A minerals research contract report
May 1981

# DESIGN OF AN EXTENDED BUMPER FOR MINE HAULAGE TRUCKS

Contract J0215003
Woodward Associates, Inc.

OFR
83-123

BUREAU OF MINES ★ UNITED STATES DEPARTMENT OF THE INTERIOR

# DISCLAIMER NOTICE

50272-101

**REPORT DOCUMENTATION PAGE**

1. REPORT NO.

2.

3. Recipient's Accession No.

4. Title and Subtitle

Design of an Extended Bumper for Mine Haulage Trucks

5. Report Date

May 15, 1981

6.

7. Author(s)

John L. Dahle, Lawrence Owens, Glenn E. Adkins

8. Performing Organization Rept. No.

WA R81-149F

9. Performing Organization Name and Address

Woodward Associates, Inc.
7047 Carroll Road
San Diego, CA 92121

10. Project/Task/Work Unit No.

11. Contract(C) or Grant(G) No.

(C) J0215003

(G)

12. Sponsoring Organization Name and Address

U.S. Bureau of Mines
Twin Cities Research Center
5629 Minnehaha Avenue South
Minneapolis, MN 55417

13. Type of Report & Period Covered

Program Final Report,
Dec. 1980 - May 1981

14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

This report presents extended bumper designs for 170-ton rear dump haulage trucks used in the mining industry. The extended bumper designs are to provide operator protection in the event of rear-end collisions between two trucks. The bumper designs are a result of studying critical truck characteristics important in rear-end collisions and haulage truck accident data, as well as the dynamics of a collision. In addition, existing extended bumper designs were analyzed and evaluated.

17. Document Analysis a. Descriptors

Bumper Designs
Extended Bumpers
Rear-Dump Haulage Trucks
Rear-End Collisions

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group

18. Availability Statement

19. Security Class (This Report)

Unclassified

20. Security Class (This Page)

Unclassified

21. No. of Pages

85

22. Price

(See ANSI-Z39.18)

OPTIONAL FORM 272 (4-77)
(Formerly NTIS-35)
Department of Commerce

# FOREWORD

This report was prepared by Woodward Associates, Inc., San Diego, California under USBM Contract Number J0215003. The contract was initiated under the Minerals Health and Safety Technology Program. It was administered under the technical direction of USBM Twin Cities Research Center with Mr. William Pomroy acting as Technical Project Officer. Mr. R. J. Simonich was the contract administrator for the Bureau of Mines. This report is a summary of the work recently completed as part of this contract during the period December 15, 1980 to May 15, 1981. This report was submitted by the authors on May 15, 1981.

# CONTENTS

CONTENTS (CONT)

ILLUSTRATIONS

ILLUSTRATIONS (CONT)

## ILLUSTRATIONS (CONT)

## TABLES

## SECTION 1.0

## INTRODUCTION

This report presents the results of a study to develop an extended bumper design for large (170 ton) off-highway rear-dump haulage trucks used in surface mining operations. The purpose of the extended bumper design is to provide operator protection in the event of rear-end collisions between trucks.

Operator protection is necessary because the outcome of a rear-end collision between trucks often results in the rear-end of the dump body of the forward truck penetrating into the cab area of the rearward truck causing operator injury, as well as extensive machine damage such as shown in Figure 1-1. Figure 1-2 was developed for another USBM safety research program by Woodward Associates, Inc. (WAI) entitled "Novel Cab Design Concepts to Improve Large Haulage Vehicle Safety," USBM Contract No. J0295013. It shows the relationship of the height of the rear of the dump body in relation to the top of the cab and operator's platform for various truck models. This indicates that for most truck combinations the height of the dump body is at the "right" height to penetrate the cab area. Figure 1-3 shows the results of a truck collision in which the dump bed penetrated the cab area of another truck causing serious injury to the operator and major truck damage. The objective of this program is to design a bumper extending far enough in front of the existing bumper to prevent any intrusion into the operator's cab.

There are several ways of accomplishing the objective. One obvious method is to design an energy-absorbing bumper, similar to the automotive bumper systems. This design approach should be highly acceptable, but requires laboratory testing to design and refine the system. Therefore, the basic approach used was to design a bumper long enough to prevent any intrusion into the cab area — wide enough to impact at least two rear tires and high enough above the ground to impact near the centerline of the tires. In essence the bumper is designed to structurally carry the impact loads with the impact energy being absorbed by the rear tires.

FIGURE 1-1. Schematic of a Rear-End Collision

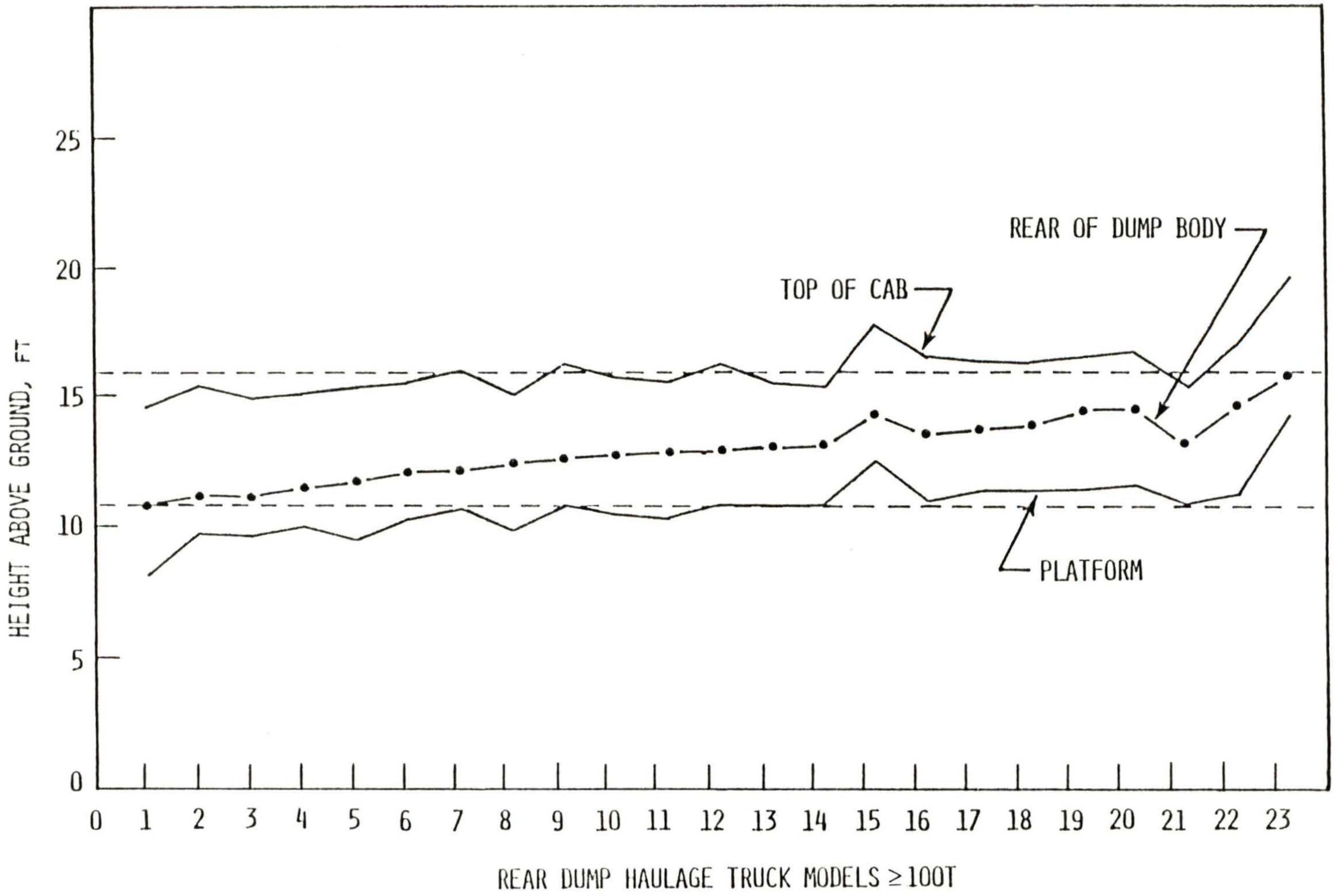


FIGURE 1-2. Cab Location versus Rear Bed Height

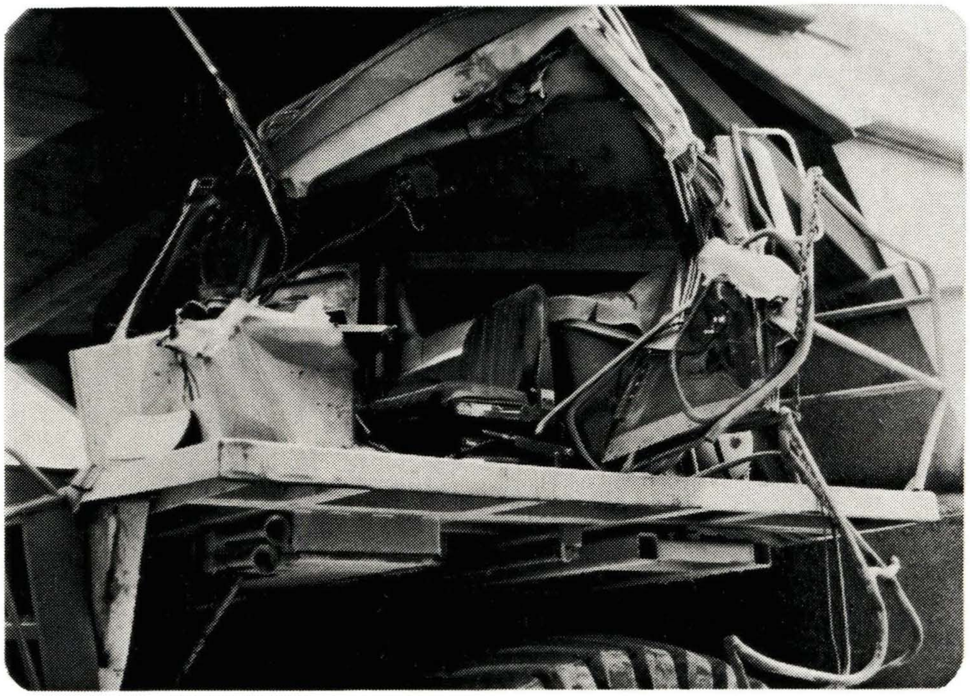


FIGURE 1-3. Results of a Rear-End Truck Collision

The basic design constraints require that the extended bumper designs must:

