded to the mounting bracket at the proper location and 28 holes 3/4" in diameter are drilled into the frame in line with holes pre-drilled in the attach plates. Bolting completes the installation of the structure and the ROPS canopy then is attached to the mounting bracket in the same manner as in the development unit.

5.2.1.3 Resilient Pads

Noise suppression and vibration-shock reduction is provided with resilient pads specified in LPC Drawing No. 299029, Kit of Resilient Pads for ROPS for 6K Forklift, Figure 34. Pads are placed on all sides of the sockets to completely isolate the post feet from metal-to-metal contact with the sockets. In addition, washer pads are placed under the heads of the cap screws.

The resilient pad material is Fabreeka. This is a specially manufactured material composed of layers of tightly twisted, closely woven cotton duck impregnated with rubber. The physical properties of Fabreeka are suited to applications of shock, vibration and noise reduction.
NOTES:
1. ALL WELDING PER BS4560
2. TOLERANCES - ± 0.0625
3. QUANTITIES SHOWN ARE FCS
4. NO FILLET TOLERANCED ON WELD
5. ALL SOCKET STRUCTURE MUST BE PENCERATED 5/8" MINIMUM VALVE
6. FABRICATION METHOD MUST BE MADE OF MORE THAN 1/2" PENETRATION, DON'T BURN "S" PLATE
7. APPLY 1 COAT HU-PLATE CO. (CALIF). ZZO S. LINES
8. PERMANENTELY MARK WITH APPROPRIATE PA
NOTES
1. PERMANENT INK MARK EACH PAD WITH APPROPRIATE PART NO.
2. PARTS IN QUANTITIES SHOWN COMPRIS (०) KIT USED IN THE INSTALLATION OF ROPS PER DWG 299279.
3. BAG & TAG EACH KIT. PERMANENT MARK TAG WITH NUMBER 299029-501.

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<tr>
<th>QTY</th>
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<th>DESCRIPTION</th>
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<td>73015</td>
<td>-105 WAS</td>
</tr>
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<td>4</td>
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<td>-103 PA</td>
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<td></td>
<td>73015</td>
<td>-101 PA</td>
</tr>
</tbody>
</table>

NOTES:
- DO NOT SCALE THIS DRAWING UNLESS OTHERWISE SPECIFIED.
- INTERPRET THIS DRAWING PER STANDARDS IN MIL-STD-100.
- DIMENSIONS ARE IN INCHES.
- TOLERANCES:
  - ±0.01
  - 0.01
  - TOLERANCE ON ANGLES ±15°
- SURFACE ROUGHNESS 125
NOTES

1. PERMANENT INK MARK EACH PAD WITH APPROPRIATE PART NO.

2. PARTS IN QUANTITIES SHOWN COMPRISE (1) KIT USED IN THE INSTALLATION OF ROPS PER DWG 299279.

3. BAG & TAG EACH KIT. PERMANENT MARK TAG WITH NUMBER 299029-501

INSTALLATION

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<th>QTY</th>
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<th>PART OR IDENTIFYING NO.</th>
<th>NOMENCLATURE OR DESCRIPTION</th>
<th>MATERIAL</th>
<th>SPECIFICATION</th>
<th>ZONE</th>
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<td>73015</td>
<td>-105</td>
<td>WASHER-.125 THK NOM</td>
<td>FABREEKA</td>
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<tr>
<td>4</td>
<td>73015</td>
<td>-103</td>
<td>PAD</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>4</td>
<td>73015</td>
<td>-101</td>
<td>PAD</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

LIST OF MATERIALS OR PARTS LIST

LOCKHEED PROPULSION COMPANY
A DIVISION OF LOCKHEED AIRCRAFT CORPORATION
REDLANDS, CALIFORNIA 92373

KIT OF RESILIENT PADS FOR ROPS FOR 6K FORKLIFT

SIZE CODE IDENT NO. DRAWING NO.
1 C 06491 299029

SCALE 1/2

IMPO 684 - 58C-1001
NOTES:
1. QUANTITIES SHOWN ARE FOR ATTACHMENT
   OF 1 ROPS UNIT. SEE SERVICE BULLETIN 112
2. DELETED
3. DELETED
4. PERMANENT MARK WITH APPLICABLE PART NO.
5. DELETED

<table>
<thead>
<tr>
<th>DIA.</th>
<th>CODE</th>
<th>CODE</th>
<th>PART OR</th>
</tr>
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</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1C3</td>
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</tbody>
</table>

ASSEMBLY PROCEDURE:

SERVICE BULLETIN 112

BEVEL NUT
STEEL
ASTM A-36

SPACER BLOCK
STEEL
ASTM A-36

WASHER
STEEL
ASTM A-36
5.2.1.4 ROPS Assembly

The assembly of the ROPS, sockets and chassis reinforcements mounted on the forklift is shown on LPC Drawing No. 299279, Revision A, 6K Forklift Bolt-On System ROPS Installation, Figure 34a. The details of assembly procedure are specified in Service Bulletin 112 called out as Note 2 of the drawing. Additional detail parts required for ROPS installation and called out on Drawing No. 299279A are shown in LPC Drawing No. 299572, Revision A, ROPS Attachment Parts for 6K Forklift, Figure 34b.

5.2.2 Structural Analysis

5.2.2.1 Analysis Approach

The method of analysis used was identical to the method used on the development unit except additional analysis was performed for an actual rollover condition. This was done because the bolted-on (prototype) unit develops higher stresses in the forklift chassis than the development weld-on design. To perform this analysis the vehicle mass was assumed to be concentrated at two locations. The C.G. of one of the mass segments was located in the center of the aft vehicle structure and the other was located at the center of the forward structure 70 inches forward of the ROPS socket. Then the frame was analyzed for a total side load equal to the SAE required side load of 15,000 lbs applied to these C.G. locations and reacted at the ROPS socket location. The resulting frame stresses exceeded the yield strength of the forklift frame. However, since frame yielding was felt to provide an additional source for developing energy and clearance and installation problems would be encountered with larger reinforcements, the reinforcement size was maintained and the frame was allowed to yield.

5.2.2.2 Analysis Results

The predicted ROPS side load vs. deflection curve is shown in Figure 35. The long foot design did not significantly change the elastic stiffness of the structure. Therefore the elastic and transition section of the curve is based on the development unit test data. Since the long foot design changes the plastic hinge location, the ultimate capability was recomputed and reduced by an actuator rotation factor. The ultimate capability was then given a load range to account for material strength variation and added to the curve.

The predicted ROPS vertical load vs. deflection is shown in Figure 36 and is based on the development unit test data.

The structural analysis of the unit is given in Section 6.5 of the Appendix and a summary of the results is shown in Tables 5, 6, and 7. Table 5 is identical to Table 1 except ratioed for a slightly higher expected maximum side load, \( P_1 \) of 33,300 lbs.

Table 6 is a summary of frame stresses. Location 1 is a check of weld shear between the socket vertical plates and bottom plate. Point 2 is a check of the outboard area of the socket shearing out due to a right hand side load. Note
Figure 36 - Predicted ROPS Vertical Load Deflection
Table 5 - ROPS Stress Summary

<table>
<thead>
<tr>
<th>Location</th>
<th>Stress</th>
<th>Allowable</th>
<th>F.S.</th>
</tr>
</thead>
<tbody>
<tr>
<td>DUE TO P₁</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>33,300 lbs</td>
<td>38,000 lbs (col)</td>
<td>1.28</td>
</tr>
<tr>
<td>2</td>
<td>16,700 lbs (col)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>16,200 psi</td>
<td>38,000 Fᵧ</td>
<td>2.34</td>
</tr>
<tr>
<td>4</td>
<td>7,100 psi</td>
<td>38,000 Fᵧ</td>
<td>High</td>
</tr>
<tr>
<td>DUE TO P₂</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>152,000 psi</td>
<td>183,000 Fᵤ</td>
<td>1.20</td>
</tr>
<tr>
<td>6</td>
<td>23,500 lbs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>49,000 psi</td>
<td>57,000 Fᵧ</td>
<td>1.16</td>
</tr>
<tr>
<td>Location</td>
<td>Stress</td>
<td>Allowable</td>
<td></td>
</tr>
<tr>
<td>----------</td>
<td>--------</td>
<td>-----------</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>$f_a = 37,000$ psi</td>
<td>$45$ ksi P su</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>$f_b = 41,000$ psi</td>
<td>$45$ ksi P su (rollover)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>$f_c = 24,000$ psi</td>
<td>$48$ ksi P by</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>$f_d = 29,000$ psi</td>
<td>$38$ ksi F by</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>$f_e = 32,500$ psi</td>
<td>$38$ ksi F by</td>
<td></td>
</tr>
</tbody>
</table>

*Table 6 - F-Frame Stress Summary*
Table 7 - Frame Stress Summary (Cont'd)
that for an actual rollover, the side load may be applied in line with the ROPS vertical legs. The ROPS then can develop more side load capability and make the socket more critical. Locations 3, 4, 5 are crossbeam bending stress checks for the ROPS lower fixity moments, $M_x$ and $M_z$.

Table 7 is a summary of stresses due to frame bending moments. Points 1 through 3 are local bending checks, point 4 is a hole bearing check at the highest bolt load location. Location 5 through 7 are additional local bending checks. Location 1 is a rollover check of the forklift frame and reinforcement jointly carrying the SAE required side load of 15,000 lbs. Location 5 is a check of the frame at the edge of the reinforcement for the same condition. The stress levels of 102,000 psi and 90,000 psi are predicting yielding at these two points. The rollover test conducted on this unit 11 October 73 did produce yielding at these two locations. Therefore, the magnitude of the SAE required side load appears to be similar to that experienced in the rollover test.

5.2.2.3 Comparison with Test Results

A comparison of predicted side load to test side load is shown in Figure 37. A comparison of predicted vertical load to test vertical load is shown in Figure 38. A thorough discussion comparing predicted loads to test loads is given in Section 6.7, "Analysis of Prototype Test Results". In summary, the vertical load prediction is felt to be sufficiently accurate. The change in socket design from the development unit did not affect severely foot rotation in the socket. Therefore the vertical load prediction based on the development test was accurate.

The change in socket design did, however, greatly affect foot twisting in the socket which produced a sag in the curve and made the elastic curve softer than expected. The error was predicting an elastic curve based on the 6K development test instead of basing the elastic curve on the caterpillar bedplate test which utilized a similar socket design. Ultimate capability developed in the test was in the middle of the predicted range.

Analysis of the prototype test results shows that not only the non-linear fixity mechanism for rotation, discussed in Section 5.1.2.2, is required, but a non-linear fixity mechanism for foot twisting is required for a computer model of ROPS structures with sockets. These points, it is felt, demonstrate the difficulty in predicting the ROPS elastic curve for ROPS designs with sockets.

A review of the strain gage data indicates material yielding only in the ROPS vertical tubes and in the ROPS gussets at the upper end of the vertical tubes. Assuming ROPS tube $F_{TY} = 55,000$ psi,

\[
\epsilon_{\text{P.L.}} = \frac{F_{TY}}{E} = \frac{55000}{29 \times 10^6} = 1900 \mu \text{in/in}
\]

\[
\epsilon_{\text{Yield}} = 1900 \mu \text{in/in} + 2000 \mu \text{in/in} = 3900 \mu \text{in/in}
\]
Figure 37 - Comparison of ROPS Side Load Deflection to Prediction
NOMINAL CALCULATED DEFLECTION = 3.40 IN.

$P_v = 23,500 \text{ LB (SAE-J1394a)} - \text{VEHICLE WEIGHT}$

DEFLECTION, INCHES

Critical Zone
$\Delta_c = 14.5 \text{ IN}$

Figure 1b - Comparison of ROPS Vertical Load Deflection to Prediction
At required side load energy, strain gage 1 at 2400 \( \mu \) in/in exceeded the material proportional limit and strain gage 2 at 3900 \( \mu \) in/in reached material yield strength.

One of the two strain gages on the gussets recorded the highest strain in the test. At required side load energy, gage 8 and 10 developed 3860 \( \mu \)in/in and -4750 \( \mu \) in/in respectively. Assuming ROPS plate \( F_{TY} = 40,000 \) psi,

\[
\epsilon_{P.L.} = \frac{40,000}{29 \times 10^6} = 1380 \mu \text{in/in}
\]

\[
\epsilon_{Yield} = 1380 + 2000 = 3380 \mu \text{in/in}
\]

Both gages exceeded material yield strain of 3,380 \( \mu \)in/in. However, from LPC Specification EMSD103, material elongation at failure is 20% or, 200,000 \( \mu \) in/in. Therefore, the ROPS structure met required energy at

\[
\frac{4750 \times 100}{200,000}, \text{ or } 2\% \text{ of failure elongation}
\]

5.2.3 Fabrication

The Critical Design Review (CDR) for the 6K Prototype ROPS was held by telecon with S. Newman and W. Stewart of M ERC on 23 July 73. Approval was given by M ERC for LPC to proceed with fabrication of the Prototype hardware. Bids were received and the fabrication contract awarded to Tube-Lok Products, Portland, Oregon on 3 August 73 with a scheduled delivery date of 20 August.

During fabrication, a dimensional discrepancy was disclosed on the drawings which would have resulted in a poor fit-up between the canopy and the attachment structure. Since the canopy was built and part of the attachment structure was also completed, it was decided to modify the attach structure dimensions to fit the canopy. The modification would permit installation on the test frame but would not be maintained on the production design because it did not provide latitude for the band of shape variations expected in the field.

5.2.4 Certification Testing

The certification testing for the 6000 lb forklift ROPS consisted of tests to demonstrate compliance with SAE standards for falling object protection, side load force and energy, and vertical load.

5.2.4.2 ROPS Installation for Certification Test

The ROPS and attachment structure were installed to the Type "F" chassis in preparation for certification testing and possible usage during a subsequent roll demonstration test.
Upon receipt of the structure, it was found that the modification made during fabrication to correct the dimensional discrepancy resulted in a skewing of the sockets, and there was interference with the bar through which the rear wheels are attached to the frame.

The bar was ground off to permit installation after it was determined that the material to be removed was not load carrying and removal would not invalidate the test.

During the installation procedure, time for each operation was noted and careful observation was maintained for information to be used in the installation procedures. Other than the interference, no problems developed during installation.

Tie down of the 6K frame for the prototype test differed from the development test. In the latter test, the structure was attached to the test bay floor by tie downs welded to the frame reinforcement structure (see Figure 39). After review of this method with some members of the SAE sub-committee 12 (Vehicle Test Codes) on tour of our facility, it was decided that a more realistic load path would be developed if the axles were attached to the floor and the axles were blocked to the vehicle frame. Figures 40 and 41 show the tie-downs at the rear wheels and Figure 42 shows the conditions at the front wheels.

5.2.4.3 ROPS Certification Test

Static certification testing was performed with the prototype ROPS and reinforcements installed on the Type "F" 6K Forklift on August 28. The tests were witnessed by W. Stewart and S. Newman of USAMERDC. The unit passed successfully all SAE requirements. The testing (in sequence conducted) with significant requirements and results is summarized as follows:

1. A 500-lb weight was dropped 17 feet onto the steel mesh on top of the ROPS in compliance with the FOPS requirements of SAE recommended practice J231. Figure 43 shows the hit in the test bay just prior to dropping the weight for the FOPS test. The weight did not penetrate the top of the critical zone (SAE Recommended Practice J297a) 14.5 inches below the mesh. The structure deflected 6.18 inches upon impact of the weight as measured from the high speed movies. Post-test examination disclosed a small crack in the weld of one of the screen bars, and a deformation of 1.34 inches of the screen. Figure 44 shows the screen after impact.

2. A test was conducted to show compliance with the 15,000 lb side load and 122,000 in-lb side load energy requirements of SAE Recommended Practice J294a.

Figure 45 shows the load deflection curve for the side loading condition and indicates the structural adequacy for both the side load and energy requirements. The slope of the deflection curve indicates a softer system than had
Figure 40 - Prototype Test Rear Wheel Tie Down
Figure 43 - Prototype Test Prior to FOPS Test
been noted in the development tests.

Careful consideration of the data indicated that the tolerances and design of the foot and socket had taken us out of the range of design characteristics of the development unit. Analysis of the previous design had varied the fixity of the lower end of the vertical legs in bending between pinned and fixed. Torsional rotation of the lower end was held to be negligible, an assumption in keeping with observed performance. In the prototype unit, however, the loosened tolerances and configuration of the foot and socket permitted enough torsional rotation to have an effect on deflection. Analytical considerations are presented in Appendix 6.7 where it is shown that with the inclusion of torsional rotation in the analysis, the deflection observed is predictable. It should also be noted that the torsional stiffness of the attach points contributed to the low initial stiffness observed during the Caterpillar 830MB and Clark 290M ROPS tests and is much more significant for 2 post designs than for 4 post. Figure 46 shows the vehicle at the maximum test load condition.

Review of strain data from the prototype test indicates higher strain than observed in the development test. Canopy gussets in the prototype test were in the material yield range as was one of the vertical tubes at its upper end whereas all points were within material yield stress in the development test. The level of strains reached are acceptable since maximum strain observed was only 2% of the minimum material capability and no excessive distortion was noted in the ROPS. The change in strain from the development test can be attributed to movement of the prototype foot in the socket which causes higher moments in the upper ends of the tube than in the development design and is discussed in greater detail in Section 5.2.2.3 and Appendix 6.7.

3. A vertical load of 23,500 lb, equal to the vehicle weight, was imposed at the geometric center of the ROPS roof as required by SAE Recommended Practice J394a. Vertical test loading results are shown in Figure 47 and Figure 48 shows the vehicle under maximum load. Adequacy for this loading condition is evident in both of these figures.

Upon completion of the certification test, some of the loading conditions were repeated with instrumentation located to obtain better definition of movement of the structure. These data are to assist in analysis of the deflection characteristics of the ROPS.

After the certification test, the prototype unit was completely disassembled from the vehicle and an overall visual inspection and dye penetrant inspection of all welds were performed. A slight crack was found in the weld between the vehicle frame and the bar which attaches the rear wheel structure to the frame. This area had been ground away to accommodate a dimensional discrepancy of the prototype ROPS attach structure. All other vehicle and ROPS areas were sound.

5.3 Field Rollover Test

5.3.1 Roll Analysis and Vehicle Preparation

The roll starting position used was chosen from five different potential
starting positions for producing the most realistic ROPS roll loads and for providing the greatest probability to induce a 360-degree roll. After the starting position was chosen, a dynamics analysis was performed to determine the required dropping height to complete the first roll. The analysis approach was to assume the energy developed from the initial drop plus roll had to be equal or greater than the energy required to raise the vehicle up and over the ROPS plus system energy losses. Since a roll experiences both side and vertical loads, system losses were assumed to be equal to the energy developed during the SAE side load test plus the SAE vertical load test. The analysis indicated the uphill wheel should be at least 16 inches vertically above the plane of the 32° hill with the vehicle tilted so the C.G. is approximately over the uphill wheels.

Before the roll test, a slight crack was found in a vehicle weld, as noted in Section 5.2.4.3. This weld was ground to remove all indications of the crack and rewelded to the original configuration. Since all of the vehicle and ROPS structure was sound, the decision was made to roll the ROPS and Type "F" vehicle from the certification test.

5.3.2 Roll Test

On October 11th, the roll-over test was conducted at the LPC Porrero facility. The vehicle was suspended over the test slope with its RH wheels on a platform. The cable holding the vehicle in this position was released and the left side of the forklift dropped onto the slope to start the roll. Figure 49 shows the roll sequence from still photos taken every 1/4 second. Deflection of the ROPS is evident in the 5th and 6th views from the combined side and vertical loading. The 7th and 8th views show that in the inverted position the load is imposed on the forward part of the ROPS. As the forklift goes from the 1/2 to 3/4 roll position, the aft end begins to go farther down hill than the forward end so that in the 11th view, an end-over-end roll starts which imposes forward and vertical loads on the ROPS. This roll continues until the vehicle is back on its wheels, just after the last picture in the sequence. Figure 50 shows the condition of the ROPS after this test. This same ROPS had been used in the prototype certification test and had some residual deformation, but most of the deformation seen in these figures came from the roll. Although there was more damage than in the certification static tests, the adequacy of the two-post design was substantiated by the severe conditions imposed on the ROPS in the roll test. The roll started by the left wheels dropping 110 inches before hitting the slope, which was inclined 32 degrees and was 100 ft long. The end-over-end roll was so severe that the shock of the last impact caused the counterweight to break loose. The structure holding the seat and operating controls was loosened and tilted over although it is possible that some of the bolts holding this structure may have been missing before the test.

5.4 ROPS Installation and Delivery

A ROPS system was installed on a type A Forklift to check out the installation instructions and to provide a system for performance testing at USAMERDC. The time required for the various operations was:
1. Chassis preparation 10 manhours

2. Installation of attachment structure (includes 8 hours welding) 24

3. Installation of ROPS 3

4. Re-installation of vehicle components 16

53 manhours

Not included in this figure are approximately 12 man-hours required to rework metal parts such as the fenders. Since the method of rework was developed during the process of modifying these items, the time spent is not representative of that now required with the instructions available. Figure 51 shows the right rear portion of the vehicle with the tie down removed ready for fit-up of the attachment structure. Figure 52 shows the attachment structure being located for installation. Figure 53 show the ROPS installed and ready for use on the forklift. This unit was shipped by commercial truck to MERDC on October 30.

The complete installation instructions are included in Appendix 6.8.

The ROPS system to be used by USAMERDC personnel for early service experience in ROPS installation was shipped from Portland, Oregon on October 4th and delivered to Ft. Belvoir on October 24th.
6.0 APPENDICES

APPENDIX 6.1

MATERIAL AND PROCESS SPECIFICATIONS
APPENDIX 6.1.1

MATERIAL SPECIFICATION EMSD103,

STEEL, CARBON, HIGH STRENGTH
MATERIAL SPECIFICATION

STEEL, CARBON, HIGH STRENGTH

1. SCOPE

1.1 This specification covers the requirements for structural steel with low-temperature impact strength properties intended for use in roll over protective structures.

2. APPLICABLE DOCUMENTS

2.1 The following documents form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest revision shall apply.

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)

Specifications

ASTM A 6 General Requirements for Delivery of Rolled Steel Plates, Shapes, Sheet Piling, and Bars for Structural Use

ASTM A 20 General Requirements for Delivery of Steel Plates for Pressure Vessels

ASTM A 370 Mechanical Testing of Steel Products, Methods and Definitions for

ASTM A 516 Carbon Steel Plates for Pressure vessels for Moderate and Lower Temperature Service

ASTM A 593 Charpy V-Notch Testing Requirements for Steel Plates for Pressure Vessels

(Application for copies should be addressed to the American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania 19103.)
3. REQUIREMENTS

3.1 Material. Steel furnished under this specification shall meet the requirements specified herein and ASTM A 516, Grade 65, or Grade 70. In the event of a conflict, the requirements herein apply.

3.2 Chemical composition. The composition shall comply with the following:

<table>
<thead>
<tr>
<th>Element</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon, %</td>
<td>≤ 0.26 maximum</td>
</tr>
<tr>
<td>Manganese, %</td>
<td>0.85 to 1.20</td>
</tr>
<tr>
<td>Silicon</td>
<td>≤ 0.04 maximum</td>
</tr>
<tr>
<td>Sulfur</td>
<td>≤ 0.05 maximum</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>≤ 0.05 maximum</td>
</tr>
</tbody>
</table>

* Silicon killed fine grain practice for improved notch toughness.

3.3 Mechanical properties. The mechanical properties shall be as follows:

**Tensile**

- Tensile strength, psi: 70,000 to 90,000
- Yield point, psi: 38,000 minimum
- Elongation in 2 inches, percent: 20 minimum

**Impact** (Tested by the Charpy V-notch method in accordance with ASTM A 593.)

<table>
<thead>
<tr>
<th>Specimen Size</th>
<th>Test temperature</th>
<th>Impact value, Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 mm x 10 mm</td>
<td>-20°F (-30°C)</td>
<td>8 ft. lb. (10.8 J)</td>
</tr>
<tr>
<td>10 mm x 5 mm</td>
<td>-50°F (-45°C)</td>
<td>5 ft. lb. (6.8 J)</td>
</tr>
<tr>
<td>10 mm x 2.5 mm</td>
<td>-70°F (-57°C)</td>
<td>2 ft. lb. (2.7 J)</td>
</tr>
</tbody>
</table>

3.4 Manufacturing tolerances, surface condition, and workmanship shall be in accordance with either ASTM A 6 or ASTM A 20.

4. QUALITY VERIFICATION

4.1 Certifications. Compliance with the specified requirements shall be verified for each heat or heat lot by certified test results from the supplier.
APPENDIX 6.1.2

MATERIAL SPECIFICATION EMS104,
STEEL TUBING, CARBON
MATERIAL SPECIFICATION
STEEL TUBING, CARBON

1. SCOPE

1.1 This specification covers the requirements for square, rectangular, and round structural steel tubing with low-temperature impact strength properties intended for use in roll over protective structures.

2. APPLICABLE DOCUMENTS

2.1 The following documents form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest revision shall apply.

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)

Specifications

ASTM A 370 Mechanical Testing of Steel Products, Methods and Definitions for

ASTM A 500 Cold-formed Welded and Seamless Carbon Steel Structural Tubing in Rounds and Shapes

ASTM A 501 Hot-formed Welded and Seamless Carbon Steel Structural Tubing

(Application for copies should be addressed to the American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania 19103.)
3. REQUIREMENTS

3.1 Material. Steel furnished under this specification shall meet the requirements specified herein and either ASTM A 500 or ASTM A 501. In the event of a conflict, the requirements herein apply.

3.2 Chemical composition. The composition shall be in accordance with ASTM A 500 or ASTM A 501.

3.3 Mechanical properties. The mechanical properties shall be as follows:

**Tensile**

- Tensile strength, psi: 60,000 to 80,000
- Yield point, psi: 50,000 minimum
- Elongation in 2 inches, percent: 20 minimum

**Impact** (Tested by the Charpy V-notch method in accordance with ASTM A 370.)

<table>
<thead>
<tr>
<th>Specimen size</th>
<th>Test temperature</th>
<th>Impact value, Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 mm x 10 mm</td>
<td>-20°F (-30°C)</td>
<td>8 ft. lb. (10.8J)</td>
</tr>
<tr>
<td>10 mm x 5 mm</td>
<td>-50°F (-45°C)</td>
<td>5 ft. lb. (6.8J)</td>
</tr>
<tr>
<td>10 mm x 2.5 mm</td>
<td>-70°F (-57°C)</td>
<td>2 ft. lb. (2.7J)</td>
</tr>
</tbody>
</table>

3.4 Manufacturing tolerances, surface condition, and workmanship shall be in accordance with either ASTM A 500 or ASTM A 501.

4. QUALITY VERIFICATION

4.1 Certifications. Compliance with the specified requirements shall be verified for each heat or heat lot by certified test results from the supplier.
APPENDIX 6.1.3

PROCESS SPECIFICATION DPSF100,
WELDING REQUIREMENTS FOR ROLLOVER
PROTECTIVE STRUCTURES
PROCESS SPECIFICATION

WELDING REQUIREMENTS FOR ROLL OVER
PROTECTIVE STRUCTURES

1. SCOPE

1.1 This specification covers the requirements for weld fabrication of roll over protective structures.

2. APPLICABLE DOCUMENTS

2.1 The following documents form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest revision shall apply.

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)

Specifications

ASTM A 233 Mild Steel Arc-Welding Electrodes, Specification for

ASTM A 559 Mild Steel Electrodes for Gas Metal-arc Welding, Specification for

(Application for copies should be addressed to the American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania 19103.)
AMERICAN WELDING SOCIETY (AWS)

Specifications

AWS A5.1 Specifications for Mild Steel Covered Arc Welding Electrodes

AWS A5.18 Specification for Mild Steel Electrodes for Gas Metal-arc Welding

(Application for copies should be addressed to the American Welding Society, Inc., 345 East 47th Street, New York, New York 10017.)

3. REQUIREMENTS

3.1 Qualification of welders. Before assigning any welder to manual welding work the supplier shall furnish to the procuring activity certification that the welder has passed qualification testing as prescribed by any of the following listed codes for the type of welding operation to be performed. Such qualification shall have current effectivity as defined by the particular code.

(a) Standard Qualification Procedure of the American Welding Society

(b) Welding Qualification of the ASME Boiler and Pressure Vessel Code

3.2 Materials.

3.2.1 Base metals. The base metals to be welded in accordance with this specification are structural steel and castings as specified on the applicable drawing.

3.2.2 Filler metals. Filler metals shall be as follows:

(a) Shielded Metal-arc Welding -- Use ASTM A 233, Class E7018 or AWS A5.1, Class E7018.

(b) Gas Metal-arc Welding -- Use ASTM A 559, Class E70S-6 or E70T-5, or AWS A5.18-69, Class E70S-6 or E70T-5.

3.3 Equipment.

3.3.1 Arc welding machines. Arc welding machines shall be demonstrated to show ability to consistently reproduce machine setting variables within their usable range. Machines shall be provided with suitable means of controlling output variables.
3.3.2 Gas welding equipment. Gas welding equipment, such as torches and regulators, shall be of a standard type which have demonstrated ability to perform the function intended and shall be capable of maintaining a uniform flame.

3.3.3 Calibration of equipment. Sufficient calibration of machine setting variables shall be maintained on all welding equipment so as to assure the reproducibility and the operational consistency of established production weld settings.

3.3.4 Supporting equipment. Jigs, clamping devices, and tack welding shall be used whenever necessary to prevent warping and ensure proper alignment of parts.

3.4 Welding method. Welding shall be performed by either the shielded metal-arc or gas metal-arc process. Welding shall be performed in any position necessary to achieve a satisfactory weldment.

3.4.1 Cleaning. All weld zone areas of parts shall be free from rust, scale, paint, grease, and other foreign matter. All slag and spatter shall be completely removed from each weld bead before depositing the next successive bead. When a through-weld is to be obtained by welding both sides of a joint, the root of the first weld shall be chipped or ground to sound metal before welding the second side.

3.4.2 Weld joint fit-up. Weld joint fit-up shall be such that the configuration requirements of the applicable drawing are met.

3.5 Weld quality

3.5.1 Workmanship. Finished welds shall be smooth and free of undercutting. All undercutting shall be removed or faired in by grinding. Weld beads shall be uniform in width and shall be smooth and spatter free.

3.5.2 Surface defects. Any cracks or porosity on the surface of a weld bead shall be removed by grinding before depositing the next successive bead.

4. QUALITY VERIFICATION

4.1 Inspection. All welds shall be visually inspected to verify compliance with this specification.
APPENDIX 6.2

STRUCTURAL ANALYSIS OF DEVELOPMENT UNIT
IV. Geometry

[Diagram showing geometric figures and labels such as P, M, V, T1, etc., with dimensions and annotations.]
BENDING MOMENT CAPABILITY

FOR $F_{tu} = 64,000$ Psi:

$B.M. (0^\circ) = 64,000 \times 2 \left[ \frac{2.125}{2} \times 0.375 \times \left( \frac{3}{2} \right) + 9.25 \times 0.375 \times 2.375 \right] = 687,000 \text{ in-lb}$

$B.M. (15^\circ) = 64,000 \times 2 \times 0.375 \left[ 0.78 \times 3.43 \times 1.98 + 9.25 \times 1.97 \right] = 672,000 \text{ in-lb}$

$B.M. (30^\circ) = 64,000 \times 2 \times 0.375 \left[ 0.78 \times 3.43 \times 1.98 + 9.25 \times 1.97 \right] = 672,000 \text{ in-lb}$

$B.M. (45^\circ) = 64,000 \times 2 \times 0.375 \left[ 4.25 \times 1.64 \right] = 669,000 \text{ in-lb}$

$B.M. (90^\circ) = 64,000 \times 2 \times 0.375 \left[ 9.25 \times 1.64 \right] = 669,000 \text{ in-lb}$

$B.M. (150^\circ) = 64,000 \times 2 \times 0.375 \left[ 0.78 \times 3.43 \times 1.98 + 9.25 \times 1.97 \right] = 672,000 \text{ in-lb}$

$B.M. (210^\circ) = 64,000 \times 2 \times 0.375 \left[ 0.78 \times 3.43 \times 1.98 + 9.25 \times 1.97 \right] = 672,000 \text{ in-lb}$

$B.M. (225^\circ) = 64,000 \times 2 \times 0.375 \left[ 0.78 \times 3.43 \times 1.98 + 9.25 \times 1.97 \right] = 672,000 \text{ in-lb}$
Forklift ROPS BENDING MOMENT CAPABILITY

BENDING MOMENT VS. ANGLE

\[ \frac{685}{690} \times 77.4 \times 0.97 \]

\[ \theta = 5.0 \text{ to } 30 \text{ degrees} \]

ROPS STANDARD MOMENT VS TORSION STIFFNESS CALC.

\[ \Delta = \frac{P L^3}{3 E I} \]

\( I = \frac{1}{12} \times 9.35 \times 3.25 \)

\( J = \frac{93}{2} \times 0.0105 = 0.225 \text{ in} \]

\( \% \text{ MV reacted by moment} = \frac{225}{315} \times 100 = 60\% \)

\( \% \text{ MV reacted by torsion} = \frac{131}{315} \times 100 = 40\% \)
DUE TO 'P' APPLIED 36 IN FROM VERTICAL LEGS: (PG. 1)

\[ P_x = \frac{925}{43 \times 2} = 1.075 \, P \]
\[ P_y = 0.500 \, P \]
\[ M_x = \frac{P}{2} \times \frac{L_x}{2} = \frac{P \times 75.50}{2} = 18.90 \, P \]
\[ M_y = P_x \times \frac{L_y}{2} = 0.502 \, P \times \frac{75.50}{2} = 19.0 \, P \]
\[ M_z = 90.2 \left( \frac{36 \, P}{2} \right) = 7.2 \, P \]

SECTION XX

\[ M = 18.90 \, P \rightarrow 19.00 \, P = 26.9 \, P \text{ at } \Theta = 95^\circ \]

From PGs 2, 3 allow \( B \times M = 15 \),
\[ = 667,000 \, \text{ in}^2 \]
\[ 26.9 \, P = 667,000 \, \text{ in}^2 \]
\[ P = \frac{669,000}{26.9} = 24,900 \, \text{ in}^2 \]
\[ \frac{K_{act}}{K} = 1.47 \times 1.50 = 0.98 \]
\[ MATL \ CORR = \frac{72.4}{124.0} = 0.58 \]
\[ P_{corr} = 0.98 \times 1.21 \times 24,900 = 29,500 \, \# \]
**6K FORKLIFT ROPS**

**BASE STRUCTURE CHECK - SECTION Y-Y PAGE 1**

(IN MOUNTING SOCKET): \( P = 29,500 \# \) (pg. 4)

\[ P_x = 0.5 \times P = 14,750 \# \]
\[ P_y = 0.5 \times P = 14,750 \# \]

\[ P_z = 1.025 \times P = 1.025 \times 29,500 = 30,775 \# \]

\[ M_x = 18.90 \times P + 8.00 \times P_y = 18.90 \times 29,500 + 8.00 \times 14,750 = 675,000 \text{ IN}^2\# \]

\[ M_y = M_x = 675,000 \text{ IN}^2\# \]

\[ M_z = 7.2 \times P = 7.2 \times 29,500 = 212,400 \# \text{IN} \]

---

**ZAHALAT**

2/23/74

15 January 1974

Page 106
$P_2 = 31,700 \# \quad P_x = P_y = 14,750 \#$

$M_x = 675,000 \text{ N} \cdot \text{m}$

$M_y = M_z = 675,000 \text{ N} \cdot \text{m}$

$M_H = 212,000 \text{ N} \cdot \text{m}$

$A_r = 20 \text{ in}^2$

$J_{xx} = 23.5 \text{ in}^4$

$J_{yy} = 91.5 \text{ in}^4$

$F_x = \frac{31,700}{24} = 1300 \text{ PSI}$

$F_y = \frac{675,000 \times 1.03}{23.5} = 52,500 \text{ PSI}$

$S_F_{yield} = \frac{128 \times 38,000}{52,500 + 7,000} = 0.74$

$S_F_{ult} = \frac{15 \times 70,000}{52,500 + 7,000} = 1.60$
S.F.ult. 160 is inaccurate. Compare capability of section Y-Y to ROPS tube.

\[ \text{CAPABILITY} = 100\% \times \frac{F_{TUx}}{F_{TU_{ops}}} \times \frac{Z_{xx}}{Z_{rosp}} \times \frac{M_{rops}}{M_{xx}} \]

\[ \frac{F_{TUx}}{F_{TU_{ops}}} = \frac{70}{23.5} = 1.00 \]

\[ \frac{Z_{xx}}{Z_{rosp}} = \frac{1.83}{2.19} = \frac{12.80}{8.77} = 1.46 \]

\[ \frac{M_{rops}}{M_{xx}} = \frac{55,700}{675,000} = 0.825 \]

\[ \text{CAPABILITY} = 100 \times 1.00 \times 1.46 \times 0.825 = 121.0\% \]
5K FORKLIFT LOADS

SECTION 2-2 (PG. 7A)

\[ M_x = 675,000 \text{ in} \cdot \text{ft} \quad (P 4.7) \]

\[ P_5 = \frac{M_x}{8.0} = \frac{675,000}{8.0} = 84,000 \text{ lb} \]

\[ \gamma = \frac{89,000}{2.25} = 39,400 \text{ psi} \]

SECTION 22-22

\[ t = 0.53 \text{ in} \]

\[ f_s = \frac{9000}{2t} = \frac{9000}{2 \times 0.90} = 5000 \text{ psi} \]

\[ F_{su} = 6427 \times 70,000 = 450,000 \text{ psi} \]

\[ S.F. = \frac{95000}{20700} = 4.59 \]
USE REVERSE LOADS FROM POS. 1, 7:

Due to \( P_x \):
\[
P_5 = \frac{47300}{2 \times 0.9527} = 14750 \text{ #}
\]

Due to \( P_y \):
\[
P_1 = \frac{47300}{2 \times 0.9527} = 8180 \text{ #}
\]
\[
P_2 = \frac{-12000}{5 \times 0.736 \times 2} = 130000 \text{ #}
\]

Due to \( M_x \):
\[
P_1 = \frac{675000}{3.05} = 22000 \text{ #}
\]
\[
P_2 = \frac{-12000}{3.5} = 60500 \text{ #}
\]

SUMMING LOADS:
\[
P_1 = 8180 + 97300 - 60500 = -9900 \text{ #}
\]
\[
P_2 = 8180 + 97300 + 60500 = 161600 \text{ #}
\]
\[
P_3 = 97300 \text{ #}
\]
\[
P_4 = 97300 \text{ #}
\]
\[
P_5 = 19750 + 83800 = 103550 \text{ #}
\]
\[
P_6 = 83800 \text{ #}
\]
\[
P_7 = 130000 \text{ #}
\]
\[
P_8 = (98600 + 83800) \times 1.17 = 22200 \text{ #}
\]
GA FORKLIFT ROPS

SOCKET CHECK

[Diagram with various labeled parts and dimensions]

10.25 in

10.50

14.50
6K Forklift ROPS

SECTION A-A (Pg 11)

\[ P_2 = 116,000 \text{ lb (Pg. 9)} \]
\[ P_a = 116,000 \text{ lb} \times 27^\circ = 52,700 \text{ lb} \]
\[ A_{AA} = 2.00 \times 2.00 = 4.00 \text{ in}^2 \]
\[ S = 52,700 / 4.00 = 13,200 \text{ psi} \]
\[ P_N = 130,000 \text{ lb (Pg. 9)} \]
\[ A_{TENS} = 2.00 \times 10.25 = 20.50 \text{ in}^2 \]
\[ S_{T\text{N}} = 130,000 / 20.50 = 6,300 \text{ psi} \]
\[ F_{TY} = 38,000 \text{ psi} \]
\[ S.F. Y = \frac{3800.0}{13,200 + 6,300} = 1.95 \]

SECTION B-B

\[ P_B = 116,000 \cos 27^\circ = 103,000 \text{ lb} \]
\[ A_{B-B} = 2.50 \times 2.00 = 5.00 \text{ in}^2 \]
\[ S = \frac{103,000}{5.00} = 20,600 \text{ psi} \]
\[ S_{T\text{N}} = 6,300 \text{ psi} \text{ (Ref. Above)} \]
\[ F_{SU} = 6.2 \times 70,000 = 455,000 \text{ psi} \]
\[ R_{TY} = \frac{6.3}{38} = 0.17 \]
\[ R_s = \frac{20.6}{4.5} = 4.6 \]
\[ S.F. Y = \frac{1}{0.17 + 4.6} = 2.09 \]
6k Forklift Ropes
Socket Check - Section C-C (Pg. 10)

\[ P_B = 103,000 \text{ #} \quad \text{(Pg. 11)} \]

\[ A_{C-C} = (2.00 \times 2.00) + (1.50 \times 1.00) = 5.5 \text{ in}^2 \]

\[ \sigma_T = \frac{103,000}{5.5} = 18,700 \text{ psi} \]

Due to \( P_N \), \( \sigma_{TN} = 6,300 \text{ psi} \) (Pg. 11)

\[ F_{TY} = 38,000 \text{ psi} \]

\[ S.F. Y = \frac{38,000}{18,700 + 6,300} = 1.52 \]

---

Section D-D (Pg. 10)

\[ P_S = 98,600 \text{ #} \quad \text{(Pg. 9)} \]

\[ M = 1.5 \times 98,600 = 150,000 \text{ in} \times \text{#} \]

Assume \( z \) in effective.

\[ \sigma_E = \frac{6 \times 150,000}{2 \times (2.50)^2} = 72,200 \text{ psi} \]

Due to \( P_N \), \( \sigma_{TN} = 6,300 \text{ psi} \)

\[ R_6 = \frac{72,000}{15 \times 70,000} = .69 \]

\[ R_T = \frac{6,300}{7000} = .09 \]

\[ S.F. U = \frac{1}{.69 + .09} = 1.30 \]