- Provide "adequate" operator protection.
- Be readily adaptable on a retrofit basis (170-ton haul trucks).
- Be readily adaptable to other models and sizes of trucks.
- Minimize potential maintenance problems.
- Be cost effective.
- Be easily fabricated.
- Minimize the damage to the truck main frame resulting from a rear-end collision.

The basic approach used in this study considered the following six factors in conjunction with the above constraints:

a. Analysis of accident and fatality data relating to haulage trucks.

b. Analysis of physical truck dimensions critical to an effective design.

c. Analysis of the impact dynamics of rear-end collisions to determine the magnitude and direction of loads.

d. Survey and evaluation of existing extended bumper concepts.

e. Evaluation of existing extended bumper designs.

f. Design and analysis of a "universal" extended bumper.

# SECTION 2.0

## SUMMARY

In order to design an extended bumper system to provide operator protection, it was necessary to define and establish the basic criteria which characterize a rear-end collision between off-road rear-dump haulage trucks. This involved an analysis of rear-end collisions to determine qualitatively characteristics of the impact such as vehicle speed and direction. After the basic characteristics of rear-end collisions were determined a detailed analysis of the collision dynamics was performed identifying the magnitude and direction of impact loads, the amount of energy that must be absorbed during impact, and important factors that affect the outcome of a collision.

In addition, several existing extended bumper designs were analyzed and evaluated using the criteria generated. Finally, "universal" extended bumper designs were developed for all 170-ton haulage trucks. The basic design approach used to design the extended bumpers was to require the following:

a. The impact energy is predominately dissipated by deflecting the rear tires of the forward truck and sliding one truck along the ground.

b. The configuration or geometry of the extended bumper must prevent intrusion into the cab area for the determined impact conditions.

c. For the determined impact conditions, the bumper and haulage trucks should suffer minimal damage.

Two basic extended bumper designs were required in order to satisfy the criteria that were established. Although there are two distinct designs, the overall dimensions of the bumpers are the same. One bumper design was required for the relatively narrow frame found on the WABCO and Terex 170-ton haulage trucks. The other design was required for the wider frame Unit Rig and Euclid trucks.

Previous USBM research, Contract No. H0282001, "Development and Demonstration of Improved Truck Ladders," has identified truck ladders as both a high maintenance item and an area where many injuries occur while getting on and off the hauler. One method for reducing injuries can be to install a staircase type of ladder on the front of the trucks, however, this can result in increased maintenance requirements since this type ladder is more susceptible to being damaged. With an extended bumper a staircase type of ladder can be added as illustrated in Figure 2-1 without increasing maintenance requirements. In fact, the maintenance requirement may be reduced for this design when compared to the conventional ladder which on some trucks is outside the zone protected by the bumper. One problem with the staircase ladder as illustrated in this figure is that anyone climbing up the ladder is not visible to the operator. With an extended bumper this problem can also be eliminated as illustrated in Figure 2-2. With this design anyone getting on the truck steps upon the bumper from the driver's side of the truck and walks across the front of the bumper in order to go up the staircase ladder.

The bumper installation illustrated in Figure 2-3 is typical of the extended bumpers presently in use. The bumper is equipped with headlights, clearance lights, wheel chocks, and an automatic central lubrication unit. In addition, an emergency engine kill switch, a fire extinguisher, and a fire suppression switch are located near the ladder for use in emergencies.

The major uses and advantages of extended bumpers include the following:

- Provides protection for the machine operator and equipment in the event of a rear-end collision.
- Provides an area for relocating the headlights downward and forward to reduce glare.
- Provides a convenient location for side marker lights to illuminate around the bumper area.
- Provides a location for fire extinguisher, emergency cutoff switch, first-aid kits, batteries, and central lubrication unit.

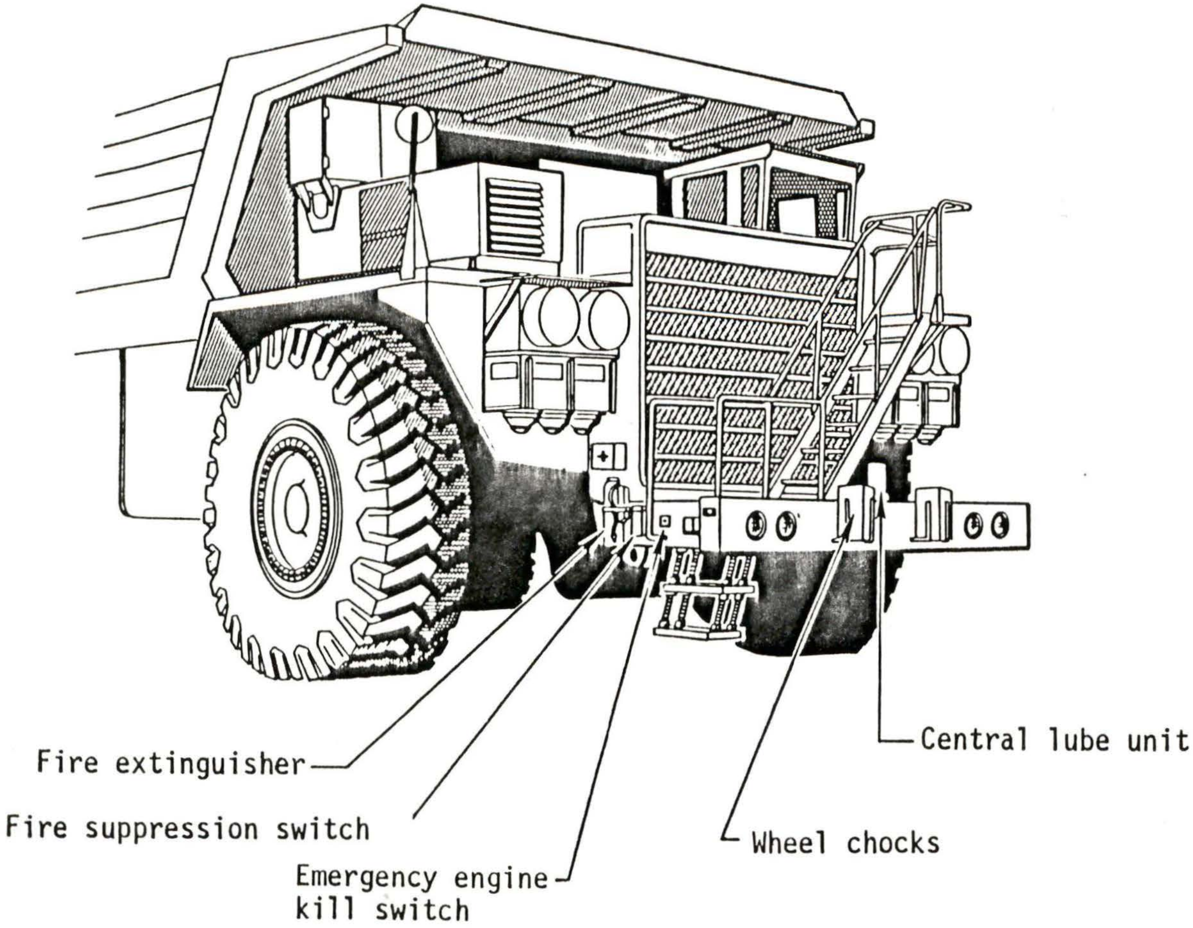


FIGURE 2-1. WAI Extended Bumper Concept With an Improved Ladder System

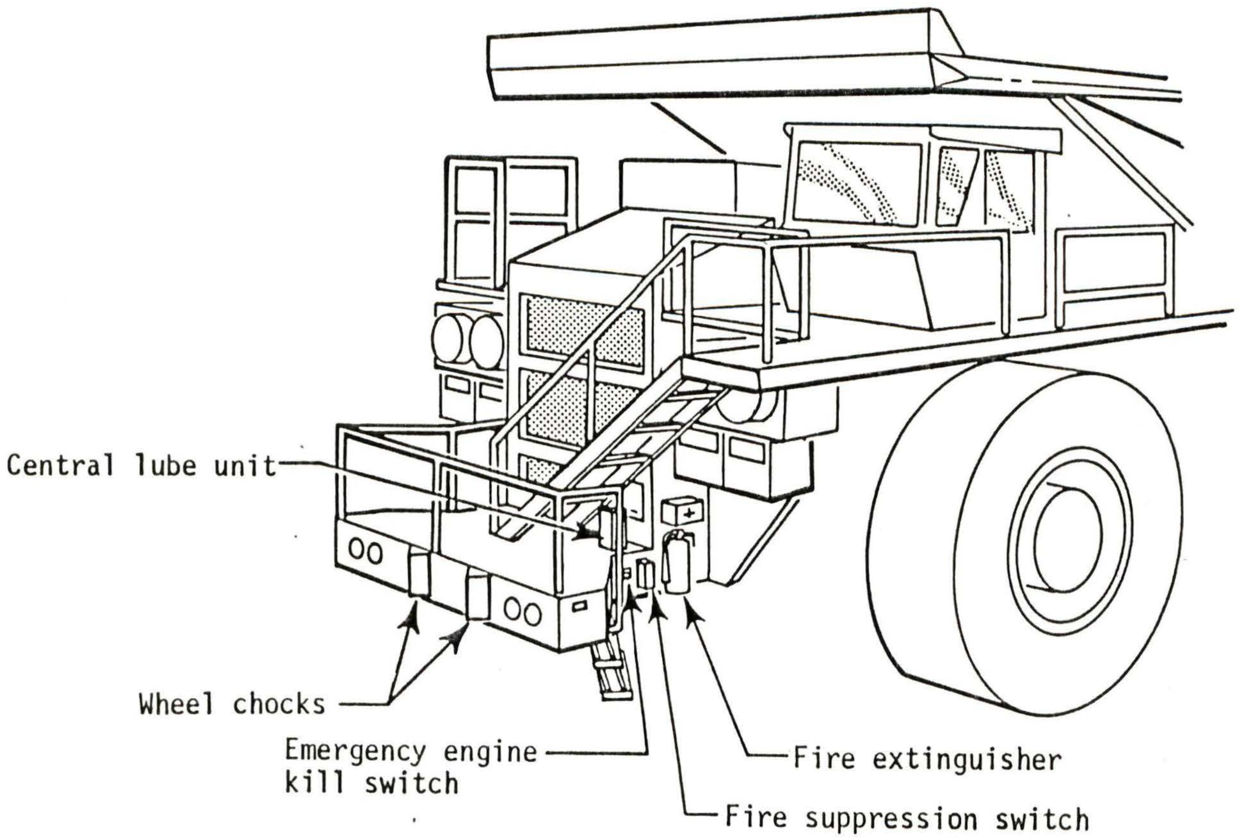


FIGURE 2-2. WAI Extended Bumper Concept With a Modified Ladder System

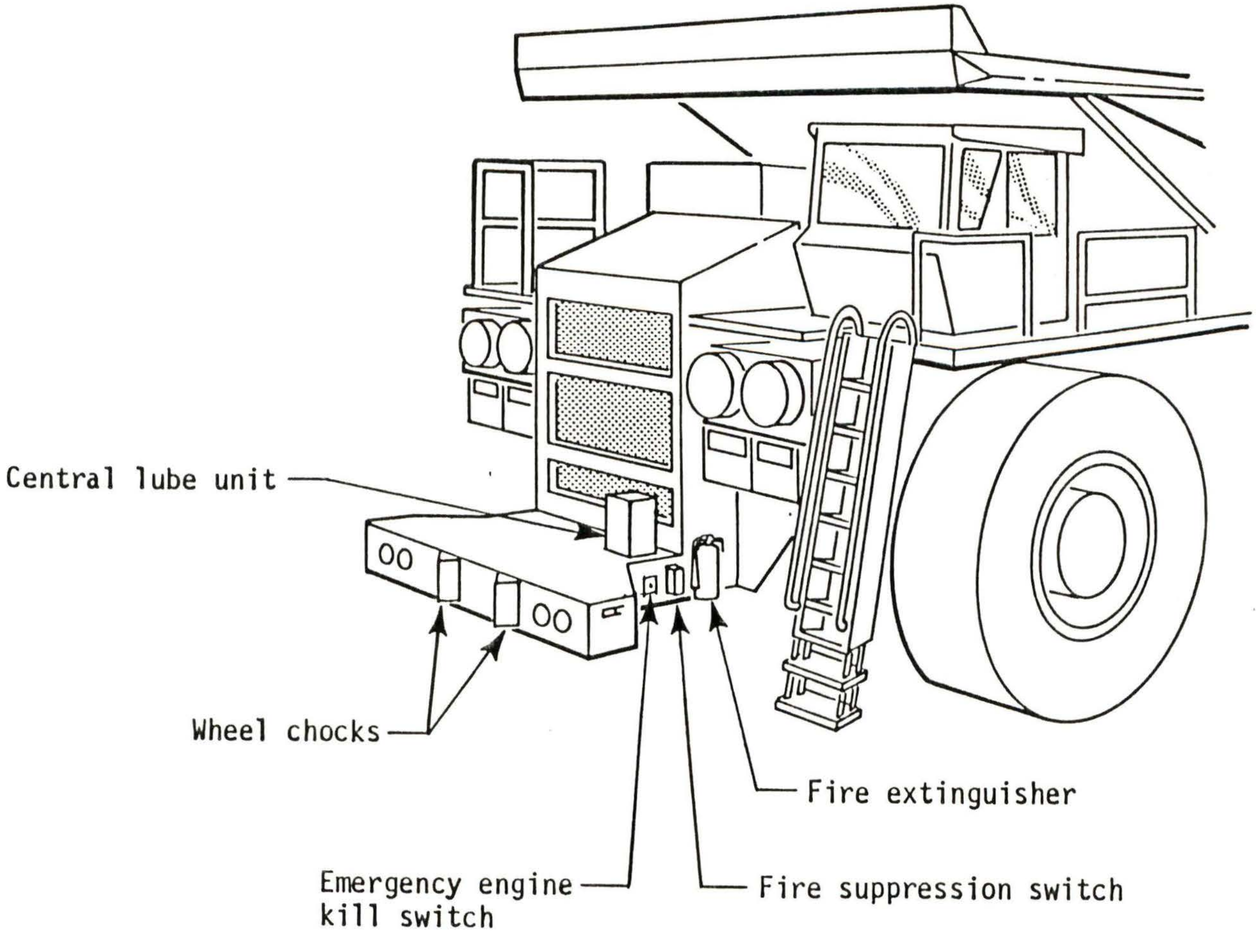


FIGURE 2-3. Basic Extended Bumper Design Concept

- Provides a work platform for front area of truck.
- Allows improved ladder arrangements.
- Provides protection for existing ladder arrangements.

Some of the disadvantages to adding extended bumpers onto existing haulage trucks include the following:

- Possible damage to the main frame of the truck due to fatigue.
- Increased loading on front tires by approximately 2,800 pounds per tire.
- Added weight reduces payload capacity by approximately 0.6 percent.

However, the increased front tire loading amounts to an average increase of only 1.2 percent which in most cases is negligible. In actual use the payload capacity is not affected. In fact it is not an uncommon practice for haulage trucks to overload by 10 percent although it is not a recommended practice. The possibility of frame damage is real; however, the mine which has used extended bumpers for five years does not attribute their frame damage to the use of the extended bumpers. Also, they have not observed any unusual tire wear.

The following summarizes the efforts required to arrive at the extended bumper designs.

## 2.1 ACCIDENT ANALYSIS

The accident analysis was conducted using data collected from the Mine Safety and Health Administration's Health and Safety Analysis Center (MSHA-HSAC) for the year 1978 and data collected from safety directors of the western surface copper mining companies. The objective of the accident analysis was to identify and evaluate typical rear-end collisions involving off-highway trucks. While the 1978 statistics indicate that rear-end collisions account for a small percentage of the accidents, the severity of injury is high. In conjunction with the high injury severity, most rear-end collisions result in considerable equipment damage. Additional accident information was examined from a previous study conducted by Woodward Associates, Inc. for the U.S. Bureau of Mines entitled "Novel Cab Design Concepts to Improve Large Haulage Vehicle Safety," USBM Contract No. J0295013.

A detailed analysis of the rear-end collisions shows that the one fatality was due to faulty brakes resulting in a high-speed collision. The remaining 10 collisions were the result of one haul truck backing into another.

One rear-end collision with an extended bumper has been documented. The extended bumper design designated as No. 1 design for WABCO was involved in a rear-end collision impacting another truck at 5 to 10 mph according to an eyewitness report. The collision involved no injuries and virtually no damage to either truck.

The analysis of the accident data leads to the following factors affecting the extended bumper design:

- Most rear-end collisions are a result of one truck backing into another at a low speed (0-3 mph).
- The extended bumper should minimize machine damage, as well as protect the operator.
- A relatively conservative design criteria should be considered since the potential for "high-speed" collisions is always present.