Added Cusset - Improve S.F. (Pg. 16)
6K Forklift ROPS

SECTION E-E (Pg. 10)

\[ P_3 = P_4 = 47,300 \quad P_6 = 83,800 \quad (Pg. 9) \]

\[ P_5 = (47,300 + 97,300) \cos 22^\circ = 89,000 \quad \text{lb} \]

\[ A_5 = (1.00 \times 1.07 \times 9.50) + (2 \times 7.5 \times 1.5) = 24.2 \quad \text{in}^2 \]

\[ \sigma_5 = \frac{89,000}{24.2} = 3,690 \quad \text{psi} \]

Due to \( P_6 \),

\[ P_5 = \frac{14,560 \times 83,800}{10.50} = 116,000 \quad \text{lb} \]

\[ A_5 = 1 \times 1.07 \times 9.50 = 6.72 \quad \text{in}^2 \]

\[ F_5 = \frac{116,000}{6.72} = 17,300 \quad \text{psi} \]

\[ F_{5u} = 45,000 \quad \text{psi} \quad (Pg. 11) \]

\[ \text{S.F.} = \frac{95,000}{1,900 + 17,500} = 2.23 \]

\[ = 1.90 \]
GK Forklift Rops

Pure Bending Distribution - Socket Upper

SECTION I

Existing Struc. P1 = 59,500 lb
Add. Struc. P3 = 72,000 lb

APPLIED LOADS:

\[ P_1 = 9,900 \text{ lb} \]
\[ P_2 = 116,000 \text{ lb} \]
\[ P_5 = 78,600 \text{ lb} \]

(Pg. 9)

\[ P_5 \text{ reacted at } P_5 \text{. Resulting moment, } M_5 = 3.00 \times 78,600 = 296,000 \text{ in} \cdot \text{lb} \]

Moment reacted at \( P \& - P_2 \)

\[ P_1 = \frac{296,000}{375} = 80,000 \text{ lb} \]

Summing Loads:

\[ P_1 = -9,900 + 89,500 = 80,000 \text{ lb} \]
\[ P_2 = 116,000 - 89,500 = 26,500 \text{ lb} \]

\[ P_A = \left[ 2.00(31,500 \cos 17^\circ) + 7.60(50,000 \cos 22^\circ) \right] / 9.60 \]

\[ = 62,300 \text{ lb} \]
SECTION F-F (PG. 14)

\[ P_A = 62,300 \text{ lb} \]
\[ P_I = 84,500 \text{ lb} \]

Assume \( P_A \) of\ lateral component of \( P_I \) form a couple.

\[ M = 2.00 \times 62,300 = 124,600 \text{ in-lb} \]

Assume effective height at F-F = 3.00 in for bending.

\[ f_b = \frac{6M}{6t^2} \cdot \frac{6 \times 125000}{3.00 \times 2.00} = 62,500 \text{ psi} \]

\[ P_T = P_I \sin 27^\circ = 84,500 \sin 27^\circ = 38,300 \text{ psi} \]

\[ A_T = 4.00 \text{ in}^2 \text{ (PG. 11)} \]

\[ f_T = \frac{18700}{9.00} = 9600 \text{ psi} \]

\[ f_N = 6300 \text{ psi} \]

\[ R_{tu} = \frac{9600 + 6300}{70,000} = 0.227 \]

\[ R_{bu} = \frac{62,500}{15 \times 70,000} = 0.595 \]

\[ S, F, U = \frac{1}{0.227 + 0.595} = 1.22 \]
SECTION G-G (PG 10)

\[ P_s = 98,600 \text{ psi} \quad (\text{PG. 9}) \]

\[ M_{g6} = 3.00 \times 98,600 = 296,000 \text{ in.k} \]

1 inch weld at section G-G, 4.00 in. long.

\[ \sigma = \frac{6M}{6t^2} = \frac{6 \times 296,000}{100 \times 9.3^2} = 96,000 \text{ psi} \]

EXCESSIVE ADD. 5X5X1 GUSSETS.

\[ \sigma = \frac{6 \times 296,000}{100 \times 9.0} = 22,000 \text{ psi} \]

\[ F_{ty} = 38,000 \text{ psi} \]

\[ S.F. \gamma = \frac{38,000}{22,000} = 1.73 \]
6k FORKLIFT HOOPS

SECTION H-H (pg. 14)

\[ M = 296,000 \text{ in-lb} \]
\[ P = 296,000 / 42.00 = 7050 \text{ lb} \]

\[ M_{H-H} = 24 \times 7050 = 169,000 \text{ in-lb} \]

\[ \sigma = \frac{6M}{bh^2} = \frac{6 \times 169,000}{100 \times 5.00^2} = 20,800 \text{ psi} \]

\[ F_{TY} = 37,000 \text{ psi} \]

\[ S.F. \; \psi = \frac{37000}{20800} = 1.73 \]
SECTION 5.5  
(POS 12, 17)

\[ M = 19 \times 7050 = 134,000 \text{ in-lb} \]

\[ f_b = \frac{134,000 \times 7.8}{24} = 21,000 \text{ psi} \]

\[ F_{tye} = 5 \times 500 \text{ psi} \]

\[ S.F.U = \frac{5 \times 500}{21,000} = 0.24 \]
OK FORKLIFT ROPS

SECTION A-A (REF SKETCH, P. 9)

Assumed effective section.

Assume \( M_2 \) reacted by cross beam & reacted by 7,000 in. couple at top beam.

From Pg. 11,

\[
M_x = 716,000 \text{ in} \times \text{ft}
\]

\[
M_2 = 229,000 \text{ in} \times \text{ft}
\]

\[
P_5 = P_2 - 28,000 = 7200 - 2800 = 4400 \text{ in} \times \text{ft}
\]

\[
P = 39,200 \text{ in} \times \text{ft}
\]

Upper beam check:

Due to \( M_x \), \( P_T = \frac{716,000}{14.50} = 48,900 \text{ in} \times \text{ft} \)

\[
T = 48,900 / 4.00 = 12,200 \text{ psi}
\]

Due to \( M_2 \), \( P_T = \frac{229,000}{7.00} = 32,700 \text{ in} \times \text{ft} \)

\[
T = 32,700 / 2.00 = 16,300 \text{ psi}
\]
SECTION A-A (CONT'D)

\[ S_T = 17,000 + 16,300 = 33,000 \text{ PSI} \]

\[ F_{TH} = 36,000 \text{ PSI} \]

\[ \frac{5}{F_s} = \frac{36,000}{33,000} = 1.09 \]

SECTION B-B

BEAM SHEAR CHECK

\[ q = \frac{P_3}{10.5} = \frac{25200}{10.5} = 2400 \text{ #/in} \]

\[ F_s = \frac{7700}{50} = 74.00 \text{ PSI} \]
**ZAHNRAZ**

**6 Ton Fork Lift ROPS**

**SECTION B-B (Pg. 14)**

---

*P* = 68,000 *DUE TO M* \( \text{X} \) (Pg. 12)

\[ M_{x} = 229,000 \text{ in} \] (Pg. 12)

\[ P_{588} = \frac{P}{2} = 68,000 \]

\[ M_{288} = 119,000 \]

\[ M_{288} = 229,000 - 1.75(68,000) = 110,000 \text{ in} \]

\[ f_{S} = \frac{P_{588}}{A_{5}} + \frac{M_{288}}{2A_{7}} \]

\[ A_{5} = 2[(4.50 \times 3.5) + (3.85 \times 2.65)] = 5.2 \]

\[ A = 4.50 \times 3.85 = 17.3 \text{ in}^{2} \]

\[ f_{S} = \frac{68,000}{5.2} + \frac{9,100}{2 \times 173 \times 35} = 22,900 \text{ psi} \]

\[ F_{50} = 59500 \text{ psi} / (0.15 \times 0.75) \]

\[ S.F. = \frac{59500}{23,200} = 2.5 \]
CAP REINFORCEMENT WELDED OVER AXLE MOUNT SUPI

6K FORKLIFT ROPS

13212E3779-25

12.50

A

D

E

P

P

2.00

590

15 January 1974
Page 124
SECTION C-C (PG. 16)

\[ P_{SV} = 39,200 \text{ # (PG. 12)} \]

\[ P_{SH} = 25,600 - 12,000 = 13,600 \text{ #} \]

\[ M_{HOL} = 2 \times 19,200 = 38,400 \text{ in} \cdot \text{lb} \]

\[ F_{HOL} = \frac{6 \times 80,000}{1.00 + 3.5} = 40,000 \text{ PSI} \]

\[ M_{VERT} = 2 \times 12,600 = 25,200 \text{ in} \cdot \text{lb} \]

\[ F_{VERT} = \frac{M}{A} = \frac{25,000}{2.5 \times 3.5 \times 0.5} = 6000 \text{ PSI} \]

\[ F_{TY} = 55,000 \text{ PSI} \]

\[ S.F. = \frac{55,000}{40,000 - 6000} = 1.20 \]

(Conservative check)

SECTION D-D (PG. 16)

WELD CHECK \[ P_{SV} = 39,200 \text{ # (PG. 12)} \]

\[ P_{WELD} = \frac{5.0 \times 39,200}{6.50} = 32,500 \text{ #} \]

\[ A_{WELD} = 5.00 \times 0.5 = 2.5 \text{ in}^2 \]

\[ F_{T} = \frac{32,500}{2.5} = 13,000 \text{ PSI} \]

\[ F_{TY} = 56,000 \text{ PSI} \]

\[ S.F. = \frac{56,000}{13,000} = 2.70 \]
SECTION EE (PG 16)

WELD CHECK \( P_i = 39,200 \text{ lb} \) (PG 12)

\[
P_{\text{safe}} = \frac{12.5 \times 39,200}{9.5} = 52,000 \text{ lb}
\]

\[
A_{\text{weld}} = 0.50 \times 3.00 = 1.5 \text{ in}^2
\]

\[
F_{\text{y}} = \frac{52,000}{1.5} = 35,000 \text{ psi}
\]

\[
F_{\text{tu}} = 36,000 \text{ psi}
\]

\[
S.F. = \frac{36,000}{35,000} = 1.03
\]

(Conservative Check)
From pg. 111, \( P_x = 25,600 \) #

\( P_y = 13,000 \) #

\( P_z = 67,200 \) #

\( M_y = 625,000 \) in#

Assume structural react \( M_2 = 129,000 \) in#.

\( P_1 = \frac{(18.5 \times 67,200 - 625,000)}{42.00} = 19,700 \) #

\( P_2 = 25,600 \) #\( /2 \)

\( P_3 = \frac{(18.5 \times 13,000 + 229,000)}{42.00} = 11,200 \) #
K. Forklift PDPs

\[ P_d = \frac{(23.5 \times 67.200 + 625.000)}{92.00} = 52.50 \]  
\[ P_s = 25.600 / 2 = 12.800 \]  
\[ P_k = \frac{(23.5 \times 13.000 - 229.000)}{92.00} = 1.800 \]

If structure doesn't react \( M_2 \),
\[ P_k = \frac{(23.5 \times 13.000)}{42.00} = 7.280 \]

\[ \text{SECTION F-F} \]

\[ M_{y} = 17.00 \times 14.700 = 247,000 \text{ in}^2 \text{lb} \]
\[ M_{zz} = 17.00 \times 11.200 = 190,400 \text{ in}^2 \text{lb} \]

\[ f_{yy} = \frac{6x121,000}{100(12.5)^2} = 7.300 \text{ ksi} \]
\[ f_{zz} = \frac{147,000 \times 3.75}{19} = 26,500 \text{ ksi} \]

\[ F_{ty} = 36,000 \text{ ksi} \]

\[ S. F. = \frac{36,000}{26,500} = 1.36 \]

\[ f_{22} = 24,000 \text{ ksi, including Channel Section} \]
WELD CHECK AT $P_3$ (pg. 19)

$P_3 = 11,200 \, \text{#}$

$A = 9 \times 0.50 \times 2 = 9 \, \text{in}^2$

$F_T = \frac{11,200}{9} = 1200 \, \text{psi}$

$M_S = \text{HIGH}$

SECTION G-G

$M_y y^2 = 12,800 \times 20.5 = 262,000 \, \text{in}^2$  

$P_T = \frac{262,000}{6.5} = 40,000 \, \text{psi}$

ASSUME 7" EFFECTIVE

$F_T = \frac{40,000}{3.00 \times 1.00} = 14,000 \, \text{psi}$

$F_{Ty} = 56,000$  

$S.F. = \frac{56,000}{14,000} = 4.0$

WELD CHECK FOR $P_T$

$P_T = 52,500 \, \text{#} \quad \text{(pg. 19)}$

$A_S = 10 \times 0.5 \times 7.07 = 3.5 \, \text{in}^2$

$F_S = \frac{52,500}{3.5} = 15,000 \, \text{psi}$

$F_{Su} = 37,000 \, \text{psi}$

$S.F. U = \frac{37,000}{15,000} = 2.47$
OK FORKLIFT ROPS

SECTION H-H

WALL COLUMN CHECK

\[ P_1 = 26,000 \text{ #} \]

\[ P_{\text{column}} = \frac{26,000}{2} = 13,000 \text{ #} \]

\[ P_{\text{allow}} = \frac{\pi^2 E I}{L^2} = \frac{\pi^2 \times 20 \times 10^6 \times 0.0065}{7.00^2} \]

\[ = 38,000 \text{ #} \]

\[ P_{\text{allow II}} = Fty \times A = 36,000 \times 1.25 = 45,000 \text{ #} \]

\[ S.F. = \frac{38,000}{13,000} = 2.9 \]

SECTION J-J

\[ P_2 = 26,000 \text{ #} \]

\[ M = \frac{P_2}{2} \times 18 = 9 \times 26,000 = 234,000 \text{ in#} \]

\[ F:Q = \frac{234,000 \times 1.25}{17.9} = 33,000 \text{ psi} \]

\[ S.F. = \frac{33,000}{33,000} = 1.09 \]
6K FORKLIFT PROPS

SECTION K-K

\[ P_x = 26,000 \text{ } \# \]

Assume 10" Long Movement at Pots 5.

From \( F = RB \), \( \theta = \frac{F}{R} = \frac{10}{2.5} = 4.0 \text{ rad} \)

\[ \approx 26^\circ \]

As a result, \( P_x \) will be applied at 26°.

\[ P_{x1} = 26,000 \sin 26^\circ = 11,400 \text{ } \# \]

\[ P_{x2} = 26,000 \cos 26^\circ = 23,300 \text{ } \# \]

\[ M_{WB} = \frac{30 \times 11,400}{2} = 170,000 \text{ in} \# \]

\[ \theta = \frac{6 \times 170,000}{.5 \times (5)^2} = 82,000 \text{ psi} \]

Excessive! Assume full M22 is reacted at L-L.

\[ M_{LL} = 30 \times 11,400 = 340,000 \text{ in} \# \]

\[ I_{LL} = 17.9 \text{ in}^4 \text{ (pg. 23)} \]

\[ \theta = \frac{340,000 \times 2.5}{17.9} = 47,500 \text{ psi} \]

Excessive! Add \( \frac{4 \times 4\times 1}{8} \) Gussets at K-K or add diagonal.

\[ A \text{ diagonal} = \frac{11,400 \times 2}{\cos 91^\circ \times 3600} = 0.84 \text{ in}^2 \]

\[ \theta = \frac{6 \times 170,000}{.925 \times 78^2} = 17,000 \text{ psi} \]
\[ M = \frac{PA}{2} \left( \frac{3C}{E} - 1 \right) \]

\[ C = \frac{I_2}{I_1} \left( \frac{h}{L} \right) \]

\[ I_1 = \frac{5 - 9.25}{12} = 2.5 \]

\[ I_2 = \frac{5 - 9.25}{12} = 17.9 \text{ in}^4 \]

\[ C = \frac{17.9}{25} \left( \frac{23}{9.2} \right) = .773 \]

\[ E = 1 + 6 \left( \frac{387}{3.3} \right) = 3.3 \]

\[ M = \frac{PA}{2} \left( \frac{3 \times 3.3^3}{3.3} - 1 \right) = .65 \left( \frac{PA}{2} \right) \]

\[ .65 \left( \frac{26,000 \times 23}{2} \right) = 195,000 \text{ in}^2 \]
SECTION M-M PLS 27, 25

\[ P = 26,000 \text{ kN} \]

\[ P_3 = 13,000 \text{ kN} \]

\[ m = 1,000 \text{ kN/m} \]

\[ M_{\text{MM}} = 13,000 \times 23 = 195,000 \text{ kN-m} \]

\[ f = \frac{6m}{6 + 2} = \frac{6 \times 105,000}{50 \times 5} = 50,000 \text{ psi} \]

EXCESSIVE! USE GUSSETS AT M-M

SECTION N-N

\[ P_3 = 26,000 \text{ kN} \]

\[ S = 1.53 \text{ kN/m} \]

\[ P_{\text{allow}} = \frac{\pi \times 27 \times 1.53}{31,000} = 450,000 \text{ kN} \]

AT PT A DUE TO P3 = 26,000 kN:

\[ M_A = \frac{26,000}{2} \times 14,000 = 940,000 \text{ kN-m} \]

ASSUME \( \frac{1}{2} \) OF \( M_A \) IS ON SECTION M-M

\[ M_{\text{MM}} = \frac{940,000}{2} = 220,000 \text{ kN-m} \]

USING GUSSETS, BASIC SECTION CHECK:

\[ f = \frac{120,000 \times 2.5}{17.9} = 30,000 \text{ psi} \]

\[ F_{\text{BY}} = 36,000 \text{ psi} \times 1.22 = 43,000 \text{ psi} \]

\[ F.S. V = \frac{8,000}{9,000} = 1.2 \]
6K FORKLIFT ROPS

SECTION 0-0

\[ M_{00} = 22,000 + 12,000(23.00) = 522,000 \text{ in-lb} \]

\[ F = \frac{522,000 \times 2.5}{25} = 52,000 \text{ psi} \]

\[ F_{tu} = 55,000 \text{ psi} \]

\[ E.S.U = \frac{55,000 \times 1.2}{52,000} = 1.27 \]


\[ L = 33.5'' + 3'' \quad \text{DEFL} = 36.5'' \]

\[ M_p = 36.5 \times 23,500 \div 2 = 428,000 \text{ in#} \]

\[ F_b = \frac{428,000 \times 2.5}{21.9} = 99,000 \text{ PSI} \]

\[ F_{dy} = 1.14 \times 50,000 = 57,000 \text{ PSI} \]

\[ S.F. = \frac{57}{49} = 1.16 \]
CHECK OFF CENTER LOAD DISTRIBUTION

\[ P_L = \frac{36.0}{41.5} \times 23,500 = 20,400 \text{ lb} \]
\[ P_R = \frac{5.5}{41.5} \times 23,500 = 3,100 \text{ lb} \]

\[ L = 72 + \text{defl.} = 72 + 5.5 = 77.5 \text{ in} \]

\[ M_L = 37.5 \times 20,400 = 765,000 \text{ in-lb} \]
\[ S = \frac{765,000 \times 9.5}{21.9} = 87,500 \text{ psi} \]

Consider cross coupling of torsion member.

\[ \text{For } M = 10,000 \text{ in-lb,} \]
\[ G_T = \frac{T_L}{K_G} = \frac{10,000 \times 41.5}{40.2 \times 10^6} = 0.0094 \]
\[ K_T = \frac{10,000}{0.0094} = 1,060 \times 10^6 \text{ in-lb/RAO} \]
Assume left vertical leg is at yield stress, \( F_{ty} = 50,000 \text{ psi} \).

\[
\begin{align*}
\sigma & = 50,000 \\
\varepsilon & = 0.002 \\
\end{align*}
\]

Elastically, \( \varepsilon = \frac{\sigma}{E} = \frac{50,000}{29,000} = 0.017 \text{ in/in} \)

Plastically, \( \varepsilon = 0.002 \text{ in/in} \)

\[
\varepsilon_{el} = 0.0017 + 0.002 = 0.0037 \text{ in/in} \\
\varepsilon_{pl} = \frac{\sigma}{E} = \frac{50,000}{0.0037} = 13,500 \text{ psi}
\]
\[ M = 10,000 \text{ in} \times \text{ (cont.)} \]

\[ \Theta_{MK} = \frac{ML}{EI} = \frac{10,000 \times 72.5}{29 \times 10^6 \times 21.9} = .00166 \text{ rad} \]

\[ K_{M_{\text{RIGHT}}} = \frac{10,000}{.00166} = 6.05 \times 10^6 \text{ in} \times \text{ rad}^{-1} \]

\[ K_{M_{\text{LEFT}}} = \frac{13.5 \times 10^6}{29 \times 10^6} = 6.85 \times 10^6 \text{ in} \times \text{ rad}^{-1} \]

\[ K_{M_{\text{RIGHT}}} = \frac{1}{K_2} + \frac{1}{K_{M_{\text{RIGHT}}} 10.6} + \frac{1}{6.85} = .0944 + .146 = .24 \]

\[ K_2 = \frac{1}{.24} = 4.16 \times 10^6 \]

\[ K_1 = K_{M_{\text{LEFT}}} = 3.19 \times 10^6 \]

Since \( K_2 \) becomes larger than \( K_1 \), even load distribution occurs before left leg reaches FEY. Go to pg. 28.