## 2.2 DETERMINATION OF CRITICAL PHYSICAL DIMENSIONS

In order to ensure that the bumper meets the basic criteria of impacting the rear tires of a truck and prevents the dump bed from penetrating the cab area, it was necessary to determine the physical dimensions of the trucks and bumper.

It was shown in Figure 1-1 that the rear-end of the dump body for most haulage trucks over 100 tons is at a height that would impact the cab on another truck. Therefore, it was necessary to collect other physical dimensions of those trucks to ensure the criteria were met. Some of the data have previously been presented in the study completed by WAI entitled "Novel Cab Design Concepts to Improve Large Haulage Vehicle Safety," USBM Contract No. J0295013. These dimensions included:

$x$ = distance from the existing bumper to cab

$y'$ = distance from rear tire to end of dump body

$r$ = loaded tire radius

$z$ = height to top of existing bumper

$z'$ = height to bottom of existing bumper

$d$ = distance between inner rear wheels

These dimensions were used to determine the following extended bumper configuration:

- Overall extended bumper length, L, is defined by

  $$L > (y' + \text{tire deflection} + \text{bumper deflection}) - x$$

- The overall extended bumper width, W, to impact two rear tires is defined by

  $$W \geq d + 2(\text{tire width})$$

- The height of the bumper, H, should be

  $$H \approx r$$

Since one of the requirements is to minimize damage to the extended bumper during an impact, it was necessary to determine the tire deflection available for 170-ton haul trucks before any suspension component is impacted. For WABCO, Unit Rig, and Euclid trucks there are 18 inches of tire deflection available to absorb the impact energy before a suspension component is hit. However, the Terex 170-ton haul truck has suspension components rearward of the rear tires. Therefore, the bumper designs may not be effective when impacting a Terex truck.

The dimensions of the extended bumper for 170-ton trucks are as follows:

Length = 4 feet

Width = 13 feet

Height = 5 feet ± 6 inches

## 2.3 DYNAMIC CONSIDERATIONS OF REAR-END COLLISIONS

For purposes of analysis three different impact configurations were considered for designing the extended bumper. These cases were chosen to ensure structural integrity for a wide range of loading conditions:

- Case 1 — Direct rear-end collision. The longitudinal centerlines of the two trucks are in line resulting in a symmetric end loading of the bumper. The extended bumper impacts the inner left and right rear tires.
- Case 2 — Offset rear-end collision. The extended bumper impacts one set of dual rear wheels.
- Case 3 — Angle impact such that one tire is impacted by one corner of the extended bumper causing a side load on the bumper as well as a front and vertical load (see Figure 6-3).

A dynamic analysis was conducted to determine the load magnitudes for the three impact conditions. Since the accident data indicated that most impacts were low-speed impacts, the impact loads on an extended bumper were determined as follows:

- Case 1 — Impact velocity = 5 mph
- Case 2 — Impact velocity = 5 mph
- Case 3 — Impact velocity = 3 mph

Other factors that influenced the assumed speed at impact were:

- The extended bumper must be weaker than the truck frames in order to minimize frame damage.

- The velocity for case 3 is lower since the bumper may only impact one rear tire, limiting the amount of impact energy absorbed.
- Design for high-speed collisions will substantially increase the bumper weight resulting in potential fatigue frame damage. A sensitivity analysis is needed to determine the optimum trade-off point of bumper weight versus frame damage from both frame fatigue and ultimate strength standpoints.

The dynamic analysis assumes the worst case of two of the heaviest 170-ton trucks impacting when both are fully loaded. The following is a summary of the factors included in the dynamic analysis:

- Truck weights of 575,000 pounds each.
- Rotational inertia — 15 percent.
- Actual load deflection characteristics of tires used on 170-ton haulage trucks (36 X 51 type E-3 or E-4).
- Assumed tire pressure of 75 psi.
- Conservative value for a road adhesion coefficient (0.85) resulting in higher bumper forces before a machine may slide on the ground.
- Truck frame capability.
- Impact velocity (3-5 mph).

The analysis results in the following governing impact loads for an extended bumper for the three loading cases:

- Cases 1 and 2:
    - Front load . . . . . . . . . . . . . . . 640,000 pounds
    - Vertical load . . . . . . . . . . . . . 38,400 pounds

- Case 3:
  - Front load . . . . . . . . . . . . . . . 280,000 pounds
  - Vertical load . . . . . . . . . . . . . 16,800 pounds
  - Side load . . . . . . . . . . . . . . . 75,000 pounds

## 2.4 DESIGN AND STRUCTURAL CAPABILITY OF EXTENDED BUMPER DESIGNS

There are presently two different surface mining operations using extended bumper designs. One mine has a design for a WABCO 170-ton truck (designated as design 1). Another mining operation also has a design for a WABCO truck (designated as design 2), as well as a bumper design for a Unit Rig 170-ton truck. Photographs and prints of the bumper designs were obtained during mine visits in order to evaluate the designs using the developed criteria.

As a result of this study extended bumper designs were developed for the four 170-ton model trucks manufactured by WABCO, Unit Rig, Euclid, and Terex. The objective was to develop a minimum number of design configurations to accommodate the trucks. Essentially two different designs were developed:

- A "narrow frame" design for WABCO and Terex trucks.
- A "wide frame" design for Euclid and Unit Rig trucks.

The prints for resulting extended bumper designs developed are shown in Appendices A through D. The bumpers are designed to connect to the existing frame of the trucks.

Table 2-1 provides a comparison of the extended bumpers designed by Woodward Associates, Inc. and the existing designs to the developed criteria. The WAI designs were aimed at meeting or exceeding the established criteria. In all cases the desired loads were exceeded.

TABLE 2-1. Comparison of Extended Bumpers

| | | | | Load Case 1 | | Load Case 2 | | Load Case 3 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Design | Weight (lb) | Cost | Dimensions (ft) | Front (lb) | Vertical (lb) | Front (lb) | Vertical (lb) | Front (lb) | Vertical (lb) | Side (lb) |
| Criteria | -- | -- | -- | 640,000 | 38,400 | 640,000 | 38,400 | 280,000 | 16,800 | 75,000 |
| WAI narrow frame (WABCO and Terex) | 1,900 | $3,000 | | 680,000 | 40,800 | 807,000 | 48,400 | 318,500 | 21,000 | 85,400 |
| Length | | | 4.0 | | | | | | | |
| Width | | | 13.0 | | | | | | | |
| Section height | | | 1.5 | | | | | | | |
| WAI wide frame (Euclid and Unit Rig) | 1,900 | 2,500 | | 664,100 | 39,900 | 837,000 | 52,200 | 362,100 | 24,000 | 100,000 |
| Length | | | 4.0 | | | | | | | |
| Width | | | 13.0 | | | | | | | |
| Section height | | | 1.5 | | | | | | | |
| Existing design 1 (WABCO) | 1,600 | 2,400 | | 417,700 | 25,100 | 295,000 | 17,700 | 136,200 | 8,200 | 35,400 |
| Length | | | 4.0 | | | | | | | |
| Width | | | 10.0 | | | | | | | |
| Section height | | | 1.5 | | | | | | | |
| Existing design 2 (WABCO) | 1,400 | 2,100 | | 92,500 | 5,550 | 167,500 | 4,000 | 39,900 | 2,400 | 10,400 |
| Length | | | 4.0 | | | | | | | |
| Width | | | 12.0 | | | | | | | |
| Section height | | | 1.5 | | | | | | | |
| Existing design 3 (Unit Rig) | 1,500 | 2,300 | | Minimal | Minimal | Minimal | Minimal | 7,700 | 500 | 1,900 |
| Length | | | 4.0 | | | | | | | |
| Width | | | 10.0 | | | | | | | |
| Section height | | | 2.0 | | | | | | | |

# SECTION 3.0

# CONCLUSIONS AND RECOMMENDATIONS

## 3.1 CONCLUSIONS

The extended bumper designs developed by WAI should provide operator protection for rear-end collisions of at least 3 to 5 mph when installed on the 170-ton rear-end dump trucks. The use of such bumpers should also reduce the extent of truck damage. Although the detailed designs are applicable to the 170-ton trucks, only minor modifications would be necessary for application on other sizes and models of haulage trucks. The major differences would be the spacing of the two main structural members in order to match the various frame widths. The bumper's length, width, and height above ground would not vary substantially.

The extended bumper design concept assumes that the bumper impacts the rear tires of another truck. However, a problem exists with the Terex trucks because suspension struts and components are located rearward of the rear wheels. In this case there may be damage to the bumper or truck. However, for all other trucks considered, there should be minimal damage to the extended bumper or truck. In any case, there should be no damage to the main frame of the trucks.

The additional bumper weight on the front of the trucks is not anticipated to cause fatigue damage to the main frame. Experience with extended bumpers to date has shown no frame problems because of the added weight. Also the trucks which have been operating since 1976 with extended bumpers have experienced no unusual tire wear.

The extended bumper concept could be readily adapted by truck manufacturers by simply extending the truck frame forward. The forward section would serve as the extended bumper and could be designed to minimize the main frame damage.

The major advantages of the extended bumper designs include the following:

- Provides protection for existing ladder systems.
- Allows for improved ladder arrangements.
- Provides a location for:
  - Batteries and an emergency shutoff switch near the ladder.
  - First-aid kit.
  - Central lubrication unit.
  - Headlights and side marker lights.
- Provides a work platform for the front area of the truck.

The extended bumper is designed to protect the operator and withstand a 5 mph rear-end collision between two loaded haulers with little or no damage to the bumper or trucks. The factors and assumptions used in determining the forces acting on the bumper in a rear-end collision were conservative in that they represented the worst case condition. Higher speed collisions can be withstood if some of the factors and assumptions are changed to represent a less critical but realistic condition. For example, a less critical condition would be as follows:

- Empty truck weight = 210,000 pounds each.
- Rotational inertia = 15 percent.
- Brakes are not applied on the parked truck.
- Road adhesion coefficient = 0.6.

For this situation it is quite likely that the bumper would survive a rear-end collision of 10 mph protecting the operator with no major damage to either the bumper or the truck frame.

For a given set of conditions the bumper will provide protection to the operator at speeds between 5 and 10 mph depending on the exact conditions that exist. However, for any given set of conditions if the speed is increased above 10 mph, the bumper will probably fail due to the increase in the amount of energy which must be absorbed for the higher speed. The exact condition of failure is difficult to predict. Since a design criterion was to minimize damage to the bumper, energy absorbed during plastic deformation of the bumper was not considered. This may absorb a substantial amount of the impact energy, providing some operator protection for higher speed collisions.

While there are several factors which affect the energy which must be absorbed by the bumper in a collision, the two most important are the weight and the velocity of the truck. Of these two a change in velocity has a much greater affect on the energy level when compared to a change in weight. For a given set of conditions if the speed is doubled, the energy to be dissipated is four times as great.

Due to the large increase in energy as truck speed is increased, the best means of making a bumper system capable of surviving a collision at speeds over 10 mph and protecting the operator would be to develop a system which could absorb the increased level of energy. With the extended bumper systems designed for the 170-ton trucks, catastrophic failure of the bumper is expected between 10 and 20 mph.

The extended bumpers that were designed exceed the strength criteria established as part of this program. The existing design 1 for a WABCO truck does not meet the criteria; however, it did survive a rear-end collision with virtually no damage. An eyewitness to the accident estimated the impact velocity at about 5 to 10 mph. This would indicate a conservative factor in the criteria. Detailed analysis of the accident indicates that the conservative factor may be the assumption of a relatively large vertical force component.

The bumper design and its mounting should be tested in order to validate the design of the improved bumper. The mounting of the bumper to the truck frame can be subjected to a nondestructive test by putting a vertical load of approximately 40,000 pounds on the front of the bumper. The vertical load is the best means of evaluating the mounting arrangement because it subjects the mounts to a bending moment, which is the primary failure mode of the mounting connection. This could be easily done at the mine with the bumper mounted on the truck using two 10-ton hydraulic rams and a pump with a pressure gauge.

The basic load capacity of the extended bumper could be verified by conducting static tests on a bumper in a static test fixture. The bumper would be mounted to a solid fixture and subjected to the nondestructive design loads. This would be very similar to the static tests conducted to certify rollover protective structures. However, the tests on the bumper would be nondestructive. It would be nearly impossible to conduct a front loading of the bumper while mounted on the truck at a mine because of the large loads required. Even attempting to obtain the loads by using other machines, such as a larger dozer, would not be possible.

Verification of the actual loads for an extended bumper during an impact would require dynamic testing of the extended bumper. This would require either two expendable haulage trucks or two test units which would duplicate the important characteristics of the trucks. The important characteristics or variables which would have to be duplicated include the following:

- Weight both loaded and empty.
- Brakes both applied and off.
- Tires, number, size, pressure, and deflection limits.

It would also be possible to conduct such instrumented testing using only one truck equipped with an extended bumper and simulation of the rear-end and tires of another truck.

An alternative means of determining impacts load would be to conduct impact tests on smaller trucks and scale the results to larger trucks. This may be a more cost-effective and practical first step in obtaining impact loads. Under no circumstances should an operator be placed in the trucks during testing.

The existing designs 2 and 3 for WABCO and Unit Rig trucks, respectively, have capabilities substantially below the desired criteria.

## 3.2 RECOMMENDATIONS

Based on the design and analysis of extended bumpers for haulage trucks, the following additional recommendations are made:

- Conduct static tests on the bumper in order to validate that the strength of the extended bumper meets the designed loads.
- Conduct nondestructive vertical static tests at a mine site with the bumper installed on a truck to ensure proper mounting design and procedures.
- Conduct a series of instrumented impact tests on 170-ton or smaller size trucks to confirm that the design criteria are adequate.
- Conduct a long-term, in-mine evaluation of the bumper designs. The preferred selection of the model truck would include the WABCO or Unit Rig in which a new staircase system could be installed on the bumper.
- Investigate the design of a shock-absorbing bumper system, which would provide additional protection for the operator. The shock-absorbing bumper system is especially needed to provide protection when impacting the rear-end of a Terex truck.
- Notify the mines using extended bumpers on their haulage trucks of the results of the study:
    - The No. 1 design for WABCO trucks may not provide protection in a side impact.
    - The No. 2 design for a WABCO truck and the design for a Unit Rig truck may provide inadequte protection in a 5 mph impact.

## SECTION 4.0

## ACCIDENT ANALYSIS OF HAULAGE TRUCKS

The accident data and information acquired for analysis were obtained from two primary sources:

- Mine Safety and Health Administration — Health and Safety Analysis Center (MSHA-HSAC).
- Mining safety directors at several surface copper mines in the west.

The MSHA-HSAC data consisted of computer printouts containing categorized accident characteristics involving off-highway haulage trucks. These are records of accidents as reported on Form 7000-1 by the coal and metal/nonmetal surface operations to MSHA-HSAC. The year reviewed was 1978. The requirements for reporting accidents occurring in mining operations are contained in 30 CFR 50.

The accident information obtained from the safety directors was by telephone conversations and direct contact through mine visits by WAI personnel during this program and previous USBM programs. This resulted in obtaining photographs of accidents involving haul truck collisions as well as their accounts of accidents which occurred outside the time frame (1978) for which the MSHA-HSAC data were reviewed.

Examples of this accident information are contained in Figures 4-1 through 4-4. Figures 4-1, 4-2, and 4-3 are photographs of rear-end collisions occurring in western surface copper mines during 1974 and 1975. These three accidents occurred as the result of the haulage truck in front backing up at relatively slow speed (1-3 mph). The injuries to the operators were minor in the first two (Figures 4-1 and 4-2) and more serious in the third (Figure 4-3). However, the cost to repair the haulage trucks for all three accidents was considerable. These three accidents, in addition to a number of similar ones, were a strong motivation for the installation of extended bumpers at one western surface copper mine.