Due to \( M \):

\[ M_1 = \frac{6.85}{6.85 + 4.16} \cdot M = .622 \cdot M \]

\[ (11.01) \]

\[ M_2 = \frac{4.16}{11.01} \cdot M = .378 \cdot M \]
APPENDIX 6.3

DEVELOPMENT TEST RESULTS
LOCKHEED PROPULSION COMPANY
POTRERO TEST SERVICES

ROLL-OVER PROTECTIVE STRUCTURE
TEST DESCRIPTION

TEST SPECIMEN Two-post ROPS

TEST TYPE FOPS, Horizontal and Vertical Loading

TEST DATE 29 May and 6 June 1973

TEST TEMPERATURE 96 - 106°F

LPC WORK ORDER 684-7-44

TEST RESULTS

The 6K forklift chassis was modified in accordance with LPC Drawing 299025. The chassis was mounted in the test bay in compliance with SAE Technical Report J-394A. The tiedown arrangement is shown in Drawing 299025.

The five-inch ROPS was installed on the chassis with two each 1½" bolts and torqued as for field service.

The FOPS test made use of high speed movies to ensure that the critical zone was not violated during the FOPS test. Deflection of the ROPS would be measured by a photo target grid that was mounted beyond the ROPS in view of the camera.

FOPS

Solid wooden forms representing the critical zone were installed in the ROPS to aid in the final determination of success or failure. The critical zone was installed per SAE J-397A and LPC Drawing 299025.

A 500-pound standard drop object was positioned over the ROPS, raised 17 feet and dropped. There was no violation of the critical zone.

HORIZONTAL LOADING

A load application system consisting of one 700,000-pound hydraulic ram was installed to contact the ROPS roof for horizontal loading. The test setup is shown in Figure 1.
The test operations procedure is presented on pages 5 through 8.

One fourteen-inch linear potentiometer was utilized to measure deflection at the point of load application.

The force and deflection measurements were displayed in digital format for monitoring during the test and were also recorded at each deflection increment.

A total of 40 strain measurements were recorded during the horizontal loading to monitor the ROPS deformation. The strain gage locations are shown on Drawing 299023. The strain gage data are presented in Addendum I.

In addition, 3 optical deflection measurements were taken in accordance with Drawing SK-684-118 to monitor the test progress. These deflection readings are presented on page 9.

Steel scales were installed on the ROPS and read with a surveyor's transit to measure deflection. These readings are presented on page 9.

The load was applied, as required, to produce approximate one-half inch deflection increments during the initial loading. At 3.1 inches deflection the minimum force requirement was met. At 8.0 inches, the minimum energy requirement was met and the horizontal load test was terminated. A plot of force versus deflection is shown in Figure 2 from data on page 10.

At full load and deflection, the critical zone was not violated.

VERTICAL LOAD

The load column was aligned with the geometric center of the ROPS with a load beam to distribute the load laterally across the top surface of the ROPS.

The camera target was installed and camera position was noted to calculate the deflection for each of the 6 load points. Strain gage data was also recorded and are presented in Addendum II.

The full load position is shown in Figure 3, and shows that the critical zone was not violated during the vertical test.

HORIZONTAL OVERTEST

Following compliance to SAE requirements, the horizontal load system was reinstalled. The test was performed for engineering evaluation. The test was continued until a deflection increase could be accomplished without an increase in force. The maximum recorded load was 24,000 pounds. Strain gage data were recorded but not reduced.
VERTICAL OVERTEST

To complete the test on the 6K forklift ROPS, a vertical overtest was conducted on 6 June 1973. This test was conducted for engineering evaluation. The purpose of this test was to determine the load capability of the unit before the critical zone was invaded. Strain gage data was recorded but not reduced. The test was terminated when the loading distribution plate slipped.
ROLL-OVER PROTECTIVE STRUCTURE
EQUIPMENT LIST

Hydraulic Ram (Horizontal) 700K, Pickens Inc. 9480-18-3683
18-inch stroke

Hydraulic Ram (Vertical) 300K, Rodgers Hydraulic, Part
Number 1-150 BR-7½, 7½-inch stroke

Load Cell (Horizontal) Ormond L-25-50K-557

Load Cell (Vertical) Ormond L-25-50K-557

Displacement Transducers 1 each 14-inch, 3 each Starrett
Dial Indicators and 3 each 18-inch scales, and 1 Bourns
2001081615 potentiometers

Data Acquisition System Beckman 210, 84-channel Digital
Data System

OPTIONAL EQUIPMENT

Strain Gages BLH FAP-12-12 or equivalent

Thermocouple Potentiometer

Conditioning Box Controller

MEASUREMENT ACCURACY

The measurement systems and devices utilized in support of this
test program are periodically maintained and calibrated to assure
the following steady state accuracies. Instrument calibrations
are traceable to the National Bureau of Standards.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Force</td>
<td>+1 percent</td>
</tr>
<tr>
<td>Displacement</td>
<td>±2 percent</td>
</tr>
<tr>
<td>Temperature</td>
<td>±5°F</td>
</tr>
</tbody>
</table>
3.0 TEST OPERATIONS

3.1 Preliminary Preparations

3.1.1 Install chassis reinforcements per assembly drawing 299025. (Certified welder required.)

3.1.2 Install 40 post yield strain gages as shown on special red-lined drawing 299025.

3.1.3 Install the vehicle chassis in the test bay by welding per drawing 299025.

3.1.4 Install the ROPS 299026 into the socket mounts 299027 and torque the eye bolts to 500+40 foot-pounds.

3.1.5 Paint the assembly as required. Colors: chassis - olive drab; ROPS - yellow; tie-down fixtures - gray.

3.1.6 Install the critical zone per SAE J-397A and drawing 299025.

3.1.7 Prepare two 2' x 8' photo targets by carefully applying 1" black tape to a white background as shown in Figure 1.

3.2 FOPS TEST

3.2.1 Attach the 500-pound drop weight to a mobile crane using an electrically operated bomb release.

3.2.2 Conduct sufficient practice drops on clear ground to ensure reliable release and good vertical attitude at the proposed impact point.

3.2.3 Position the drop weight at the center of the ROPS section covered with wire mesh.

3.2.4 Set up documentary movie cameras to record the drop sequence.
3.0 **TEST OPERATIONS** (Continued)

3.2.5 Install one photo target horizontally on the wall behind the critical zone to record the dynamic deflection of the steel mesh.

Revised 5-25-73

3.2.6 Install a 1" diameter x 6" long probe (approximate dimensions) extending downward under the drop point to be viewed by the high speed camera. Attach with wire, do not weld.

Revised 5-23-73

3.2.7 Position the 200 pps movie camera viewing the target grid at the same level as the critical zone top. See sketch, Figure 2.

3.2.8 Raise the weight 17 feet above the ROPS roof and conduct the ROPS test per SAE J-231.

3.2.9 Ensure the critical zone has not been violated. Take post test photographs per test engineer direction.

3.2.10 If the deformed wire mesh is too close to the critical zone to conduct the horizontal load test, restore it to the original minimum level.

3.3 **Horizontal Load Test**

3.3.1 Ensure load column center line is contacting the ROPS roof at the exact distance from the vertical supports as shown on drawing 299025 and is in a level attitude. The load distribution plate must span 20 inches minimum along the ROPS top and it must be free to rotate horizontally as load is applied.

3.3.2 Install precision scales for optical deflection measurements in accordance with drawing 299025 and position the surveyor's transits for viewing.

3.3.3 Install dial gages in accordance with drawing 299025.
3.0 TEST OPERATIONS (Continued)

3.3.4 Calibrate all instrumentation and prepare for recording all data.

3.3.5 Take prefire photographs of the ROPS and test setup.

Revised 5-23-73

3.3.6 Install the two photo targets vertically on north and west walls behind the ROPS side surfaces to view the deformation during loading. Set up black and white still cameras on tripods and take one exposure at each inch of deflection. See sketch, Figure 2. Record and sketch exact camera placement.

3.3.7 Apply load to achieve incremental deflections of 0.5 inches and conduct the side loading in accordance with SAE J-394A.

3.3.8 Record the dial gages and optical scales at each inch of deflection.

3.3.9 At each deflection step, calculate total energy.

3.3.10 Continue loading until both the minimum load and minimum energy have been achieved.

NOTE

IF BOTH CONDITIONS OF LOAD AND ENERGY CANNOT BE SATISFIED, CONSULT THE TEST ENGINEER.

3.3.11 While at full load, ensure the critical zone has not been violated.

SAFETY NOTE

USE EXTREME CAUTION IN APPROACHING FULLY LOADED ASSEMBLY. A VIOLENT STRUCTURAL FAILURE COULD OCCUR AT ANY TIME.
3.0 TEST OPERATIONS (Continued)

3.3.12 Take documentary photographs per test engineer direction.

3.3.13 Remove the side load and record the post test measurements on all channels.

3.3.14 Take post test photographs per test engineer direction.

3.4 Vertical Load Test

3.4.1 Ensure load column is aligned to the center of the ROPS roof.

3.4.2 Ensure data acquisition for digital display and strain gage recording is ready for test.

Revised 5-23-73

3.4.3 Install one camera target horizontally behind the ROPS and set up black and white camera on a tripod to record deflection at each vertical load increment. Record and sketch exact camera placement.

Revised 5-23-73

3.4.4 Apply load increments of 10K, 16K, 21K, 22K, 23K, and full load of 23.5K in accordance with SAE J-394A, paragraph 5.2. Record all specified data channels and optical deflection measurements at each load increment.

3.4.5 While at full load, verify that the critical zone has not been violated.

3.4.6 Take documentary photographs per test engineer direction.

3.5 Horizontal Failure Test

3.5.1 Remove vertical loading system and reinstall the horizontal load column.

Revised 5-23-73

3.5.2 Resume horizontal loading at 0.5-inch increments until structural failure occurs or as directed by the test engineer.

3.5.3 Take post test photographs per test engineer direction.
LOCKHEED PROPULSION COMPANY
POTRERO TEST SERVICES

ROLL-OVER PROTECTIVE STRUCTURE
TEST DATA SHEET

TEST ITEM  6K Forklift  TEST DATE  29 May 1973

HORIZONTAL LOAD TEST PER SAE J-394A
REQUIRED ENERGY, U, POUND-INCHES,  122,204
REQUIRED MINIMUM HORIZONTAL LOAD  15,031  POUNDS

<table>
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<th>Δ NOMINAL</th>
<th>Δ ACTUAL</th>
<th>HORIZONTAL LOAD APPLIED</th>
<th>CALCULATED ENERGY, U</th>
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Prepared by: B.J. Miller  Approved by: J.E. Paine
Figure 1 - Test Set Up - Horizontal Load
Figure 3 - Vertical Load
LOCKHEED PROPULSION COMPANY  
POTRERO TEST SERVICES  
ROLL-OVER PROTECTIVE STRUCTURE  
TEST DATA SHEET

<table>
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<th>LOAD-LBS</th>
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TR-684-059
ADDENDUM I
PLOTS OF STRAIN VERSUS LOAD
DURING HORIZONTAL LOADING
ROPS DEVELOPMENT TEST
6K FORKLIFT
PI917
29 MAY 1973
T7074
ROPS DEVELOPMENT TEST
6K FORKLIFT
P1817 T7074
29 May 1973

HORIZONTAL LOAD

LOAD (10^3)

STRAIN MICRO E./IN.
ROPS DEVELOPMENT TEST
6K FORKLIFT
P1817    T7074
29 May 1973

HORIZONTAL LOAD

LOAD-10^3 (lbs)

0.  100.  200.  300.  400.  500.  600.  700.  800.  900.

STRAIN MICRO IN/IN
TR-684-059

ADDENDUM II

PLOTS OF STRAIN VERSUS LOAD

DURING VERTICAL LOADING
ROPS DEVELOPMENT TEST
6K FORKLIFT
29 May 1973
S17

10. (x10^-5)
LOAD ISS

Vertical Load

1817
17074
ROPS DEVELOPMENT TEST
6K FORKLIFT
P1817 T7074
29 May 1973

Vertical Load

LOAD-1/S (10^3)

STRAIN GROUNDL/1
ROPS DEVELOPMENT TEST
6K FORKLIFT
T1817 T7074
29 May 1973
S7 37 Vertical Load

LOAD-LS (10^3) Vertical Load

0.  20.  40.  60.  80.  100.  120.  140.  160.  180.

STRAIN GUAGE
APPENDIX 6.4

ANALYSIS OF DEVELOPMENT TEST RESULTS
6K ROPS Test Data Reduction

ROPS Rotation Influence on Side Load

Last valid deflection gage readings occur at 6.00 inch deflection. At this time, side load - 22,180 lbs. This is within 8% of maximum side load of 24,000 lbs. Therefore, a slight increase of this value is reasonable for use at maximum side load.

Deflection, S-1 Gage = 8.31 - 1.00 = 7.31 in.
Deflection, S-2 Gage = 2.84 - 1.00 = 1.84
Deflection, S-3 Gage = 6.00 - 1.20 = 4.80 in.

Deflection gage location and ROPS rotation relative to side load actuator is shown and developed by graphical construction on following page.
6K ROPS Test Data Reduction

\[ \delta_{s-1} = 7.31 \text{ in} \]

\[ \delta_{s-2} = 1.84 \text{ in} \]

Actuator Rotation = 4°
Use 5° for value at maximum side load

Actuator Length = 69.00
6K ROPS Tests Data Reduction

ROPS Rotation Influence on Side Load

Modify "ROPS load vs. deflection calculation", pg. A-4 for effect of actuator rotation.

\[
V_u = \frac{K_{Bu}}{K_{Bu} + K_{tor}} \left( \frac{P_t}{W} \right)_{\text{eff.}}
\]

\[
\left( \frac{P_t}{W} \right)_{\text{eff.}} = \left( .87 P \times 34.5^\circ \right) \div \frac{0.87 \times 54.00}{43.00} = .905 \, P
\]

\[
V_u = \frac{.76}{.76 + .44} \times .905 \, P = .573 \, P
\]
rops load vs. deflection calculation

\[ L_{eff} = \text{length from post foot tangent to 1" into upper gusset.} \]

\[ L_1 = \text{distance from top of socket to 5" into upper gusset.} \]

\[ L_2 = \text{distance from top of socket to upper structure \&} \]

\[ L_3 = \text{length 5" into gusset on each side.} \]

---

elastic curve

<table>
<thead>
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<th>ultimate capability</th>
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<tbody>
<tr>
<td>( \frac{PL_1^3}{6EI} )</td>
</tr>
<tr>
<td>----------------------</td>
</tr>
</tbody>
</table>

\[ K_{tor} = \frac{1}{8} = \frac{1.148}{8} \]

\[ K_{BE} = \frac{1}{8} = \frac{1.148}{8} \]

\[ K_{BU} = \frac{1}{8} = \frac{W}{R_{fl}} \]

\[ P_{e} = \frac{K_{BE} \cdot (P \cdot e)}{W} \]

\[ V_{U} = \frac{K_{BU} \cdot (P \cdot e)}{W} \]

\[ P_{s} = \frac{P}{2} \cdot \frac{L_{2}}{W} \]
6K Test Data Reduction

ROPS Rotation Influence on Side Load

\[
M_{\text{lat}} = \frac{P \cdot L_{\text{eff}}}{4} = \frac{\frac{1}{4} \times 0.99P \times 75.5}{4} = 18.70P
\]

\[
M_{\text{long}} = \frac{V_u L_{\text{eff}}}{2} + \frac{0.087P (L_2 - 7.00)}{2}
\]

\[
= \frac{.573P \cdot 75.5}{2} + \frac{.087P (85.5)}{2} = 21.6P + 3.7P = 25.3P
\]

\[M = M_{\text{lat}} + M_{\text{long}} = 18.70P + 25.3P = 31.5P \text{ at } 31^\circ\]

From Page A-4 moment capability at 31°

= 795,000 in. lbs for material \(F_{tu} = 77,400 \text{ psi}\)

Coupon tests of 6K ROPS test tubes average 75,600 psi. Moment capability for this material

\[= \frac{75,600}{77,400} \times 795,000 = 776,000 \text{ in lbs}\]

\[P = \frac{776,000}{31.5} = 24,600 \text{ lbs}\]

1. Maximum side load developed by test = 24,600 lbs

2. Deflected shape of test was very similar to deflected shape shown on page A-2 where right ROPS vertical leg had essentially no longitudinal deflection.

Two points above indicate reduced side load is contributable to actuator rotation.
APPENDIX 6.5

STRUCTURAL ANALYSIS OF PROTOTYPE UNIT
6K ROPS - BOLT ON
FOR $F_U = 77.4$ ksi  $P = 28,900 \#$

$(Ref. 
R0P5 LOAD VS. DEFLECTION CALCULATION)$

$$P_{\text{MAX}} = \frac{86}{77.4} \times 28,900 = 30,000 \#$$

$$P_x = V_0 = 0.53 \times 30,000 = 15,900 \#$$

$$P_y = 0.5P = 15,000 \#$$

$$P_z = \frac{45.3}{21.5} \times 15,000 = 31,600 \#$$

$$M_x = 18.90 \times 30,000 = 567,000 \text{ in} \#$$

$$M_y = 20.00 \times 30,000 = 600,000 \text{ in} \#$$

$$M_z = \frac{K_{\text{TOA}} \cdot P_E}{2} = \frac{0.94}{2} \frac{30,000 \times 16}{2} = 199,000 \text{ in} \#$$
OK REPS - BOLT ON

LOADS IN SOCKET: (Ref PG51, 2, 3)

\[ P_x = 15,900 \text{ #} \]
\[ P_y = 15,000 \text{ #} \]
\[ P_z = 31,600 \text{ #} \]
\[ M_x = 567,000 + (8,00 \times 15,000) = 687,000 \text{ in#} \]
\[ M_y = 600,000 + (8,00 \times 15,900) = 727,000 \text{ in#} \]
\[ M_z = 199,000 \text{ in#} \]

IN BEAM:

\[ P_x = \frac{687,000 + (4 \times 31,600) - (5,500 \times 15,000)}{17.00} = 43,000 \text{ #} \]
\[ P_x = \frac{199,000 + (8,00 \times 15,900)}{17.00} = 15,400 \text{ #} \]

EXTERNAL LOADS:

\[ P_{ FRAME, y} = P_y = 15,000 \text{ #} \]
\[ P_{ FRAME, x} = P_x + P_{S,x} = 15,900 + 15,400 = 31,300 \text{ #} \]
\[ P_{ FRAME, z} = P_z + P_{S,z} = 31,600 + 43,000 = 74,600 \text{ #} \]
\[ M_{ FRAME, y} = 727,000 - (5,500 \times 15,900) = 637,500 \text{ in#} \]
SECTION A-A (PG. 1)

OPENING AT TOP OF SOCKET = 3.25 X 7.00.

Foot width = 3.25 - .34 = 2.91 in

Foot length at top of socket = 7.00 - .250 = 6.75.

Foot length one inch down into socket = 6.75 - .25 = 6.50 in.

\[ M_x = 687,000 \text{ in} \# \]
\[ M_y = 727,000 \text{ in} \# \]
\[ M_2 = 199,000 \text{ in} \# \]

\[ f_{6x} = \frac{687,000 \times 1.146}{13.3} = 75,000 \text{ psi} \]
\[ f_{6y} = \frac{727,000 \times 3.25}{66.5} = 35,500 \text{ psi} \]

\[ f_{sT} = \frac{M_2(3a+1.86)}{8a^2.62} = \frac{650 \times 3.25}{8 \times 3.25 \times 1.86} = 12.18 \text{ psi} \]

\[ f_T = \frac{199,000(3 \times 3.25 + 1.8 \times 1.46)}{8 \times 7.25 \times 1.46^2} = 17,700 \text{ psi} \]

\[ E f_6 = 75,000 + 35,500 = 110,500 \text{ psi} \]

\[ F_{TU} (4340 Steel, 125 ksi H.T.) = 125 \text{ ksi} \]

\[ F_{6u} = 1.47 \times 125,000 = 183,750 \text{ psi} \]

\[ S.F. = \frac{183,750}{110,500} = 1.67 \]
USE REVERSE LOADS, FROM PG. 3:

DUE TO $P_x$, 
\[ P_3 = 15,900 \, \# \]

DUE TO $P_y$, 
\[ P_1 = 15,000 \, \# \]

DUE TO $P_z$, 
\[ P_2 = \frac{31,600}{\sin 7^\circ \times 2} = 130,000 \, \# \] (PG. 1)

DUE TO $M_x$, 
\[ P_1 = \frac{667,000}{8.75} = 77,500 \, \# \]
\[ P_3 = \frac{227,000}{8.75} = 83,100 \, \# \]

CONSIDERING SOCKET LOADS ON ROPS FOOT:

$M_2 = 199,000 + 2.90(15,000 + 78,500) - 1.80(78,500) + 2.10(15,900)$
\[ = 362,000 \, \# \]

DUE TO $M_2$, 
ASSUMING $M_2$ REACTED BY $P_2$ & $P_5$,
\[ P_2 = \frac{362,000}{100,000} = 3.6 \, \# \]
\[ P_5 = \frac{100,000}{100,000} = 1.0 \, \# \]

SUMMING LOADS:
\[ P_1 = 15,000 + 78,500 = 93,500 \, \# \]
\[ P_2 = 78,500 + 100,000 = 178,500 \, \# \]
\[ P_3 = 15,900 + 83,100 = 99,000 \, \# \]
\[ P_4 = 5,100 \, \# \]
\[ P_5 = 100,000 \, \# \]
\[ P_6 = 130,000 \, \# \]
ZAHAREE 6/18/73

6K ROPS - BOLT ON

ASSUMING $M_2$ REACTED BY $P_4$ & $P_6$,

$P_4 = \frac{362000}{225} = 161,000 \#$

$P_6 = \frac{440}{161} = 161,000 \#$

SUMMING LOADS:

$P_1 = 15,000 + 78,500 = 93,500 \#$

$P_2 = 78,500 \#$

$P_3 = 15,000 + 83,100 = 98,100 \#$

$P_4 = 83,100 + 161,000 = 244,100 \#$

$P_5 = 0 \#$

$P_6 = 161,000 \#$

SECTION M-M

(Spec. 5)

SHEAR CHECK OF 1.50" SOCKET EDGE

PLATE FOR $P_4$.