FIGURE 4-1. Haulage Truck Backing Into Parked Haulage Truck

FIGURE 4-2. Rear-End Collision Showing Dump Body and Cab Contact

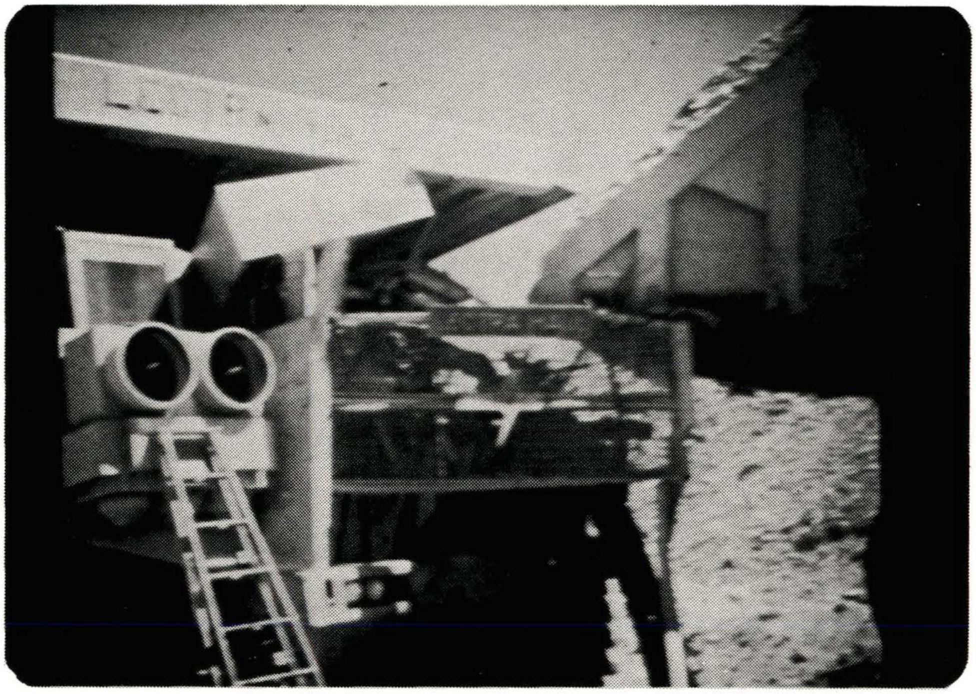


FIGURE 4-3. Haulage Truck in Front Backing Into Haulage Truck at an Angle

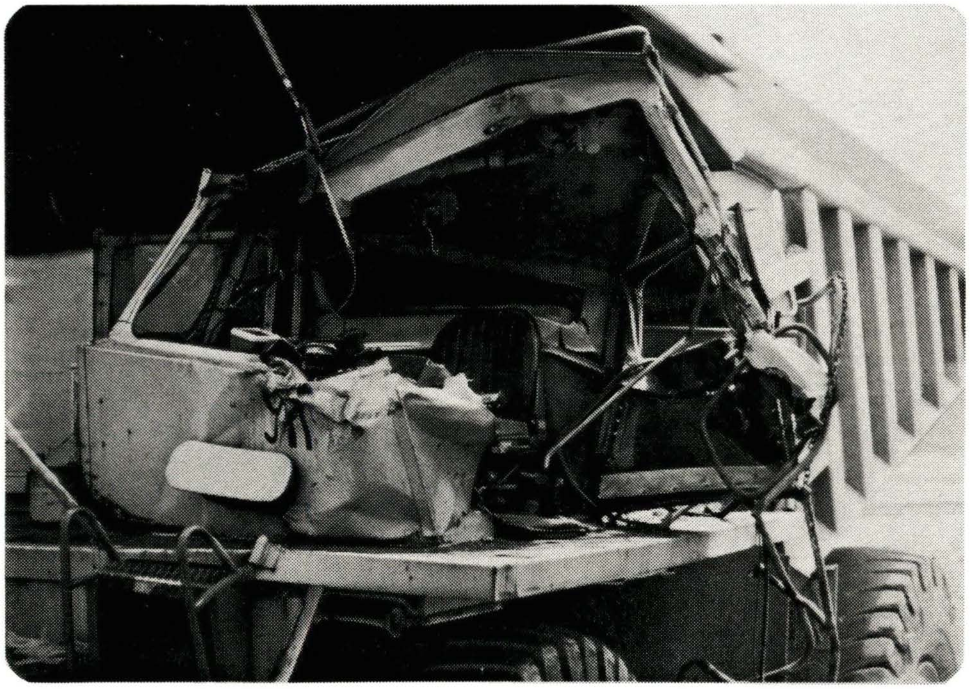


FIGURE 4-4. Results of Rear-End Collision — View of Cab Damage

Figure 4-4 is a photograph of the results of a rear-end collision accident occurring at a western surface copper mine in late 1980. The haulage truck shown in this photograph was traveling approximately 10-15 mph and collided with the rear bed of another 170-ton capacity truck. The operator of this truck suffered extensive injuries to his legs and upper body. This accident has prompted the installation of extended bumpers on the haulage trucks operated at the mine where this accident occurred.

## 4.1 HAULAGE TRUCK ACCIDENT ANALYSIS

The objective of the accident analysis was to identify and assess typical rear-end collisions involving rear dump off-highway haulage trucks. It was anticipated that a quantitative assessment in terms of speed, angle, load, and other physical circumstances of the accidents could be made. Due to the limitations of the data in terms of the kind, amount, and consistency of necessary detail supplied with each accident report prevented a quantitative assessment. The data did make possible a general assessment of rear-end collision accidents, however.

The results of a previous accident analysis conducted by WAI under USBM Contract No. J0295013, "Novel Cab Design Concepts to Improve Large Haulage Vehicle Safety," in which 390 MSHA-HSAC reported accidents were identified as involving off-highway haulage trucks in surface mining during 1978, were used as the primary data for purposes of this analysis.

Table 4-1 shows the categorization of these accidents and provides a comparison for the way people were reported as being injured while working with and around haulage trucks.

In terms of total numbers, rear-end collisions are not a large contributor in the way mine personnel are getting injured with haul trucks. However, when they do occur the potential for severe injury is very high. The cost for equipment damage repair is also high in relation to the two highest injury-producing accident categories: (1) Struck, Jarred, Sprain, Strain and (2) Slip and/or Fall.

TABLE 4-1. Off-Highway Haulage Truck Related Accidents in Surface Mining (1978)

| Accident/Event Categories | No. of Injuries Resulting | No. of Fatalities Resulting | Total Accidents |
|---|---|---|---|
| Struck, jarred, sprain, strain | 121 | 0 | 121 |
| Slip and/or fall | 112 | 0 | 112 |
| Rollover | 65 | 5 | 70 |
| Collision | 53 | 6 | 58* |
| Rear-end involving rear-dump haulers | 10 | 1 | 11 |
| Jumped or thrown from hauler | 28 | 1 | 29 |
| Total | 379 | 12 | 390 |

*Two fatalities resulted from one accident in this category.

For the 11 rear-end collisions identified in this analysis, 10 of them were the result of one haul truck backing into another. The one fatality was the result of the operator losing control of his loaded hauler because of faulty brakes, and colliding with another loaded hauler stopped at the bottom of a 300-foot, 8-percent dumping ramp.

As previously mentioned, a quantitative analysis in terms of pertinent physical parameters was not possible. It was possible, however, to formulate some general conclusions about rear-end collisions from the data. These are listed as follows:

a. Rear-end collisions are relatively infrequent occurrences.

b. The resulting injury to operator and damage to equipment is usually high.

c. One haul truck backing into another is the most frequent and least severe rear-end collision circumstance.

d. The potential for the occurrence of rear-end collisions is highest at the loading and dumping areas.

e. Backing and losing control of the haul truck for a variety of reasons (mechanical failure and inappropriate operator action being two) are the two most frequent events resulting in a rear-end collision.

## 4.2 HAULAGE TRUCK ACCIDENTS WITH EXTENDED BUMPERS

There is only one mine which has had extended bumpers on their haul trucks for a period long enough to properly assess them in terms of accidents. Their entire fleet, currently 22 haul trucks — (15) 150-ton and (7) 170-ton rear dumps — are all equipped with extended bumpers. The first was installed in April 1976.

Conversations with mine management provided the following scenarios concerning their experiences with haul truck related accidents since the installation of extended bumpers:

> A truck was stopped at the bottom of a slope at the shovel and the operator had the brakes applied. A second truck was traveling down the 8-percent slope at about 5 to 10 mph and collided with the rear of the stationary truck. An eyewitness reported that the extended bumper of the moving truck rammed the rear duals of the stationary truck. The stationary truck moved forward only slightly when struck and the moving truck raised slightly in front upon impact and then bounced rearward. There were no injuries and no damage to either truck with the exception of a bent handrail in front of the cab on the rear truck.

This was the only instance of a rear-end collision occurring since the installation of the extended bumpers.

Another type of accident which is a relatively frequent occurrence at this particular mine and at surface mines in general can be described as follows:

> A truck driver working the third shift will fall asleep while driving the truck. The truck hits the road berm (about 15-feet high) and the bumper impacts and "grades" the berms. The machine's speed in some cases is as much as 15 mph. In all cases little or no damage occurs to the extended bumper or machine. Only rarely will the operator sustain injury.

In addition to rear-end collisions, this type of occurrence indicates another area of injury reduction potential for an extended bumper. There are numerous accident reports where an operator will lose control of his haul truck, impact a berm and roll the truck, often sustaining major injury to himself and major damage to the truck. In rare cases, the truck will go through the berm and down a highwall resulting in death to the operator and total loss of the truck.

With the extended bumper, however, there is a slowing of the truck speed when the bumper impacts and "grades" the berm, and a reduction in berm height before the truck tire contacts and rolls up the berm.

This assessment is somewhat speculative and depends on a number of factors such as truck speed and angle of impacts. However, the accident results from one mine with extended bumpers appear to support the assessment.

# SECTION 5.0

# EXISTING EXTENDED BUMPER DESIGNS

Extended bumpers are presently in use in two different copper mines in Arizona. These bumpers have been installed on WABCO and Unit Rig 150- to 170-ton rear dump haulers. The bumpers have been successfully used at one of the mines since April 1976. This mine currently has the bumpers installed on 22 WABCO trucks — (15) 150-ton and (7) 170-ton trucks.

The second mine to use extended bumpers began installing them in July 1980, after having several rear-end truck collisions. At present they have installed the extended bumpers on 12 haulers. The bumpers have been installed on Unit Rig Mark 36 and WABCO 150- to 170-ton trucks.

To date there has been no observed damage to the truck frames as a result of the addition of an extended bumper.

## 5.1 EXTENDED BUMPER DESIGN 1 FOR WABCO 150- TO 170-TON TRUCKS

This extended bumper design which has been in use since April 1976 is a 4-foot extension and is the same width and height as the original bumper. The bumper, shown in Figures 5-1 and 5-2, is approximately 10 feet wide and 5-1/2 feet high. This bumper design has successfully withstood impacts between two trucks at speeds between 5 and 10 mph with no damage to the bumper and only minor damage to either of the haulers. The headlights are mounted in the front of the extended bumper as shown in the figures. The batteries are also mounted on the bumper along with an emergency cutoff switch. Also, near the ladder is a fire extinguisher and a manual control for the fire suppression system.