$P_4 = 244,000 \#$ (REF. ABOVE)

ASSUME 3" ALONG SOCKET BASE AND 2" ALONG SOCKET INBOARD PLATE EFFECTIVE IN SHEAR.

$A_S = 5.00 \times 1.50 = 7.50 \text{ in}^2$

$F_S = \frac{244000}{7.50} = 33,000 \text{ psi}$

$F_{su} = .64 \times 70,000 = 45,000 \text{ psi}$

$S.F. = \frac{95000}{33,000} = 2.96$
Upper Cross Beam Loads

\[ P_1 = 93,500 \text{ lb} \quad \text{(Pg. 5)} \]

\[ \delta = \frac{93,500 + 93,500}{35.00} = 5390 \text{ \#/in} \]

\[ P_{sup} = \frac{(4.50 - 3.8) \times 93,500}{75.00} = 11,000 \text{ \#} \]
**6K ROPS - BOLT ON**

**SECTION 8-8 (PG. 5)**

\[ P_1 = 93,500 \text{ ft} \]  
\[ \begin{align*}  
&M_2 = 90 \times 93,500 = 8,400 \text{ in} \times \text{lb} \\
&\sigma_2 = \frac{6 \times 37,400}{2 \times 1.75^2} = 37,000 \text{ psi} \\
&F_{6y} = 1.28 \times 38,000 = 48,000 \text{ psi} \\
&S.F. y = \frac{9800}{37000} = 1.30 \\
\end{align*} \]

\[ H_5 = 2.00 \times 1.75 = 3.50 \text{ in} \\
\sigma_5 = \frac{93500}{3.50} = 27,000 \text{ psi} \\
F_{5u} = 25,000 \text{ psi} \\
S.F. u = \frac{25000}{27000} = 1.66 \]

**SECTION C-C (PG. 6a)**

\[ \theta = \frac{5,340}{11,000} \text{ ft/in} \]
\[ P_{u,p} = 11,000 \text{ ft} \]
\[ \begin{align*}  
&M_{cc} = (22.65 \times 11,000) + (1.8 \times 93,500) \\
&= 284,500 \text{ in} \times \text{lb} \\
&P_7 = (22.65 \times 5,340) - 93,500 + 27,500 \text{ ft} \\
&\sigma_6 = \frac{6 \times 284500}{200 \times 5.00} = 34,000 \text{ psi} \\
&\tau = \frac{27500}{100 \times 5.00} = 2,750 \text{ psi} \\
&F_{7u} = 38,000 \text{ psi} = 38,000 \text{ psi} \\
\end{align*} \]
6K ROPS - BOLT ON

SECTION D-D (PG. 1)

SECTION D-D REACTS \( P_{Sx} \) & \( P_{Sz} \).

\[
P_{Sx} = 15,400 \text{ #} \quad \text{PG. 3}
\]

\[
P_{Sz} = 63,000 \text{ #} \quad \text{PG. 3}
\]

DUE TO \( P_{Sz} \), \( P_{TENS} = \frac{P_{Sz}}{10} = 5,200 \text{ #} \) (PG. 7)

\[
\frac{A_{TENS}}{\pi} = \frac{5.0 \times 1.5}{1.5} = 7.5 \text{ IN}^2
\]

\[
\frac{5,200}{7.5} = 700 \text{ PSI}
\]

SECTION D-D REACTS ALL OF \( P_{Sx} \).

\[
M = 6,000 \times 15,400 = 92,500 \text{ IN#}
\]

\[
\sigma = \frac{6 \times 92,500}{1.5 \times 5.0^2} = 15,000 \text{ PSI}
\]

\( F_{TY} = 38,000 \text{ PSI} \)

\[
\sigma_{F} = \frac{38,000}{7000 + 15,000} = 1.73
\]

SECTION E-E (PG. 1)

LOADING SAME AS D-D ABOVE.

\[
P_{TENS} = \frac{17,000}{10.00} = 1,700 \text{ #}
\]

\[
M_{zz} = 17,000 \times 15,400 = 262,000 \text{ IN#}
\]

\[
\frac{7,3000}{7.5 \times 15} = 650 \text{ PSI}
\]

\[
\sigma = \frac{6 \times 262000}{1.5 \times 7.5^2} = 18,000 \text{ PSI}
\]

\[
\sigma_{F} = \frac{38,000}{6500 + 18,000} = 1.51
\]
GIK ROPS - BOLT ON
FRAME REINFORCEMENT, TEST CONDITION

Socket & Beam Loads
From Pg. 2. Assume tiedown reacts all shear loads and My.

\[ P_1 = \frac{(13 \times 1450)}{20} = 10,800 \, \# \]
\[ P_2 = 0 \to (21600 + 29800) = 0 \to 46,400 \, \# \]
\[ P_3 = \frac{13(30,700 + 51,800) + 1,103,000}{20} = 1,700 \, \# \]
\[ P_4 = \frac{(7 \times 16650)}{20} = 5850 \, \# \]
\[ P_5 = 0 \to 46,400 \, \# \]
\[ P_6 = \frac{7(30,900 + 51,800) + 1,103,000}{20} = 83,400 \, \# \]
S2Ai-!

6K Kops - Bolt on

**SECTION G-G (PG. 9)**

\[
P_4 = 5,850 \quad P_5 = 0 \quad P_6 = 83,900
\]

\[
M_{yy} = 10.00 \times 83,900 = 839,000 \text{ in}^2 \text{lb}
\]

\[
M_{zz} = 10.00 \times 5850 = 58,500 \text{ in}^2 \text{lb}
\]

**ASSUME REVERSED LOADS.**

**AT POINT A:**

\[
A = 19.7 \text{ in}^2
\]

\[
f = \frac{46,400}{19.7} = 2390 \text{ psi} \quad (\text{comp})
\]

\[
\tilde{e} = 8.85 \text{ in}
\]

\[
f_0 = \frac{839,000 \times 12}{493} = 17,300 \text{ psi} \quad (\text{comp})
\]

\[
f = 58,500 \times 1.12 = 1000 \text{ psi} \quad (\text{comp})
\]

\[
\tilde{e} \quad f_c = 2400 + 17,300 + 1000 = 20,700 \text{ psi}
\]

**From S.M. #126, Fig. 12, For:**

\[
\frac{b}{t} = \frac{200}{.75} = 12, \quad f_{cc} \text{ IS APPROX.}
\]

29,000 psi.

\[
S.F. \quad \frac{24000}{20700} = 1.16
\]

ROLL OVER SIDE LOAD = 15,000 #
(REF. 6K ROPS PDR, PG. 7)
SECTION H-H (PG 11)

\[ F_{c.v.} = \frac{15000}{4} = 3750 \, \#/ \text{mile} \]

\[ M = 24.00 \times 3750 = 90,000 \, \text{in}^{3} \]

**CHANNEL:**

\[ t = 1.9 \, \text{in} \]

\[ v = 2.485 - .59 = 1.895 \]

\[ f_{b} = \frac{90,000 \times 1.895}{1.90} = 90,000 \, \text{psi} \]

\[ F_{b_u} = 1.5 \times 70,000 = 105,000 \, \text{psi} \]

\[ \epsilon \cdot F_{u} = \frac{105,000}{90,000} = 1.17 \]
**ZAHABEE**
6/19/73

**6K ROPS - BOLT ON, ROLL OVER CONDITION**

\[ F_{C4,bat} = 3750 \text{ kN (Ref. Pg. 12)} \]

\[ F_{mid} \]

\[ 29'' \quad 30'' \]

\[ 32.00 \]

\[ 19.00 \]

\[ 13'' \quad 18'' \]

**BOLT SHEAR LOADS**

**SOCKET & BEAM LOADS, Pg. 2'**

Due to \( P_x + P_x \) = 21,600 + 29,800 = 51,400 kN,

\[ P_5 = \frac{51,400}{14} = 3,663.57 \text{ kN (HORIZONTAL)} \]

Due to \( P_z + P_z \) = 20,400 + 51,800 = 72,200 kN,

\[ P_{mid} = \frac{18 \times 82200}{31} = 57,700 \text{ kN} \]

\[ P_{aft} = \frac{13 \times 82200}{71} = 19,500 \text{ kN} \]
6K RED - BOLT ON, ROLL OVER EMO.

**Due to Mx = 1,103,000 in #**

\[ P_{s, \text{for}} = \frac{+1,103,000}{61} = +18,100 \text{ #} \]

\[ P_{s, \text{act}} = +18,100 \text{ #} \]

**Total Bolt Shear Loads:**

\[ P_{s, \text{for}} = +18,100 \text{ #} \]

\[ P_{s, \text{mid}} = 47,700 \text{ #} \]

\[ P_{s, \text{act}} = 34,500 + 18,100 = 52,600 \text{ #} \]

**Bolt Shear Check:**

\[ \frac{P_{s, \text{act}}}{\frac{3}{4} \text{ Dia. Bolt}} = 52,600 \text{ #} \]

**Joint Critical in Bearing in .28" Channel:**

\[ P_{b, \text{br}} = 0.28 \times 0.75 = 0.21 \text{ in } \]

\[ F_{b, \text{br}} = \frac{13,500}{0.21} = 64,000 \text{ psi} \]

\[ F_{b, \text{br}} = 90,000 \text{ psi} \]

\[ \frac{5.1 - y}{64,000} = 1.48 \]
SECTION J-J (ABOVE)

From Pg. 13,

\[ F_{\text{FOR.}} = \frac{54}{30} \times 3750 = 6750 \text{ #} \]
\[ F_{\text{MID.}} = \frac{24}{30} \times 3750 = 3000 \text{ #} \]

For four bolts:

\[ P_{\text{Bolt}} = \frac{6750}{4} = 1690 \text{ #} \]

\[ M_{\text{J-J}} = 0.4 \times 1690 = 676 \text{ N#} \]

Assume .28" thick x 2.00" wide section effective at J-J.

\[ f_s = \frac{6 \times 675}{2 \times 0.28^2} = 26000 \text{ psi} \]

\[ F_{TU} = 70,000 \text{ psi} \]

S.F. = \[ \frac{26000}{70000} = 2.70 \]
6K ROPS - BOLT ON

SECTION K-K (PG. 15)

\[ P_{\text{Bolt}} = 1690 \text{ #} \quad (\text{REF. PREV. PG}) \]
\[ M_{K-K} = 1.50 \times 1690 = 2540 \text{ in #} \]

Assume 1" thick x 2" wide section effective.

\[ \sigma = \frac{6 \times 2540}{2 \times 1^2} = 7600 \text{ PSI} \]

S.F. = HIGH

Use 1" backup at center & ends of frame reinforcement.

SECTION L-L (PG. 11)

\[ P_{\text{for.}} = 18100 \text{ #} \quad (\text{PG. 14}) \]
\[ F_{\text{for.}} = 6750 \text{ #} \quad (\text{PG. 15}) \]

\[ M_{yy} = 14.00 \times 18100 = 253000 \text{ in #} \]
\[ M_{zz} = 14.00 \times 6750 = 94500 \text{ in #} \]

\[ f_{yy} = \frac{6 \times 253000}{1.00 \times 7.5^2} = 27000 \text{ PSI} \]
\[ f_{zz} = \frac{6 \times 94500}{7.50 \times 1.00^2} = 75000 \text{ PSI} \]

\[ F_{6U} = 1.50 \times 70,000 = 105,000 \text{ PSI} \]

\[ S. F. = \frac{105,000}{27000 + 75000} = 1.03 \]
GK ROPS - BOLT ON, ROLL OVER ANALYSIS

SECTION N-N (PG. 11)

\[ \begin{align*}
\sigma_{\text{P}_{\text{For}}} &= +11,900 \text{ #} \\
\sigma_{\text{P}_{\text{Mid}}} &= +17,300 \text{ #}
\end{align*} \]

\[ \begin{align*}
\tau_{\text{F}_{\text{For}}} &= 6,750 \text{ #} \\
\tau_{\text{F}_{\text{Mid}}} &= 3,000 \text{ #}
\end{align*} \]

\[ M_{YY} = 32,00 \times 11,900 = 381,000 \text{ in} \cdot \text{lb} \]

\[ M_{ZZ} = 32,00 \times 6,750 = 216,000 \text{ in} \cdot \text{lb} \]

\[ F_{\text{Mid}} \text{ is applied 5.5 in. from shear web as shown.} \]

\[ A = 17.5 \text{ in}^2 \]

\[ x = 3.83 \text{ in} \]

\[ I_{yy} = 195 \text{ in}^4 \]

\[ r = 1.28 \text{ in} \]

\[ I_{zz} = 25 \text{ in}^4 \]

\[ \epsilon_{zz} = 7.0 \text{ in}^3 \]

\[ \begin{align*}
&= 16,500 - 216,000 \tan 12^\circ \\
&= 16,500 - 46,000
\end{align*} \]

ASSUME ONE OF THE TORSION FACTORS MAY BE ZERO.

TORSION = 46,000 lb

\[ f_{\text{yy}} = \frac{381,000 \times 7.17}{195} = 14,000 \text{ psi} \]

\[ f_{\text{zz}} = \frac{216,000 \times (9.25-1.28)}{25} = 26,000 \text{ psi} \]

\[ f_{\text{st}} = \frac{46,000}{7.0} = 6,600 \text{ psi} \]

SECTION CRITICAL FOR \( F_{zz} \)

\[ F_{vu} = 105,000 \text{ psi} \ (P/I, 16) \]

\[ S_{\epsilon} = \frac{105,000}{26,000} = 4.0 \]
SECTION Q-Q (PG. 13)

\[ F_{ax} = 6750 \, \text{lb} \] (PG. 13)

\[ M_{xy} = 9.50 \times 6750 = 63,900 \, \text{in} \cdot \text{lb} \]

\[ \tau = \frac{6 \times 30,400}{2.00 \times 2.00} = 23,000 \, \text{psi} \]
CK ROPS - BOLT ON

FRAME CHECK, AXLE MOUNT TEST CONFIGURATION

 SOCKET & BEAM LOADS FROM PG. 2

ASSUME TIE DOWN REACTS ALL SHEAR LOADS AND MY REACTIONS. 70 PY CALCULATED SEPARATELY.

\[
\begin{align*}
P_3 & \text{ and } P_2 = 0 \rightarrow (21,600 + 24,800) = 0 \rightarrow 46,400 \# \\
P_3 & = 1,103,000 + 15.50 \left( \frac{30,900 + 51,800}{100.00} \right) + 6.50 \times 21,600 + 2.00 \times 19,830 \\
& = 25,630 \# \\
P_6 & = 1,103,000 + 15.50 \left( \frac{30,900 + 51,800}{100.00} \right) + 6.50 \times 21,600 + 2.00 \times 19,830 \\
& = 107,930 \# 
\end{align*}
\]
Frame check, axle mount test config.

\[ V = \frac{11.90 \times 33.300}{79.00} = 11,200 \text{ ft-lb} \]

Due to \( V \), \( P_c = \frac{1155 \times 11,200}{100} = 13,000 \text{ ft-lb} \)
SECTION Y-Y

\[ V = 11,200 \text{ ft} \] (Pg. 19a)

\[ M_{YY} = 17 \times 11,200 = 190,000 \text{ in}\cdot\text{ft} \]

Add a plate at Y-Y to make total section height 7".

\[ F = \frac{6 \times 190,000}{1 \times \frac{7^2}{2}} = 23,000 \text{ psi} \]

\[ F_{tu} = 55,000 \text{ psi} \]

\[ \text{S. F.} = \frac{55,000}{23,000} = 2.40 \]
FRAME CHECK, AXLE MOUNT TEST CONFIG.

SECTION R-R (P. 19)

WELD A

WELD B

WELD C

WELD D

WELD E

WELD F
WELD A (Pg. 26)

\[ P_e = 108,000 \text{ #} \]

**WELD A:** TWO 6 IN. LONG, \( \frac{3}{4} \) IN. FILLET WELDS

\[ A_s = 2 \times 6 \times 75 \times 0.707 = 6.3 \text{ in}^2 \]

\[ f_s = \frac{108,000}{6.3} = 17,000 \text{ psi} \]

\[ F_{SU} = 0.6 \times 50,000 = 30,000 \text{ psi} \]

\[ S.F. = \frac{30,000}{17,000} = 1.76 \]

WELD B (Pg. 26)

\[ P_e = 108,000 \text{ #} \]

**WELD B:** 14.5 IN. LONG, \( \frac{1}{2} \) IN. GROOVE WELD

\[ A_t = \frac{1}{2} \times 14.5 = 7.2 \text{ in}^2 \]

\[ f_t = \frac{108,000}{7.2} = 15,000 \text{ psi} \]

\[ F_s = \frac{12,400}{7.2} = 6,000 \text{ psi} \]

\[ S.F. = \frac{50,000}{(15.0 + \frac{6}{7})^{10}} = 2.85 \]
WELD C (PG. 20)

WELD C: 18 in long, \( \frac{7}{8} \) in. fillet weld

\[
A_t = 18.0 \times \frac{7}{8} \times 0.707 = 4.80 \text{ in}^2
\]

\[
F_t = \frac{108,000}{9.8} = 23,000 \text{ PSI}
\]

\[
F_t = 50,000 \text{ PSI}
\]

S.F. = \( \frac{50,000}{23,000} = 2.20 \)

WELD E (PG. 20)

\[
P_E = \frac{P_S}{3} = \frac{96,000}{3} = 32,000 \text{ PSI} \quad \text{(PG. 19)}
\]

WELD E: 2 in long, \( \frac{3}{4} \) in. fillet weld

\[
A_s = 4.00 \times 0.75 \times 0.707 = 1.1 \text{ in}^2
\]

\[
F_s = \frac{96,000}{2.1} = 22,000 \text{ PSI}
\]

\[
F_{50} = 70,000 \text{ PSI}
\]

S.F. = \( \frac{70,000}{22,000} = 3.18 \)
\[ P_y = 33,700 \text{ #} \quad (P_{max}, \text{pg. 2}) \]

WELD F: 8 in long, \( \frac{1}{2} \) in fillet weld

\[ A_5 = 8.00 \times 50 \times 707 = 2,800 \text{ in}^2 \]

\[ S_5 = \frac{33,700}{2.80} = 12,000 \text{ PSI} \]

\[ F_{su} = 70,000 \text{ PSI} \]

\[ S, F. = \frac{70,000}{12,000} = 2.50 \]

---

**VIEW U-U (PG 20)**

**SECTION W-W**

\[ P_6 = 107,800 \text{ #} \quad (PG. 19) \]

\[ P_5 = 46,200 \text{ #} \quad (PG. 19) \]

Two \( \frac{1}{2} \) in fillet welds at W-W

\[ M = \frac{25 \times 6,400}{2} = 58,000 \text{ in #} \]

\[ S = \frac{107,800}{4 \times 17 \times 50 \times 707} = 5,000 \text{ PSI} \]

\[ F_6 = \frac{6 \times 58,000}{100 \times 17 \times 707} = 17,000 \text{ PSI} \]

\[ F_{su} = 50,000 \text{ PSI} \]

\[ S, F. = \frac{50,000}{5000 + 1700} = 2.3 \]
6K ROPS - BOLT ON

FRAME CHECK, AXLE MOUNT TEST CONFIG.

WELD C: (PG. 20)

SIDE DEFORMATION OF THE ROPS DUE TO $P_s$ & $M$ (PG. 20) CAUSES IT TO BEAR AGAINST THE FRAME AND CAUSE BENDING AT SECTION 2-2. FOLLOWING IS A CHECK OF WELD C FOR AN ULTIMATE BENDING MOMENT AT SECTION 2-2.

From $F_{bw} = \frac{MC}{I}$,

$$M = \frac{F_{bw} I}{C}$$

$F_{bw} = 1.5 \times 70 = 105 \text{ kN}$

For $t = 28$: $I = \left( \frac{2.8}{12} \right)^3 = 0.00183 \text{ in}^4$

$C = \frac{t}{2} = 0.14 \text{ in}$

$$M = \frac{105 \times 0.00183}{0.14} = 1370 \text{ in}^2 \text{ lb/in}$$

ASSUME 1/2" COUPLE DISTANCE BETWEEN WELD LOAD AND BEARING LOAD.

$$P_{weld} = \frac{1370}{1.50} = 900 \text{ lb/in}$$

$$F_{weld} = \frac{900}{3.75 \times 707} = 3.900 \text{ psi (neg.)}$$

CHECK ELONGATION AT SECTION 2-2

ASSUME 0.50 IN LATERAL MOVEMENT AT TOP OF 7" FRAME. ROTATION $\approx \frac{0.50}{900} = 0.00056 \text{ rad}$. ASSUME 0.50 IN LONG BEAM EFFECTIVE AT SECTION $E = C \theta = \frac{2.8}{2} \times 0.056 = 0.0078 \text{ in}$

$$\text{ELONGATION } E = \frac{0.0078}{0.5} = 0.0156 = 1.56 \%$$

ALLOWABLE ELONGATION = 10% MIN. (1)
REACTIONS TO $P_Y$

Assumption 1: Assume 100% $P_Y$ reacted at right side. This puts attach bolts in tension.

$P_Y = 33,300 \ # \ (P_{max}, \ Pg. \ 2')$

$P_F = 5.00 \times 33,300 / 18,00 = 9,200 \ #$

$P_A = 33,300 - 9,200 = 24,100 \ #$
6 x ROPS - Bolt on

Frame Check, Axle Mount Test Config

Section 5-5

\[ P_A = 24,100 \text{ in}^2 \] (Pa 23)

\[ M_{55} = 2 \times 24,100 = 48,200 \text{ in} \cdot \text{lb} \]

Assume 5' of \( \frac{1}{4} \) " plate effective in bending.

\[ \frac{N}{2} = \frac{6 \times 48,200}{5 \times 75} = 100,000 \text{ psi} \]

\[ F_{bu} = 1.5 \times 50,000 = 75,000 \text{ psi} \]

S, F. < 1.00

Section T-T

Check of Channel Frame Bending due to \( P_A \).

\[ M = 6,000 \times 24,900 = 195,000 \text{ in} \cdot \text{lb} \]

\[ \frac{N}{2} = \frac{195,000 (2.485 - 0.69)}{85} = 70,000 \text{ psi} \]

\[ I_{xx} = 85 \text{ in}^4 \]

\[ F_{bu} = 1.5 \times 70,000 = 105,000 \text{ psi} \]

S, F. < 1.00

\[ P_A \text{ is not able to enter frame at right side.} \]
6K ROPS - Bolt on

Frame check, Axle mount - Test config.

Reactions to PY Assumption 2:
Assume 100% of PY reacted at left side.

Section U-U (PG. 23)
SK ROPS - BOLT ON

For the check axle mount test config.

Assumption 
Assume py loads frame through bearing on 1" plate as shown on pg. 25.

WELD D (pg. 25)

\[ P_y = 77,000 \text{ lb} \quad \text{(pg. 23)} \]

WELD D: Two 5 in. long, \( \frac{1}{2} \) in. fillet welds.

\[ A_s = 5.00 \times 5.00 \times 0.707 = 1.70 \text{ in}^2 \]

\[ F_s = \frac{77,000}{1.70} = 45,000 \text{ psi} \]

\[ F_{su} = 30,000 \text{ psi} \]

\[ S.F. = \frac{F_{su}}{F_s} = 1.50 \]
**Elastomeric Curve**

**Ultimate Capability**

\[
\begin{align*}
&\text{KL = Section Properties} \\
&\text{I} = \text{Inertia} \\
&\text{J} = \text{J-section} \\
&\text{W} = \text{Web} \\
&\text{K} = \text{K-factor} \\
&\text{M} = \text{Moment} \\
&\text{G} = \text{Shear} \\
&\text{E} = \text{Modulus of Elasticity} \\
&\text{P} = \text{Load} \\
&\text{L} = \text{Length} \\
&\text{K}_{\text{tor}} = \frac{1}{8} \cdot \frac{\text{I}}{\text{JG}} \\
&\text{K}_{\text{BE}} = \frac{1}{8} \cdot \frac{1}{\text{W} \cdot 3\text{EI}} \\
&\text{K}_{\text{BU}} = \frac{1}{8} \cdot \frac{\text{I}}{\text{W} \cdot 12\text{EI}} \\
&V_E = \frac{\text{K}_{\text{BE}} \cdot \text{K}_{\text{tor}} + \text{P} \cdot \text{e}}{\text{W}} \\
&V_U = \frac{\text{K}_{\text{BU}} \cdot \text{K}_{\text{tor}} + \text{P} \cdot \text{e}}{\text{W}} \\
&P_S = \frac{\text{P} \cdot \text{L}}{2}
\end{align*}
\]

**Fig. 1.** Upl. Bend Moment Capability vs. Moment Angle

**Ft_u = 77,900 psi**
For \[ F_{tu} = 77.4 \times 4 \text{ ksi}, \quad P = 32,200 \text{ lb} \]

\[ P_{max} = \frac{80}{77.4} \times 32,200 = 73,300 \text{ lb} \]

\[ P_x = u_x \times 65 = 65 \times 33,300 = 21,500 \text{ lb} \]

\[ P_y = \frac{5}{9} P = \frac{5}{9} \times 32,200 = 16,650 \text{ lb} \]

\[ P_z = \frac{39.3}{21.5} \times 16,650 = 30,900 \text{ lb} \]

\[ M_x = 15.0 \times 33,300 = 500,000 \text{ in-lb} \]

\[ M_y = 19.50 \times 33,300 = 650,000 \text{ in-lb} \]

\[ M_z = \frac{44 \times 33,300 \times 9.6}{1.95} = 135,000 \text{ in-lb} \]

**In Socket**

\[ P_x = 21,600 \text{ lb} \]

\[ P_y = 16,650 \text{ lb} \]

\[ P_z = 30,900 \text{ lb} \]

\[ M_x = 500,000 + (21.00 \times 16,650) = 850,000 \text{ in-lb} \]

\[ M_y = 650,000 + (21.00 \times 21,600) = 1,103,000 \text{ in-lb} \]

\[ M_z = 135,000 \text{ in-lb} \]

**In Beam**

\[ (M_z = 335,000 \text{ in-lb}, \text{ Per 4'}) \]

\[ P_{s2} = \frac{850,000 + (4 \times 30,900) - (5.50 \times 16,650)}{17.00} = 51,800 \text{ lb} \]

\[ P_{s, x} = \frac{335,000 + (4 \times 30,900)}{17.00} = 29,800 \text{ lb} \]

\[ P_{frame, y} = P_y = 16,650 \text{ lb} \]

\[ P_{frame, x} = P_x + P_{s, x} = 21,600 + 13,000 = 34,600 \text{ lb} \]

\[ P_{frame, z} = P_z + P_{s2} = 30,900 + 51,800 = 82,700 \text{ lb} \]

\[ M_{frame, y} = 1,103,000 - (5.50 \times 21,600) = 939,000 \text{ in-lb} \]
SECTION P-P

\[ M_x = 734,000 \text{ in-lb} \]
\[ M_y = 952,000 \text{ in-lb} \]
\[ N_x = \frac{734 \times 71}{617} = 108,000 \text{ psi} \]
\[ N_y = \frac{952 \times 67}{801} = 80,000 \text{ psi} \]
\[ S_I = 188,000 \text{ psi} \]

SECTION 0.0

\[ M_x = 580,000 + 700 (16,650) = 617,000 \text{ in-lb} \]
\[ M_y = 650,000 + 700 (21,600) = 801,000 \text{ in-lb} \]

\[ f_x = \frac{6 \times 617,000}{5 \times 2.85^2} = 91,000 \text{ psi} \]
\[ f_y = \frac{6 \times 801,000}{1.85 \times 5.00^2} = 67,000 \text{ psi} \]
\[ S_F^2 = 158 \text{ ksi} \]
\[ F_{01} = 147 \times 125,000 = 18,300 \text{ psi} \]
\[ S_F = \frac{183}{158} = 1.16 \]
SECTION A-A

\[ M_{xy} = 850,000 \text{ in lb} \]

\[ M_{yy} = 1,103,000 \text{ in lb} \]

\[ f = \frac{850,000 \times 1.41}{12.7} = 96,940 \text{ psi} \]

\[ f_{yy} = \frac{1,103,000 \times 3.20}{63} = 56,000 \text{ psi} \]

\[ f_{0} = 1.47 \times 125,000 = 183,750 \text{ psi} \]

\[ S = \frac{183,750}{152,900} = 1.20 \]
**Socket Loads**

**Due to \( P_x \):**
\[ P_3 = 21,600 \, \# \]

**Due to \( P_y \):**
\[ P_1 = 16,650 \, \# \]

**Due to \( P_z \):**
\[
\begin{align*}
P_N &= \frac{30,900}{\sin 7^\circ \times 2} = 125,000 \, \# \\
P_2 &= \frac{952,000}{8.75} = 97,200 \, \# \\
P_1 &= \frac{1,103,000}{8.75} = 126,000 \, \# \\
\end{align*}
\]

**Due to \( M_x \):**
\[
\begin{align*}
M_x &= 135,000 + 2.90 (16,650 + 97,200) \\
&\quad - 1.80 (97,200) + 2.10 (21,600) = 335,000 \, \text{in-lb} \\
&\quad - 175,000 = 160,000 \, \text{in-lb}
\end{align*}
\]

**Assuming \( M_x \) reacted by \( P_4 \) and \( P_5 \):**
\[
\begin{align*}
P_4 &= \frac{335,000}{3.6} = 93,000 \, \# \\
P_5 &= 93,000 \, \#
\end{align*}
\]

**Summing Loads:**
\[
\begin{align*}
P_1 &= 16,650 + 97,200 = 113,850 \, \# \\
P_2 &= 97,200 + 93,000 = 190,200 \, \# \\
P_3 &= 21,600 + 126,000 = 147,600 \, \# \\
P_4 &= 126,000 \, \# \\
P_5 &= 93,000 \, \# \\
P_6 &= 0 \, \#
\end{align*}
\]
**SOCKET LOADS**

Assuming \( M_2 \) reacted by \( P_4 \) & \( P_6 \),

\[
P_4 = \frac{315,000}{2.25} = 142,222.22 \text{ } \text{\text{lb} }\left( \text{lb} \right)
\]

**SUMMING LOADS**

\[
P_1 = 16,650 + 97,200 = 113,850 \text{ } \text{\text{lb} }\left( \text{lb} \right)
\]

\[
P_2 = 77,200 \text{ } \text{\text{lb} }\left( \text{lb} \right)
\]

\[
P_3 = 21,600 + 126,000 = 147,600 \text{ } \text{\text{lb} }\left( \text{lb} \right)
\]

\[
P_4 = 126,000 + 99,000 = 225,000 \text{ } \text{\text{lb} }\left( \text{lb} \right)
\]

\[
P_5 = 0 \text{ } \text{\text{lb} }\left( \text{lb} \right)
\]

\[
P_6 = 147,000 \text{ } \text{\text{lb} }\left( \text{lb} \right)
\]

**SECTION III - M**

\[
P_4 = 275,000 \text{ } \text{\text{lb} }\left( \text{lb} \right)
\]

\[
A_5 = 5 \times 1.50 = 7.50 \text{ } \text{in}^2
\]

\[
F_5 = \frac{275,000}{7.50} = 37,000 \text{ } \text{PSI}
\]

\[
F_{50} = 45,000 \text{ } \text{PSI}
\]

\[
S.F. = \frac{95,000}{77,000} = 1.22
\]
UPPER CROSS BEAM LOADS

\[ P_1 = 113,850 \, \# \]

\[ q = \frac{113,850 + 113,850}{7500} = 6500 \, \#/in \]

\[ P_{5,up} = \frac{(0.50 - 0.18) \times 113,850}{7500} = 13,700 \, \# \]

SECTION B-B

\[ P_1 = 113,850 \, \# \]

\[ w = 0.40 \times 113,850 = 45,500 \, \#/in \]

\[ f = \frac{6 \times 45,500}{2 \times 2.00} = 14,000 \, \#/in \]

\[ F_{6y} = 1.2Y \times 58,000 = 73,600 \, \#/in \]

\[ 5.6Y, \frac{98000}{74000} = 1.31 \]

\[ A_s = 4.65 \, \text{in}^2 \]

\[ f_s = \frac{113,850}{4.65} = 24,500 \, \#/in \]

\[ F_{5,y} = 45,000 \, \#/in \]

\[ 5.6Y = \frac{45,000}{24,500} = 1.81 \]

ROLL-OVER

\[ P = \frac{81,000 \times 80}{15 \times 97.4} = 56,100 \, \# \]

\[ P_1 = \frac{56,100}{33.80} \times 113,850 = 192,000 \, \# \]

\[ A_s = (2.00 \times 2.00) + (1.5 \times 1.5 \times \tan 70 \times 4) = 4.65 \, \text{in}^2 \]

\[ f_s = \frac{192,000}{4.65} = 41,000 \, \#/in \]

\[ \rho = 45 \times 110 \]
SECTION 0-0 (Pg. 1)

\[ P_{5,2} = 51,800 \]  

\[ A_s (\text{web}) = 0.75 \times 3.00 = 2.25 \text{ in}^2 \]  

\[ \tau_s = \frac{51,800}{2.25} = 23,000 \text{ psi} \]  

\[ F_{5,0} = 45,000 \text{ psi} \]  

\[ M_{5,0} = \frac{45,000}{23,000} = 1.96 \]
SECTION D-D

\[ P_{x} = 51,800 \]  
\[ P_{s} = 24,800 \]  
\[ \frac{43,850}{93,500} \times 5340 = 6500 \text{ lb/in} \]

\[ P_T = 6,000 \times 6500 = 39,000 \text{ lb} \]

\[ M = 6,000 \times 24,800 = 149,000 \text{ in/ft} \]

\[ S_T = \frac{39,000}{5 \times 15} = 5200 \text{ psi} \]

\[ S = \frac{6 \times 149000}{15 \times 5.0^2} = 28200 \text{ psi} \]

\[ F_{T-y} = 38,000 \text{ psi} \]

S. F. \[ = \frac{39000}{249000 + 5200} = 1.30 \]

SECTION E-E

\[ P_2 = 190,200 \]  
\[ P_5 = 97,000 \]  
\[ M_2 = 335,000 \text{ in/ft} \]

\[ P_T = P_2 - P_5 = 190,200 - 97,000 = 93,200 \text{ lb} \]

\[ S_T = \frac{93,200}{7.5 \times 15} = 8700 \text{ psi} \]

\[ S = \frac{6 \times 335,000}{15 \times 7.0^2} = 23,800 \text{ psi} \]

\[ F_{T-y} = 38,000 \text{ psi} \]

S. F. \[ = \frac{38000}{8700 + 23800} = 1.17 \]
STUD ANALYSIS, 1/12 - 7 UNC TYP

\[ P_{stuv} = P_2 + \frac{2 \cdot MY}{8.75} \cdot \tan 7^\circ \]

\[ = 30,400 + \frac{2 \cdot 103,000}{8.75} \cdot \tan 7^\circ \cdot 61,400 \#

\[ A_{tens} = 0.968 \text{ in}^2 \]

\[ F_t = \frac{61,400}{0.968} = 63,000 \text{ psi} \]

\[ A_s = \frac{\pi D L}{2} = \frac{\pi \times 1.15 \times 1.25}{2} = 2.25 \text{ in}^2 \]

\[ F_s = \frac{61,400}{2.25} = 27,300 \text{ psi} \]

\[ F_{tu} = 125,000 \text{ psi} \]

\[ F_{su} = 80,000 \text{ psi} \]

STUD CRITICAL IN TENSION

\[ S, F_u = \frac{125,000}{63,000} = 1.95 \]

\[ P_{stuv} = P_2 + (P_3 + P_4 + P_6) \cdot \tan 7^\circ \]

\[ = 70,000 + (137,600 + 275,000 + 184,000) \cdot \tan 7^\circ \]

\[ = 100,000 \#

\[ F_t = \frac{100,000}{0.968} = 103,000 \text{ psi} \]

\[ A_s = \frac{\pi \times 1.15 \times 0.58}{2} = 1.05 \]

\[ F_s = \frac{100,000}{1.05} = 96,000 \text{ psi} \]

\[ F_{su} = 69 \times 150,000 = 96,000 \]
APPENDIX 6.6

CERTIFICATION TEST RESULTS
LOCKHEED PROPULSION COMPANY
A DIVISION OF LOCKHEED AIRCRAFT CORPORATION
REDLANDS CALIFORNIA

LOCKHEED PROPULSION COMPANY
POTRERO TEST SERVICES
TEST REPORT TR-684-065
CONFORMANCE TESTING ON A ROLL-OVER PROTECTIVE STRUCTURE FOR THE U. S. ARMY 6K ROUGH TERRAIN FORKLIFT

The Roll-Over Protective Structure, Part Number 299279, described herein has been tested in accordance with the applicable sections of the SAE Recommended Practice J-394a and met the required criteria.

Test Completion Date - 28 August 1973

Prepared by: H. C. Davis
Test Engineer

Approved by: T. P. Carpenter, Mgr.
Test Department

W. Dubyk, Director, Product Assurance Branch, being duly sworn, deposes and says: That the information contained in this report is the result of carefully conducted tests and is to the best of his knowledge true and correct in all respects.

Subscribed and sworn before me on this 1st day of January 1974.

J. Beth Barnes
NOTARY PUBLIC - CALIFORNIA
My Commission Expires June 28, 1974
LOCKHEED PROPULSION COMPANY
POTRERO TEST SERVICES

ROLL-OVER PROTECTIVE STRUCTURE
TEST DESCRIPTION

VEHICLE MANUFACTURER: Chrysler

VEHICLE TYPE/MODEL: 6K Forklift

VEHICLE WEIGHT: 23,500 lbs

ROPS MANUFACTURER: Tubelok

ROPS SERIAL NUMBER: NA

ROPS PART NUMBER: 299024

ROPS MATERIAL: ---

TEST DATE: 28 August 1973

TEST TEMPERATURE: 76°F

CUSTOMER ORDER NUMBER: 684

LPC WORK ORDER: T7162

- FOPS TEST PER SAE J-231
- HORIZONTAL LOAD TEST PER SAE J-394a
- VERTICAL LOAD TEST PER SAE J-394a
- CRITICAL ZONE PER SAE J397a
- IMPACT TEST - LOAD

TEST RESULTS/CONCLUSIONS:

The ROPS was subjected to a FOPS test and horizontal and vertical loads in accordance with SAE Recommended Practices J-231 and J-394a. The ROPS met or exceeded the SAE requirements.

DISCUSSION

The ROPS was mounted to the 6K forklift in accordance with LPC Drawing 299279.

The chassis was mounted in the test bay in accordance with SAE Recommended Practice J-394a. The tiedown arrangement is shown in Drawing 299500.

FOPS

A solid wooden form representing the critical zone was installed in the ROPS to aid in the final determination of success or failure. The critical zone was installed per SAE J-397a and LPC Drawing 299500. The test setup is shown in Figure 1.

The FOPS test made use of high speed movies to ensure that the critical zone was not violated during the FOPS test. Deflection

Prepared by: [Signature]

Approved by: [Signature]
ROLL-OVER PROTECTIVE STRUCTURE
TEST DESCRIPTION

TEST RESULTS/CONCLUSIONS: (Continued)

of the ROPS was measured by a photo target grid that was mounted beyond the ROPS in view of the camera.

A 500-pound standard drop object was positioned over the ROPS, raised 17 feet and dropped. There was no violation of the critical zone. The roof structure after impact is shown in Figure 2.

HORIZONTAL LOADING

A load application system consisting of one 700,000-pound hydraulic ram was installed to contact the ROPS roof for horizontal loading in accordance with Drawing 299500.

The test operations procedure is presented on pages 5 through 8.

One fourteen-inch linear potentiometer was utilized to measure deflection at the point of load application.

The force and deflection measurements were displayed in digital format for monitoring during the test and were also recorded at each deflection increment.

The digital data were entered manually into a Hewlett Packard desk top computer where each channel was converted to engineering units and the total energy, "U" was calculated and accumulated for each increment of horizontal load application. This data is presented in Table 2.

A plot of load versus deflection was also generated automatically by the computer during the test (page 11).

A total of 20 strain measurements were recorded during the horizontal loading to monitor the ROPS deformation. The strain gage locations are shown on Drawing 299500. The strain gage data are presented in Addendum I.

Steel scales and dial indicators were installed on the ROPS to measure deflection. These readings are presented in Table 1. The locations are shown on Drawing 299500.

The load was applied, as required, to produce approximate one-half inch deflection increments during the horizontal loading. At 5.5
TEST RESULTS/CONCLUSIONS: (Continued)

inches deflection, the minimum force requirement was met. At 10.0 inches, the minimum energy requirement was met and the horizontal load test was terminated.

At full deflection, Figure 3, the critical zone was not violated.

VERTICAL LOAD

The load column was aligned to the geometric center of the ROPS with a load pad to distribute the load over the full surface of the ROPS.

The incremental load and deflection were recorded during the vertical loading. Strain gage data were also recorded and are presented in Addendum II.