This extended bumper which is fabricated from 18 x 6 x 3/8-inch thick tubing and 1/4-inch plate with a 10 x 6 x 3/8-inch thick front beam was constructed at the mine. The bumper which has a removable center section for engine removal requires approximately two days for fabrication and one day for installation. The unit which is estimated to cost $2,000 adds approximately 1,600 pounds to the weight of the truck but there have been

FIGURE 5-1. Front View of Design 1 for a WABCO Truck

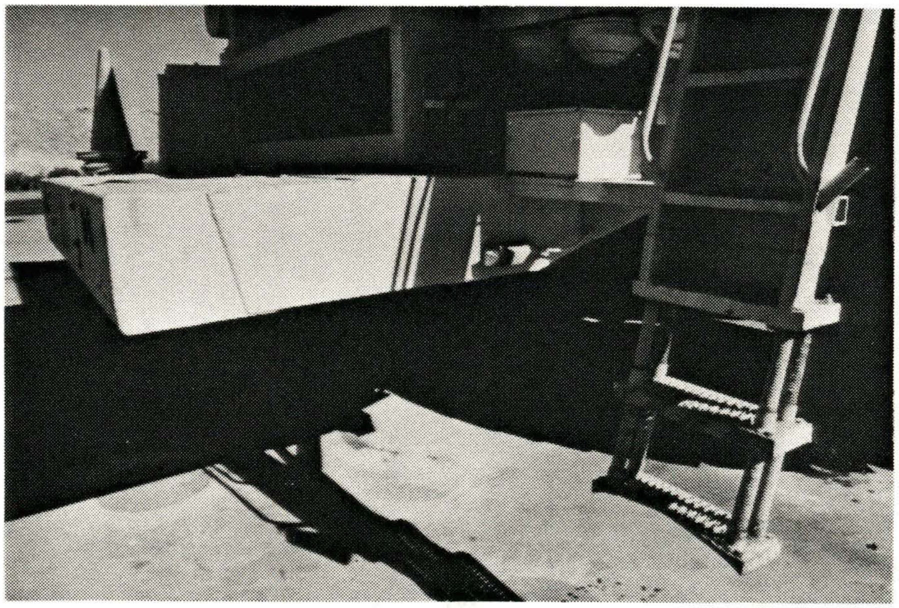


FIGURE 5-2. Side View of Design 1 for a WABCO Truck

no frame problems with any of the trucks due to this weight. The drawings for this bumper are shown in Figure 5-3.

## 5.2 EXTENDED BUMPER DESIGN 2 FOR WABCO 150- TO 170-TON TRUCKS

This extended bumper design which is shown in Figure 5-4 has been in use since July 1980. It is a 4-foot extension with a width of 12 feet at the front of the extension. The extended bumper is the same height as the original bumper. Like the first design for WABCO trucks, the center section of the bumper is bolted on for removal of the power module which rolls out through the opening. This bumper also contains two hinged doors for access to the tow hooks which are left on the bottom of the original bumper. As shown in Figure 5-5, a fire extinguisher along with a fire suppression system switch and an emergency kill switch are mounted on the bumper. This bumper is fabricated at a local shop using 12-inch I-beam and 1/4-inch plate with 10 x 6 x 3/8-inch wall tubing front beam welded to the bottom of the I-beam. The bumper which adds approximately 1,400 pounds to the weight of the truck is attached to the truck by welding it to the original bumper. Figure 5-6 shows the prints of the bumper. The cost of this bumper is estimated to be approximately $2,100 and it requires two days for installation.

## 5.3 EXTENDED BUMPER DESIGN FOR UNIT RIG MARK 36 TRUCKS

The extended bumper used on the Unit Rig Mark 36 170-ton truck is a 10-foot wide, 4-foot extended bumper. The top of the extended bumper is at the same height as the top of the original bumper which makes it approximately 6-feet high. The design of the Unit Rig Mark 36 hauler is such that no removable sections are required in the bumper for hauler maintenance. Figure 5-7 shows a truck with this extended bumper mounted on it. The truck headlights are mounted in the front of the extended bumper along with clearance lights on the sides of the bumper. As can be seen in Figure 5-8, a fire extinguisher along with a fire suppression system switch and an emergency kill switch are also mounted on the bumper near the ladder. This bumper is fabricated at a local shop from 8-inch wide flange I-beam and