Optical deflection measurements were made using steel scales and are presented on page 12.

The vertical load setup is shown in Figure 4.

The critical zone was not violated during the vertical load test.
LOCKHEED PROPULSION COMPANY  
POTRERO TEST SERVICES  
ROLL-OVER PROTECTIVE STRUCTURE  
EQUIPMENT LIST

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<th>Equipment Type</th>
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<tr>
<td>Hydraulic Ram (Horizontal)</td>
<td>700K, Pickens Inc. 9480-18-3683 18-inch stroke</td>
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<tr>
<td>Hydraulic Ram (Vertical)</td>
<td>300K, Rodgers Hydraulic, Part Number 1-150 BR-7½, 7½-inch stroke</td>
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<td>Load Cell (Horizontal)</td>
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<tr>
<td>Load Cell (Vertical)</td>
<td>Ormond L-25-50K-557</td>
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<tr>
<td>Displacement Transducers</td>
<td>1 each 14-inch, 3 each Starrett Dial Indicators and 3 each 18-inch scales, and 1 Bourns 2001081615 potentiometers</td>
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<td>Data Acquisition System</td>
<td>Beckman 210, 84-channel Digital Data System</td>
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</table>

OPTIONAL EQUIPMENT

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<td>Thermocouple Potentiometer</td>
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<tr>
<td>Conditioning Box Controller</td>
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MEASUREMENT ACCURACY

The measurement systems and devices utilized in support of this test program are periodically maintained and calibrated to assure the following steady state accuracies. Instrument calibrations are traceable to the National Bureau of Standards.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Accuracy</th>
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<tr>
<td>Temperature</td>
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</table>
3.0 TEST OPERATIONS

3.1 Preliminary Preparations

3.1.1 Install chassis reinforcements per assembly drawing 299279 (Certified welder required.)

3.1.2 Install 20 post yield strain gages as shown on 299500.

3.1.3 Install the vehicle chassis in the test bay by welding per drawing 299501.

3.1.4 Install the ROPS 299024 into the socket mounts 299239 and torque the eye bolts to 500+40 foot-pounds.

3.1.5 Paint the assembly as required. Colors: chassis - olive drab; ROPS - yellow; tie-down fixtures - gray.

3.1.6 Install the critical zone per SAE J-397A and drawing 299500.

3.1.7 Prepare 1 2' x 8' photo targets by carefully applying 1" black tape to a white background as shown in Figure 1.

3.2 FOPS TEST

3.2.1 Attach the 500-pound drop weight to a mobile crane using an electrically operated bomb release.

3.2.2 Conduct sufficient practice drops on clear ground to ensure reliable release and good vertical attitude at the proposed impact point.

3.2.3 Position the drop weight at the center of the ROPS section covered with wire mesh.

3.2.4 Set up documentary movie cameras to record the drop sequence.
3.0 TEST OPERATIONS (Continued)

3.2.5 Install one photo target horizontally on the wall behind the critical zone to record the dynamic deflection of the steel mesh.

3.2.6 Install a 1" diameter x 6" long probe (approximate dimensions) extending downward under the drop point to be viewed by the high speed camera. Attach with wire, do not weld.

3.2.7 Position the 200 pps movie camera viewing the target grid at the same level as the critical zone top.

3.2.8 Raise the weight 17 feet above the ROPS roof and conduct the ROPS test per SAE J-231.

3.2.9 Ensure the critical zone has not been violated. Take post test photographs per test engineer direction.

3.2.10 If the deformed wire mesh is too close to the critical zone to conduct the horizontal load test, restore it to the original minimum level.

3.3 Horizontal Load Test

3.3.1 Ensure load column center line is contacting the ROPS roof at the exact distance from the vertical supports as shown on drawing 299500 and is in a level attitude. The load distribution plate must span 20 inches minimum along the ROPS top and it must be free to rotate horizontally as load is applied.

3.3.2 Install precision scales for optical deflection measurements in accordance with drawing 299500 and position the surveyor's transits for viewing.

3.3.3 Install dial gages in accordance with drawing
3.0 TEST OPERATIONS (Continued)

3.3.4 Calibrate all instrumentation and prepare for recording all data.

3.3.5 Take prefire photographs of the ROPS and test setup.

3.3.6 DELETE

3.3.7 Apply load to achieve incremental deflections of 0.5 inches and conduct the side loading in accordance with SAE J-394A.

3.3.8 Record the dial gages and optical scales at each inch of deflection.

3.3.9 At each deflection step, calculate total energy.

3.3.10 Continue loading until both the minimum load and minimum energy have been achieved.

NOTE
IF BOTH CONDITIONS OF LOAD AND ENERGY CANNOT BE SATISFIED, CONSULT THE TEST ENGINEER.

3.3.11 While at full load, ensure the critical zone has not been violated.

SAFETY NOTE
USE EXTREME CAUTION IN APPROACHING FULLY LOADED ASSEMBLY. A VIOLENT STRUCTURAL FAILURE COULD OCCUR AT ANY TIME.
3.0 TEST OPERATIONS (Continued)

3.3.12 Take documentary photographs per test engineer direction.

3.3.13 Remove the side load and record the post test measurements on all channels.

3.3.14 Take post test photographs per test engineer direction.

3.4 Vertical Load Test

3.4.1 Ensure load column is aligned to the center of the ROPS roof.

3.4.2 Ensure data acquisition for digital display and strain gage recording is ready for test.

3.4.3 DELETE

3.4.4 Apply load increments of 10K, 16K, 21K, 22K, 23K, and full load of 23.5K in accordance with SAE J-394A, paragraph 5.2. Record all specified data channels and optical deflection measurements at each load increment.

3.4.5 While at full load, verify that the critical zone has not been violated.

3.4.6 Take documentary photographs per test engineer direction.
**LOCKHEED PROPULSION COMPANY**
**POTRERO TEST SERVICES**

**ROLL-OVER PROTECTIVE STRUCTURE**
**TEST DATA SHEET**

**TEST ITEM** FORKLIFT - MULTICOLE LOAD  
**TEST DATE** 8/28/73

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**COMMENTS**
- 10 - 2.5"  
- 2D - 6.5"  
- NEW ZERO OR  
- 3-5 = 7.00  
- 4.5 = 9.62
### Roll-Over Protective Structure Test Data Sheet

**Test Item:** 6K Forklift Prototype  
**Test Date:** 8-28-73

**Horizontal Load Test Per SAE J-394a**

**Required Energy, \( U \), Pound-Inches:** 122,204  
**Required Minimum Horizontal Load:** 15,031 Pounds

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<th>Calculated Energy, ( U )</th>
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Prepared by: [Signature]  
Approved by: [Signature]

**Table 2**
Figure 1 - Test Set Up
Figure 4 - Vertical Loading Set Up
ADDENDUM I

PLOTS OF STRAIN VERSUS LOAD
DURING HORIZONTAL LOADING
ADDENDUM II

PLOTS OF STRAIN VERSUS LOAD

DURING VERTICAL LOADING
6X FORKLIFT
PROTOTYPE
FLW-7 L7 17760
30 AUG 73

VERTICAL LOAD

STRADDLE MICRO IN/IN

LOAD-WEIGHT

1000.
900.
800.
700.
600.
500.
400.
300.
200.
100.
0.

00.
32.
24.
16.
8.
0.

0.
10.
20.
30.
40.
50.
60.
70.
80.
90.
100.

(20)
6K FORKLIFT\textsuperscript{*} ROTOTYPE
P1856 T7160
684 7 47 28 AUG 73

SG 11 VERTICAL LOAD

LOAD-LEIS (10^3)

-0.5

-100 0 100 200 300 400 500 600 700 800

STRAIN MICRO IN/IN

* F
d
APPENDIX 6.7

ANALYSIS OF PROTOTYPE TEST RESULTS
A comparison of predicted side load to test side load is shown on Page 4. A comparison of predicted vertical load to test vertical load is shown on Page 5. The vertical load prediction might be considered to be reasonably accurate, except the test curve breaks at 23,000 lbs rather than at 16,000 lbs as predicted. This is probably due to high material yield strength. Actual material properties are not available at this time since the ROPS is being considered for reuse for a rollover test.

The side load prediction does not agree well with the test curve. Following is the reduction of the side load test data for the purpose of determining the reason for the difference between the predicted side load curve and test side load curve.

### SIDE LOAD TEST DATA REDUCTION

Sketch, Page 6 shows the location of deflection gages for the side load test conducted on 28 August 1973. Deflections obtained from the test are given in Page 7. It was observed that side load deflection results did not agree well with predicted values; therefore a supplemental side load test was run on 29 August 1973 to obtain additional data to help determine the reason for the difference between predicted and actual side load curves. Deflection gage locations for the supplemental test are shown on pages 8 and 9 and test data is given on page 10. FS S7 and NS S7 correspond with 4S and 3S, page 6.

Before investigating the difference between the predicted and test side load curves, the history of the 6K ROPS predictions and tests has to be reviewed. The graph on page 11 shows the significant curves from the 6K ROPS program.

Curve 1 and curve 2, from 6K ROPS PDR 4 April 73 page 36, are computer predictions for the ROPS side load test run 28 May 1973. Curve 1 is for a ROPS model with the lower end of the vertical legs pinned in bending. Curve 2 is for a ROPS model with the lower end of the vertical legs fixed. Curve 3 (pinned) has always been felt to be most accurate in the small deflection range because, for small deflections, clearance and the rubber/cloth isolators allow the ROPS foot to rotate in the socket. Curve 2 (fixed) would be the most accurate curve in the large deflection range, because for large deflections, the ROPS feet make contact in the socket and develop moment capability. Even though curve 2 was not expected to be accurate in the small deflection range it was used as the prediction curve because it was expected to predict the correct maximum load. And, at that time, the computer program did not have the capability to transition from a pinned end to fixed end fixity.

Curve 3 from 6K ROPS PDR 4 April 73 page 35, is the prediction for the ROPS side load test run 29 May 1973 based on the CAT/CLARK ROPS bedplate test and obtained by conventional analysis.

Based on the test run 29 May 1973, a prediction curve, curve (5), was developed for the side load test run 28 August 1973, reference 6K ROPS CDR dated 23 July 1973, page 12. The elastic properties of the redesigned ROPS were very similar to the original ROPS therefore the same initial slope was predicted as obtained from the first test, curve (4). The maximum load was increased by conventional analysis methods for the decreased length of the upright ROPS tubes.

Curve (6) is the actual side load test curve from the test run on 28 August 1973, reference page 7.

The primary point to be brought out by comparing these curves is the importance of the foot socket clearance to overall ROPS stiffness. The original conventional analysis prediction, curve (3), was based on the CAT/CLARK bedplate test which had a conventional rectangular socket. This curve is very close to a pinned end ROPS configuration, curve (1). The actual test, curve (4), produced a much more rigid elastic curve than predicted by the CAT/CLARK bedplate test. This can now be contributed to the very rigid semi-conical foot/socket design used on the first 6K ROPS test. Proof of this effect is that curves (1), (3), and (6) which all have large clearance, rectangular sockets all have similar slopes in range R.

Since the second 6K ROPS tested incorporates a rectangular, large clearance foot/socket configuration, the prediction curve should have been curve (3) used for the first test but modified for curve (5) maximum load value due to shorter ROPS tubes. The resulting composite curve, curve (7) is practically identical to the second 6K ROPS test side load curve, curve (6), except for the flat offset between 0.0 and 2.0 inches obtained from the test. The only remaining discrepancy between the test and the corrected analytical curve then, is the flat initial offset at less than two inches deflection obtained from the test. Following is the reduction of test data to determine the cause of this initial flat offset.

Both computer and conventional side load vs. deflection analysis approaches assume the ROPS vertical legs are held from twisting in the socket (fixed for torsion). If the ROPS vertical legs are actually rotating in the sockets, analysis indicates a considerable reduction in elastic stiffness would result. The table on Pg. 12 reduces test data to determine the amount of rotation at the ROPS feet compared to the ROPS roof, and tabulates the amount of ROPS torsional fixity obtained during the test. Next, the table modifies the ROPS torsional spring rate, $K_{TOR}$, developed in "ROPS Load vs. Deflection Calculation", Page 13. Using the modified spring rate, $K_{TOR}$, the modified ROPS deflection, $\gamma_{def}$, is obtained. Each value of $\gamma_{def}$ obtained is an equation for the load/deflection curve. Therefore when the slope of each equation, $m$ is obtained, a continuous curve can be plotted. Plotting the slope from 0.0 deflection from 0.0 to 1.0 inches, slope from 2.0 inch deflection from 1.0 to 3.0 inches, slope from 4.0 inch deflection from 3.0 to 5.0 inch, etc, and adding this plot to the bottom end of the modified prediction curve (curve (7), page 14), curve (8), page 14 is obtained. The test curve, curve (6),
is repeated on page 14.

In summary, the good agreement between the two curves on page 14 indicates the differences between predicted and test side load curves is due to the larger socket clearance in the prototype 6K ROPS design.

A review of the strain gage data indicates material yielding in the ROPS vertical tubes and in the ROPS gussets at the upper end of the vertical tubes. Assuming ROPS tube $F_{ty} = 55,000$ psi,

$$\epsilon_{p.l.} = \frac{F_{ty}}{E} = \frac{55000}{29 \times 10^6} = 1900 \mu\text{in/in}$$

$$\epsilon_{yield} = 1900 \mu\text{in/in} + 2000 \mu\text{in/in} = 3900 \mu\text{in/in}$$

At required side load energy, strain gage 1 at 2400 $\mu$ in/in exceeded the material proportional limit and strain gage 2 at 3900 $\mu$ in/in reached material yield strength.

One of the two strain gages on the gussets recorded the highest strain in the test. At required side load energy, gage 8 and 10 developed 3860 $\mu$ in/in and 4750 $\mu$ in/in respectively. Assuming ROPS plate $F_{ty} = 40,000$ psi,

$$\epsilon_{p.l.} = \frac{40,000}{29 \times 10^6} = 1380 \mu\text{in/in}$$

$$\epsilon_{yield} = 1380 + 2000 = 3380 \mu\text{in/in}$$

Both gages exceeded material yield strain of 3,380 $\mu$ in/in. However, from LPC Specification EMS103, material elongation at failure is 20% or, 200,000 $\mu$ in/in. Therefore, the ROPS structure met required energy at

$$\frac{4750}{200,000} \times 100, \text{ or 2\% of failure elongation.}$$
6K ROPS CDR
SIDE LOAD AND ENERGY ABSORPTION SUMMARY

CHART NO. 12
DATE 23 JULY 73

- $P_{\text{max}} = 33,000$ lb
- $P = 27,000$ lb
- $P_{\text{min}} = 21,000$ lb

Critical Zone
$A_c = 13.5$ in

(SAE J-397a)

Test load - ROPS deformation causes direction of loading to change from perpendicular to centerline.
6K ROPS PDR
VERTICAL LOAD SUMMARY

NOMINAL CALCULATED DEFLECTION = 3.40 IN.

\[ P_v = 23,500 \text{ LB (SAE-J394a)} - \text{VEHICLE WEIGHT} \]

CRITICAL ZONE
\[ \Delta_c = 14.5 \text{ IN} \]
(SEE CHART 8)

VERTICAL LOAD, LBS \(10^{-3}\)

DEFLECTION, INCHES

- PREDICTED CURVE
- TEST CURVE
<table>
<thead>
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<th>6/6/73</th>
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<td>6/6/73</td>
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<td>6/6/73</td>
</tr>
<tr>
<td>1.8</td>
<td>6/6/73</td>
</tr>
</tbody>
</table>

Prepared by: 6270 6/6/73 Approved by: _____________
G.K. ROPS - TEST DATA REDUCTION

VIEW A-A, NEAR SIDE (NS)

FWD

5.9

10.4

9.4

3.4
TITLE - SUB TITLE

6K ROPS - TEST DATA REDUCTION

VIEW B-B, FAR SIDE (FS)
## Roll-Over Protective Structure Test Data Sheet

**Test Item**: CK - Forklift - PIPS Analysis

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### Lift Load Capacity Test

**Load Capacity Test Load**

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<th>F3</th>
<th>F4</th>
<th>F5</th>
<th>F6</th>
<th>F7</th>
<th>F8</th>
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<td>720.5</td>
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</tr>
</tbody>
</table>

*Note: MIN VALUE*

**Approved by:**

---

*Approved by:*

---

**Prepared by:**

---

**Prepared by:**

---

---

---
### S. R. 5- Side Load Test Data Reduction

#### 8/25/73 Test

<table>
<thead>
<tr>
<th>Deflection In.</th>
<th>1 S</th>
<th>2 S</th>
<th>Θ₁</th>
<th>3 S</th>
<th>4 S</th>
<th>Θ₂</th>
<th>FS 57</th>
<th>NS 57</th>
<th>Θ₃</th>
<th>NS 01</th>
<th>NS 03</th>
<th>Θ₄</th>
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#### 8/29/73 Test

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<th>FS 13</th>
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### Calculations

\[ Θ₁ = \frac{ΔS}{R} = \frac{S_{15} - S_{25}}{71.25} \text{ Radians} \]

\[ Θ₂ = \frac{ΔS}{R} = \frac{S_{35} - S_{45}}{77.5} \text{ Radians} \]

\[ Θ₃ = \frac{ΔS}{R} = \frac{S_{557} - S_{557}}{74.5} \text{ Radians} \]

\[ Θ₄ = \frac{ΔS}{R} = \frac{S_{501} - S_{503}}{5.9} \text{ Radians} \]

\[ Θ₅ = \frac{ΔS}{R} = \frac{S_{501} - S_{503}}{2.9} \text{ Radians} \]

% Torsional Fixity, NS Leg = \frac{Θ₄ - Θ₅}{Θ₅}

% Torsional Fixity, FS Leg = \frac{Θ₃ - Θ₄}{Θ₄}

\[ Ve' = \frac{KBE}{KBE + Ktor}(\frac{PL}{W}) \]

\[ S_{long} = S_{long} + Ve' \text{ in.} \]

\[ S = S_{long} + \frac{x}{2}(S') \text{ in.} \]
**RIFS LOAD & DEFLECTION CALCULATION**

\[ L_{\text{eff}} = \text{LENGTH FROM POST FOOT TANGENT TO} \]
\[ 1'' \text{ INTO UPPER GUSSET.} \]

\[ L_1 = \text{DISTANCE FROM TOP OF SOCKET TO} \]
\[ 5'' \text{ INTO UPPER GUSSET.} \]

\[ L_2 = \text{DISTANCE FROM TOP OF SOCKET TO} \]
\[ \text{UPPER STRUCTURE} \&. \]

\[ L_3 = \text{LENGTH 5'' INTO GUSSET ON} \]
\[ \text{EACH SIDE.} \]

**FIG. 1** ULT. BEND MOMENT CAPABILITY VS. MOMENT ANGLE.
\[ F_{tu} = 77,400 \text{ PSI} \]

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<th>ULTIMATE CAPABILITY</th>
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<td>[ \frac{P_{\text{eff}}}{z} ]</td>
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<tr>
<td>[ \frac{L_1(z^2)}{3EI} ]</td>
<td>[ \frac{V_e L_2^5}{8EI} ]</td>
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<tr>
<td>[ \frac{SLAT}{3EI} + \frac{SLAT^2}{3EI} ]</td>
<td>[ \frac{SLAT_1}{3EI} + \frac{SLAT_2}{3EI} + \frac{S_{LONG}}{3EI} ]</td>
</tr>
<tr>
<td>[ \frac{6}{6} ]</td>
<td>[ \frac{V}{V} ]</td>
</tr>
<tr>
<td>[ \frac{\theta}{\theta, \text{IN.}} ]</td>
<td>[ \frac{M_{LAT}^+}{M_{LONG}} ]</td>
</tr>
<tr>
<td>[ \frac{P}{P_{\text{eff}}} ]</td>
<td>[ \frac{M_{LAT}^+}{M_{LONG}} ]</td>
</tr>
<tr>
<td>[ \frac{M_{\text{fig.1}}}{\text{COEF. P}} ]</td>
<td>[ \frac{M_{\text{fig.1}}}{\text{COEF. P}} ]</td>
</tr>
</tbody>
</table>

| MATERIAL | I | J | L1 | L2 | L3 | W | E | V | \[ \begin{array}{c} \text{K}_{\text{eff}} \text{ or } \text{K}_{\text{tor}} \end{array} \] | \[ \begin{array}{c} \text{K}_{\text{eff}} \text{ or } \text{K}_{\text{tor}} \end{array} \] | \[ \begin{array}{c} \text{K}_{\text{eff}} \text{ or } \text{K}_{\text{tor}} \end{array} \] | \[ \begin{array}{c} \text{K}_{\text{eff}} \text{ or } \text{K}_{\text{tor}} \end{array} \] | \[ \begin{array}{c} \text{K}_{\text{eff}} \text{ or } \text{K}_{\text{tor}} \end{array} \] |
|----------|---|---|----|----|----|---|---|---|----------------|----------------|----------------|----------------|
| LARK 6 x 6 x 1/2 | 18.33 | 34.55 | 57.25 | 116.3 | 21.94 | 41.46 | 156.07 | 327.2 | 0.0069 | 0.0078 | 0.0098 | 0.0118 |
| LARK 6 x 6 x 1/2 | 18.33 | 34.55 | 57.25 | 116.3 | 21.94 | 41.46 | 156.07 | 327.2 | 0.0069 | 0.0078 | 0.0098 | 0.0118 |
| LARK 5 x 5 x 1/2 | 18.33 | 34.55 | 57.25 | 116.3 | 21.94 | 41.46 | 156.07 | 327.2 | 0.0069 | 0.0078 | 0.0098 | 0.0118 |

\[ K_{\text{tor}} = \frac{1}{8} = \frac{1}{8} \cdot \frac{L_3}{JG} \]
\[ K_{\text{eff}} = \frac{1}{8} = \frac{1}{8} \cdot \frac{L_3}{JG} \]

\[ V_e = \frac{K_{\text{eff}} + K_{\text{tor}}}{W} \left( \frac{P_e}{W} \right) \]
\[ V_u = \frac{K_{\text{eff}} + K_{\text{tor}}}{K_{\text{eff}} + K_{\text{tor}}} \left( \frac{P_e}{W} \right) \]
\[ P_S = \frac{P}{2} \cdot \frac{L_3}{W} \]
GK ROPS SIDE LOAD VS DEFORMATION

GK ROPS - SIDE LOAD TEST DATA REDUCTION

DEFLECTION, INCHES
APPENDIX 6.8

INSTALLATION INSTRUCTIONS
Retrofit Procedure for Installation of Roll-Over Protective Structure (ROPS) on 6000 lb Forklift Truck

Installation Drawing 299279

NOTE: All Welding to be per DPSF100.

### A. PARTS REQUIRED

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<th>Drawing No.</th>
<th>Quantity</th>
<th>Description</th>
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</tr>
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<td>8.</td>
<td>299572-103</td>
<td>2</td>
<td>Flat washer, 4.0 dia.</td>
</tr>
<tr>
<td>9.</td>
<td>299572-107</td>
<td>1</td>
<td>Spacer block</td>
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<td>10.</td>
<td>299572-109</td>
<td>2</td>
<td>Bevel nut</td>
</tr>
<tr>
<td>11.</td>
<td>299029-101</td>
<td>4</td>
<td>Resilient pad (Fabreeka)</td>
</tr>
<tr>
<td>12.</td>
<td>299029-103</td>
<td>4</td>
<td>Resilient pad (Fabreeka)</td>
</tr>
<tr>
<td>13.</td>
<td>299029-105</td>
<td>2</td>
<td>Resilient washer (Fabreeka)</td>
</tr>
<tr>
<td>14.</td>
<td></td>
<td>2</td>
<td>Cap SCR, H.H. self-locking 1.25-7 UNC, 4.5 long</td>
</tr>
<tr>
<td>15.</td>
<td></td>
<td>28</td>
<td>Bolt, H.H. SAE grade 8 3/4-10 UNC, 4.0 long</td>
</tr>
<tr>
<td>16.</td>
<td></td>
<td>28</td>
<td>Hex nut, SAE grade 8 3/4-10 UNC</td>
</tr>
<tr>
<td>17.</td>
<td></td>
<td>28</td>
<td>Flat washer, 3/4 medium</td>
</tr>
<tr>
<td>18.</td>
<td></td>
<td>28</td>
<td>Lock washer, 3/4 medium</td>
</tr>
<tr>
<td>19.</td>
<td></td>
<td>2</td>
<td>Bolt, H.H. SAE grade 8 1/2-13 UNC, 1 1/4 long</td>
</tr>
<tr>
<td>20.</td>
<td></td>
<td>2</td>
<td>Flat washer, 1/2 medium</td>
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A. PARTS REQUIRED  (Continued)

<table>
<thead>
<tr>
<th>Item</th>
<th>Drawing No.</th>
<th>Quantity</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>21.</td>
<td></td>
<td>2</td>
<td>Lock washer, 1/2 medium</td>
</tr>
<tr>
<td>22.</td>
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<td>2</td>
<td>Hex nut, SAE grade 8 1-1/4-7 UNC</td>
</tr>
<tr>
<td>23.</td>
<td></td>
<td>2</td>
<td>Mach Scr. H. H. 3/8-16 UNC, 3/4 long</td>
</tr>
<tr>
<td>24.</td>
<td></td>
<td>2</td>
<td>Flat washer, 3/8</td>
</tr>
<tr>
<td>25.</td>
<td></td>
<td>2</td>
<td>Lock washer, 3/8</td>
</tr>
<tr>
<td>26.</td>
<td></td>
<td>1</td>
<td>Hose adapter fitting, MS20822-12</td>
</tr>
<tr>
<td>27.</td>
<td></td>
<td>1</td>
<td>Electric Harness, single conductor. Cable, MIL-C-13486-1, Type I, Class A with female connector, MS27144-1 Style 1 at one end and male connector, MS27142-2 at other end. Total length 56 inches.</td>
</tr>
<tr>
<td>28.</td>
<td></td>
<td>1</td>
<td>Electric harness, similar to Item 27 except 140 inches long.</td>
</tr>
<tr>
<td>29.</td>
<td></td>
<td>11</td>
<td>Wire clamps, MS21105-3</td>
</tr>
<tr>
<td>30.</td>
<td></td>
<td>11</td>
<td>Self-tapping screw, No. 10 pan head, 3/4 long</td>
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<tr>
<td>31.</td>
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<td>4</td>
<td>10/24 Mach Scr. R. H. 3/4 long</td>
</tr>
<tr>
<td>32.</td>
<td></td>
<td>15</td>
<td>No. 10 flat washer</td>
</tr>
<tr>
<td>33.</td>
<td></td>
<td>15</td>
<td>No. 10 lock washer</td>
</tr>
<tr>
<td>34.</td>
<td></td>
<td></td>
<td>Molykote lubricant</td>
</tr>
<tr>
<td>35.</td>
<td></td>
<td></td>
<td>Adhesive, rubber-to-metal AMICON 2654</td>
</tr>
</tbody>
</table>

As Required As Required
B. PREPARATION OF LIFT TRUCK FOR RETROFIT

NOTE: Retain all fasteners for use in re-assembly.

1. Place truck on level hard surface.

2. Securely block up rear axle and remove rear wheels by unscrewing 10 stud nuts on each wheel. Set aside the two wheels, and run nuts partly on studs to protect the threads during the retrofit.

3. Disconnect the short electrical harness serving the floodlight on the forward edge of the overhead guard.

4. Remove the 4 clevis pins and lift off the overhead guard.

5. Torch cut the floodlight bracket from the guard for later welding to the ROPS.

6. Unlatch and lift off the left hand and right hand engine covers and unscrew the two forward latches from the frame.

7. Disconnect from the air cleaner outlet the tube coming from the air cleaner service indicator. See Figure 1

8. Remove the two screws attaching the service indicator to its mounting lug on the hydraulic reservoir.

9. Pull the service indicator and its tube out of the mounting lug, reverse its direction and thread back into the lug, so that the indicator unit is on the inward side toward the truck centerline.

10. Replace the two attaching screws and tighten hand tight.

11. Unfasten the clamp from the flexible air duct on the outlet of the air cleaner.

12. Remove the four bolts holding the air cleaner to the left hand rear fender, and the one bolt attaching the air cleaner stack brace to the fender.

13. Lift off the air cleaner with its stack and brace and set aside.

14. Remove the 12 bolts attaching the hood to the chassis.

15. Loosen the clamp under the hood attaching the muffler to the exhaust stack.

16. Remove the 8 bolts attaching the left hand rear fender to the chassis.

17. Remove the 10 similar bolts from the right hand rear fender.

18. Raise the loosened hood and muffler to clear the 3/4" lip on the left hand rear fender and remove the fender.
B. PREPARATION OF LIFT TRUCK FOR RETROFIT (Continued)

19. Similarly, remove the right hand rear fender.

20. Remove the 8 bolts attaching the left hand panel cover forward of the latched cover and remove the panel.

21. Remove the 11 bolts attaching the right hand panel cover forward of the latched cover and remove the panel.

22. Remove the 10 bolts attaching the bent panel forming the forward wall of the left hand wheel well and remove the panel.

23. Cut a 2" notch in the skirt of the right hand wheel well panel as shown in Figure 2.

24. Remove 2-1/2 inch bolts, nuts and washers from angle structure (one on each side of chassis) and replace with 1/2 inch bolt 1-1/4 long, flat washer, lock washer, and bevel nut Item 10 as shown in Figure 2.

25. Remove 4-3/4" bolts attaching the counterweight to the frame and remove the weight. Take care to avoid damage to the electric wires in the area.

26. Clean the truck frame and chassis exposed by these removals with steam or solvent to permit suitable working conditions.

27. Torch-cut the 2 aft tie-down lugs from the outside face of the frame. That portion of the lug root above the 1" thick axle mount support plate must be ground down flush or below the edge of the plate. That portion of the lug root under the reinforcement must be ground down to 1/4" below this flush level. (Do not grind away any part of the plate or the frame channel.) See Figure 1.

28. On the right hand side of the engine, relocate the two oil cooler hoses: Figure 3 shows the existing connections. Step a) Remove the bolt holding the two hose clips to the hose clip support angle. b) Disconnect and remove the 45° adapter fitting from the forward connection in the oil cooler, catching the small amount of oil in a receptacle. c) Install the 90° fitting included in the retro-fit kit (Item 26). d) Re-connect the forward hose. e) Attach the spacer block (Item 9) in the hose clip support angle with 3/8 inch screw, washer, and lock washer (Items 23, 24, 25), screwed up into the threaded hole in the spacer block. f) Remove the hose clips from the two hoses, turn them over, and replace them on the hoses so that they can be attached on the top side of the spacer block. g) Attach the two clips to the top of the spacer block with one 3/8 inch screw, washer, and lock washer (Items 23, 24, 25), screwed into the threaded hole in the spacer block. See Figure 4.
C. INSTALLATION OF ATTACHMENT STRUCTURE

1. Locate Spacer Plate 299239-141 (Item 7) on left hand side of the chassis frame channel as shown on Figure 5 and tack weld as shown.

2. Similarly, locate Spacer Plate 299239-135 (Item 4) on the right-hand side and tack weld. See Figure 5.

3. From directly behind the truck, move the Attachment Structure Assembly 299239-501 (Item 2) forward under the chassis, with the longer extension on the right-hand side. A fork lift truck is suggested for this operation. The longer extension must be raised at the forward end to pass over the axle during the move. See Figure 6.

4. Raise the assembly up underneath the chassis so that the top of the right-hand extension is level with the top of the chassis frame channel. Move the assembly forward so that its cross beam contacts the aft face of the 1" thick axle mount support plate shown in Figure 7. (The top of the ROPS socket will be 1/8" below the bottom of the frame channel.)

5. Clamp the right hand extension of Assy 299239-501 to the right hand channel frame, with the tack welded spacer plate in between. (Figure 8)

6. Level the assembly by jacking or blocking the left hand end of the cross beam.

7. Check level and location of the sub-assembly as follows:
   a. Right hand extension level, flush with the top of the right hand frame channel, and clamped snugly against the channel and spacer plate (Item 4).
   b. Forward face of cross beam in contact with the aft end of the axle mount support plate on both sides of the chassis frame. Top of ROPS socket 1/8" below bottom of the frame channel, both sides.

8. Securely clamp the Attachment Structure to the right hand frame channel and, using the fourteen 3/4" diameter holes as guides, drill through spacer plates and frame channel with a 3/4" drill in fourteen places. (Figure 9)

9. The fourteen 3/4" diameter holes are arranged in three patterns of 4 holes each and one group of 2 holes. Back-up plate 299239-137 (Item 5) is used for each of the 4-hole patterns and back-up plate 299239-136 (Item 6) is used for the 2-hole pattern.
C. INSTALLATION OF ATTACHMENT STRUCTURE (Continued)

10. Place a 4-hole back-up plate, (Item 5) inside the frame channel behind the aft 4-hole pattern. Lubricate the shanks, threads and underside of the heads of four 3/4-10 UNC bolts, with molykote, insert through side-plate, spacer, channel, and back-up plate, add flat washers and lock washers, and screw on the 3/4-10 UNC hex nuts, hand tight.

11. Similarly, using two more back-up plates Item 5 and one Item 6, insert and hand tighten 10 more lubricated bolts, washers, lock washers and nuts.

12. With a wrench holding the nuts on the inside of the frame channel, tighten the fourteen bolts to 125 foot-lbs of torque.

13. Securely clamp the left hand subassembly, 299239-509 to the left hand frame channel in the position shown in Figure 10.

14. Weld the -509 subassembly to the -501 assembly along the left hand side as shown on Figure 10. The welding consists of one 1-inch chamfer weld 8-5/8 inches long, continuous with one 3/4-inch chamfer weld 23-1/4 inches long, one 2-inch chamfer weld 3-1/2 inches long, and two 3/8-inch fillet welds 3-1/2 inches long. The welding procedure must prevent distortion or relative movement between the parts being joined.

15. Drill fourteen 3/4" diameter holes similarly to paragraph 8 above. Exercise care to avoid damage to tubing and electrical lines inside the frame channel, particularly at the forward end of the attachment structure.

16. Place four back-up plates in their appropriate positions inside the left hand frame channel, and install the fourteen lubricated bolts, washers, lock washers and nuts. Tighten the bolts to 125 foot-lb of torque.

D. REWORK OF FORKLIFT TRUCK COMPONENTS

1. Floodlight bracket: Trim the bracket to fit the 2-1/2" diameter beam at the front of the ROPS and weld in place per Figure 11.

2. Left hand latched engine cover: Cut in two pieces, relocate the two hooks and rework the 1-1/4" tom edges as shown in Figure 12.

3. Right hand latched engine cover: Rework similarly as shown in Figure 12.

4. Left hand rear fender: Cut rectangular opening and drill three holes per Figure 13.

-6-
D. REWORK OF FORKLIFT TRUCK COMPONENTS (Continued)

5. Right hand rear fender: Cut square opening per Figure 14.

6. Left hand panel cover forward of the latched cover: Cut off the downward projection and bend up the lower edge as shown in Figure 15.

7. Right hand cover panel forward of the latched cover: Cut off the corner and bend up the lower edge as shown in Figure 16.

8. Bent panel forming front wall of left hand wheel well: No rework of this part is required.

E. INSTALLATION OF ROLL-OVER PROTECTIVE STRUCTURE

1. Install the re-worked left hand rear fender. Only 7 bolts are required, because one bolt hole has been cut out in the rework.

2. Install the reworked right hand rear fender using the 10 bolts required.

3. Lower the muffler, and the hood to fit over the 3/4 inch lips on the two fenders.

4. Re-tighten the clamp attaching the muffler to the exhaust stack.

5. Re-attach the hood, using the 12 bolts required.

6. Hoist the ROPS by means of a sling attached to the two lifting lugs and lower it so that the two feet pass through the openings in the rear tenders and hang just above the two sockets in the attachment structure. The feet should be centered on the sockets; adjust the center distance by means of the tie rod if necessary.

7. Install two tapered resilient pads (Item 11) on the inner vertical faces of each socket, using the rubber-to-metal adhesive (Item 35). Then install two rectangular resilient pads (Item 12) on the inner sloping faces. The pads must be bottomed in the socket, and will extend almost 2 inches above the top. Be sure to follow the above sequence: tapered pads first.

8. Before the adhesive cures, carefully lower the ROPS making sure the resilient pads are not displaced. One man at each socket is recommended. The ROPS will bottom against the sloping pads. See Figure 17.

9. Place one large flat washer (Item 8) on one self-locking cap screw (Item 14), then add one resilient washer (Item 13), insert through the hole in the underside of one socket into the threaded hole in the bottom of the ROPS foot, and hand tighten. Follow this same procedure for the other leg of the ROPS. Tighten both cap screws to a torque of 300 foot-pounds.
E. INSTALLATION OF ROLL-OVER PROTECTIVE STRUCTURE (Continued)

10. Loosen the four nuts on the ROPS tie-rod to remove any strain on the rod, then re-tighten to eliminate any looseness.

F. REPLACEMENT OF FORK LIFT TRUCK COMPONENTS

1. Replace the bent panel forming the forward wall of the left hand wheel well, using 10 bolts.

2. Replace the left hand panel cover forward of the latched covers, using 4 machine screws.

3. Replace the right hand panel cover forward of the latched covers, using 8 machine screws.

4. Attach one cover latch to the left hand side of the attachment structure with two 10/24 machine screws threaded into the tapped holes, forward of the ROPS post.

5. Attach one cover latch to the right hand side of the attachment structure in the same way.

6. On the left hand side, pass engine cover "A" behind the ROPS post from the rear, hook in place and secure with the latch.

7. On the right hand side, install the "C" engine cover in the same way.

8. On the left hand side, install the engine cover "B".

9. On the right hand side, install the engine cover "D".

10. Install the air cleaner, attaching to the left hand rear fender by means of 3 bolts through the three new holes and one bolt through the original slotted hole.

11. Re-connect the flexible air duct to the air cleaner outlet, and tighten the clamp.

12. Re-connect the service indicator tube to its boss on the air cleaner outlet.

13. Loosen the clamp attaching the brace to the air cleaner inlet stack.

14. Slide the loosened clamp upward to permit the lower end of the brace to match its original bolt hole in the fender.

15. Bolt the lower end of the brace to the fender with one bolt.

16. Plumb the air cleaner inlet stack and re-tighten the clamp.
F. REPLACEMENT OF FORK LIFT TRUCK COMPONENTS (Continued)

17. Attach electric harness Item 27 (56 inches long) on the chassis as shown in Figure 18, extending from front of cockpit to top of left hand rear fender adjacent to ROPS post.

18. Attach electric harness Item 28 (140 inches long) to ROPS post and upper horizontal beam to serve flood light mounted on forward round beam (Figure 18).

19. Re-install the counterweight.

20. Mount the two rear wheels back on the truck.

21. Remove all blocking.
REMOVE THIS BOLT, NUT & WASHERS.
REPLACE WITH SHORTER BOLT & BEVEL NUT.
SEE SECTION A-A.

FUEL TANK

CHASSIS FRAME
9 IN. CHANNEL

BOLT, HH, 1/2-13 UNC
1 1/4 LONG, WITH FLAT WASHER & LOCK WASHER

-- CUT NOTCH IN SHEET
AVOID DAMAGE TO FRAME
RIGHT SIDE ONLY

BEVEL NUT - 299572-109
(ITEM 10)

SECTION A-A
TYP 2 SIDES
OF FRAME

CHASSIS REWORK
RIGHT SIDE SHOWN

-11-  

FIGURE 2
EXISTING OIL COOLER CONNECTIONS
SEEN FROM RIGHT HAND SIDE

OIL COOLER
FITTING - MS20823-12 (45°)
CHASSIS FRAME CHANNEL
HOSE CLIP SUPPORT
HOSE CLIPS

FIGURE 3
LEFT HAND SIDE VIEW

RIGHT HAND SIDE VIEW

SPACER PLATE LOCATIONS

FIGURE 5
ATTACHMENT STRUCTURE ASSEMBLY
299239-501

- CHASSIS FRAME CHANNELS
  FWD
  AXLE MOUNT SUPPORT PLATES

- SPACER PLATE
  299239-141

- METAL-TO-METAL CONTACT
  ESTABLISHES FORE-AND-AFT
  POSITION OF ATTACHMENT
  STRUCTURE.

LONGITUDINAL POSITION OF
ATTACHMENT STRUCTURE

-16-  FIGURE 7
Figure 10. Left-Hand Subassembly Welded in Place
WELD BOTH LEGS

FLOODLIGHT BRACKET

3½ MINIMUM
30° TO 45°

VIEW A-A

FLOODLIGHT BRACKET ATTACHMENT TO ROPS

FIGURE 11
ENGINE COVER - LEFT HAND, REWORK.

RIGHT HAND REWORK IDENTICAL EXCEPT IDENTIFY AS COVERS C & D.

REWORK SEQUENCE

@ CUT COVER INTO 2 COVERS A & B ON INDICATED LINE.
@ RELOCATE SUPPORT HOOKS .62 LOWER (FLUSH WITH TOP.
@ REMOVE LATCH HOOK, COVER A.
@ RELOCATE LATCH HOOK .62 HIGHER, COVER B.
@ DRILL HOLE.
@ CUT OFF ENDS OF STIFFENERS BEFORE BENDING COVERS.
@ CUT & BEND LOWER EDGE TO 90°. RETAIN WEBBING STRIP.
CUT ② OFF ON LINES SHOWN

BEND ③ UP AT 90° PER END VIEW

COVER, PANEL, LEFT HAND, REWORK.

FIGURE 15
CUT CORNER, ② OFF SQUARE
BEND ③ UP AT 90° PER END VIEW
COVER, PANEL, RIGHT HAND, REWORK
ATTACH CLIPS WITH NO. 10 PAN HEAD SELF TAPPING SCREWS .75 LONG, NO. 10 FLAT WASHERS & NO. 10 LOCKWASHERS.

DRILL HOLES WITH NO. 10 DRILL (.1470 DIA)

INSTALLATION OF ELECTRICAL HARNESSES

ITEMS NO. 27 & 28