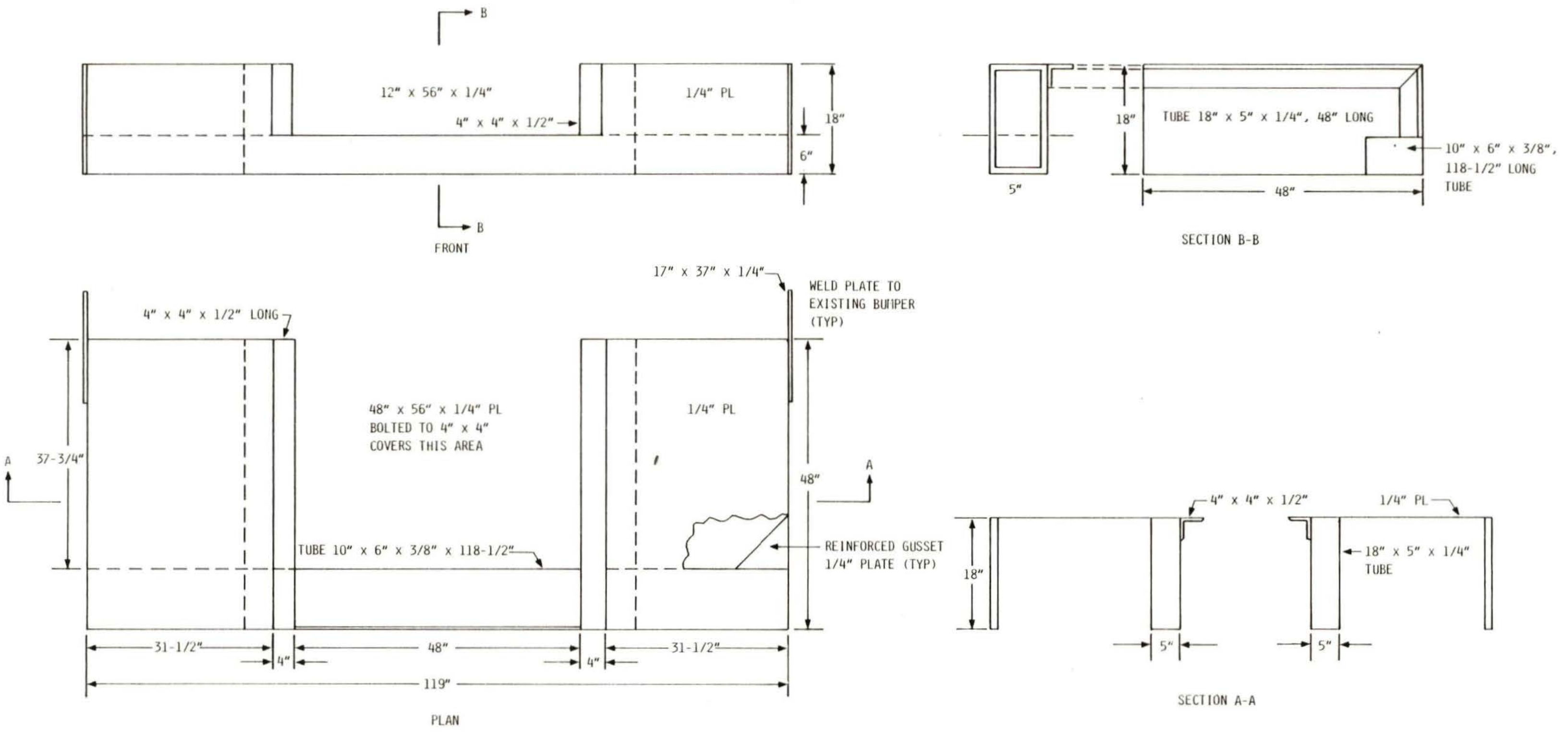


FIGURE 5-3. Existing Design 1 for a WABCO Truck

FIGURE 5-4. Front View of Design 2 for a WABCO Truck

FIGURE 5-5. Side View of Design 2 for a WABCO Truck

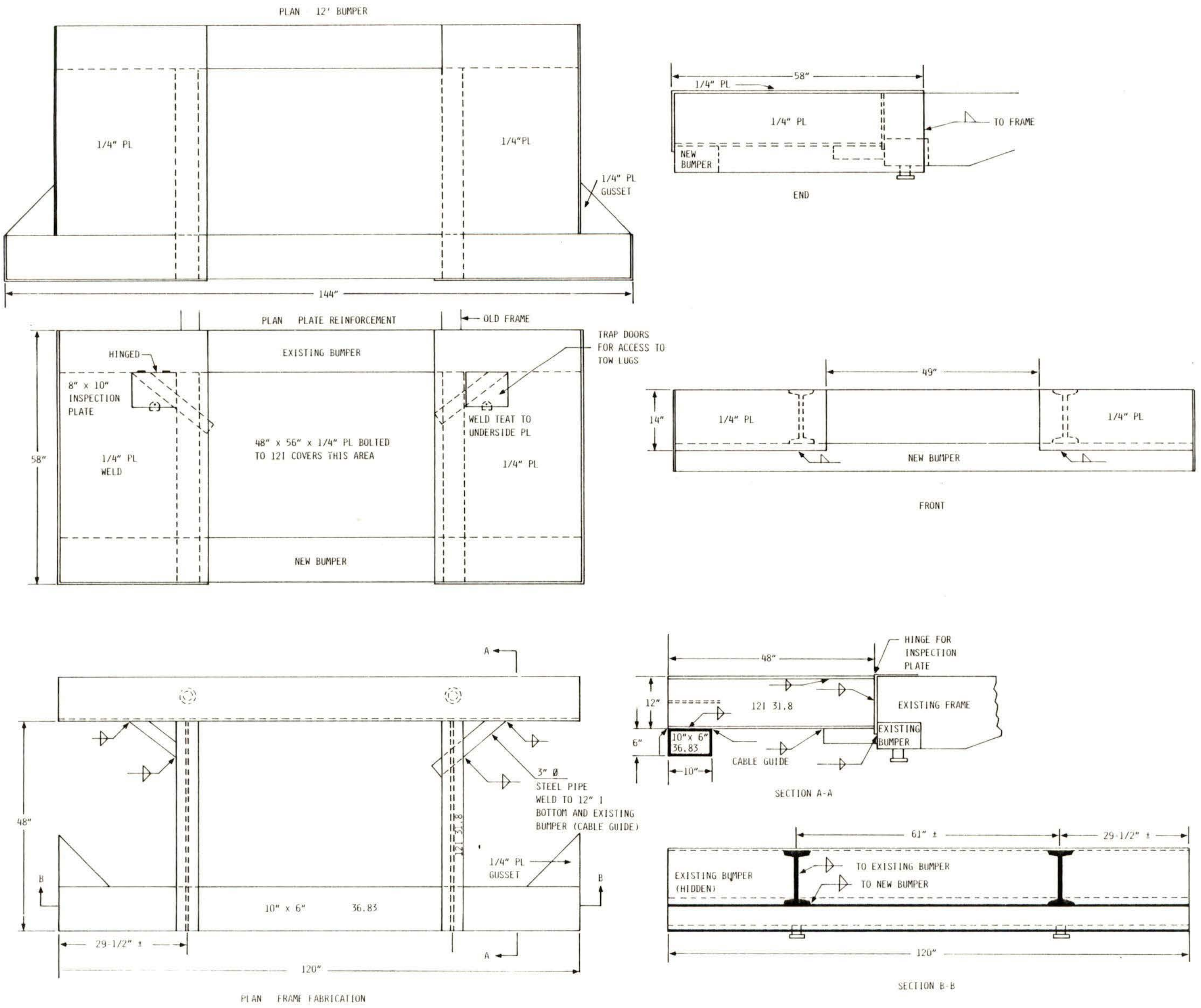


FIGURE 5-6. Existing Design 2 for a WABCO Truck

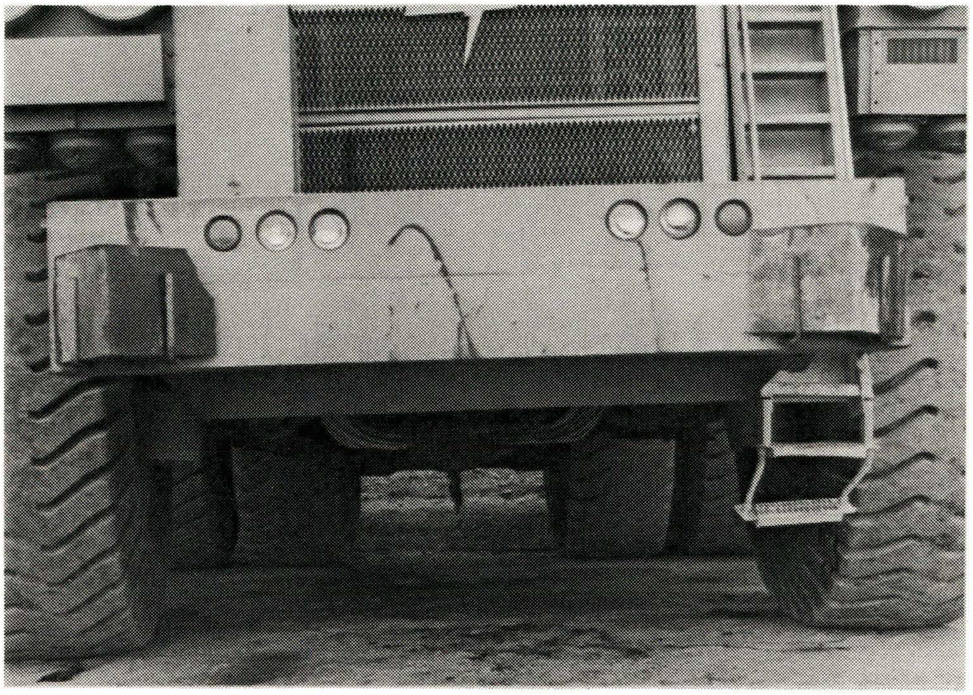


FIGURE 5-7. Front View of an Extended Bumper on a Unit Rig Truck

FIGURE 5-8. Side View of an Extended Bumper on a Unit Rig Truck

1/4-inch plate with a 10 x 6 x 1/2-inch wall tubing front beam below the bottom of the I-beam. This bumper which weighs approximately 1,500 pounds is attached to the truck by welding it to the original bumper. Figure 5-9 shows the drawing for the bumper. This bumper is fabricated at a local shop with an approximate cost estimated at $2,400 and requires two and one-half days for installation.

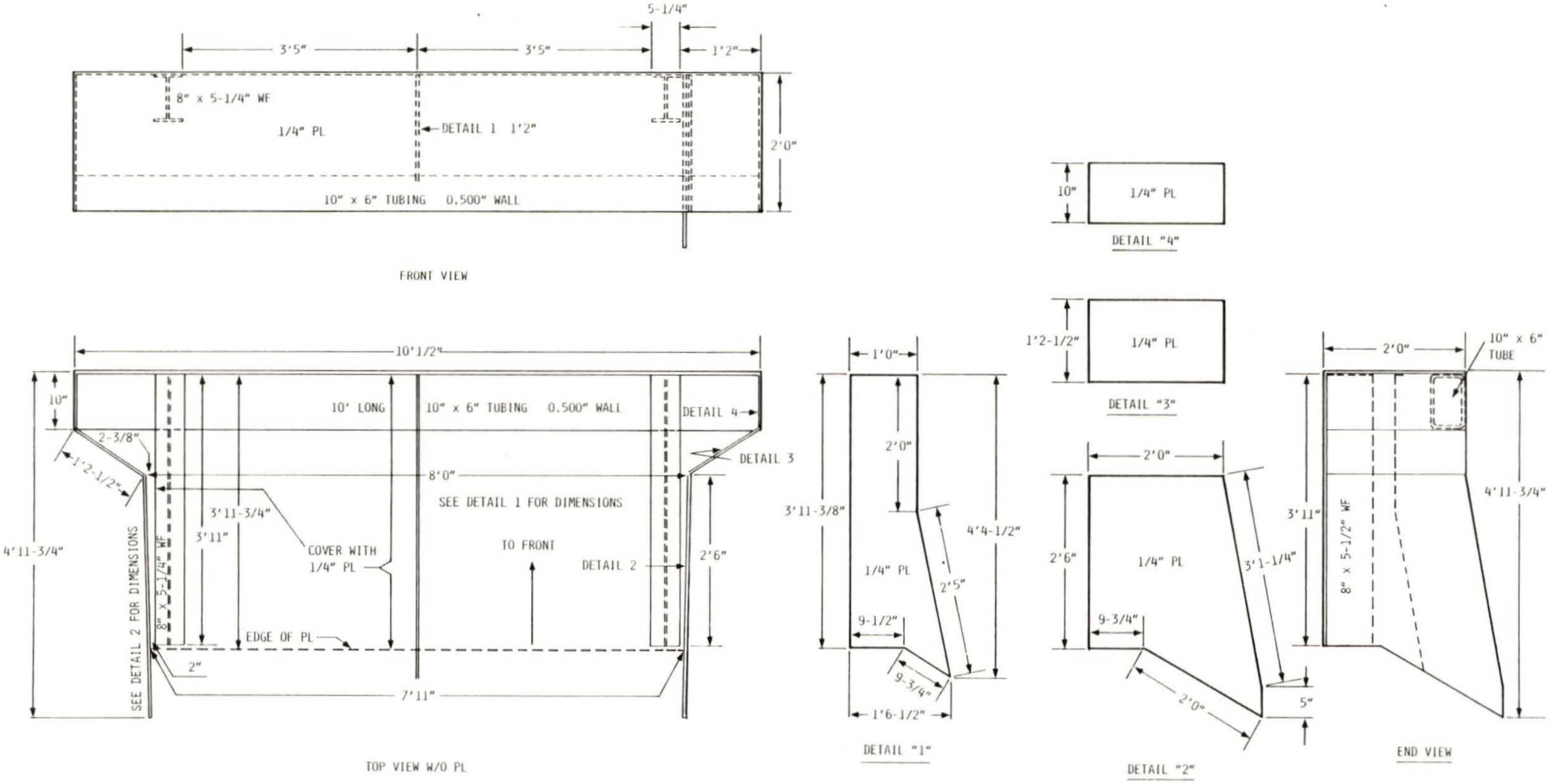


FIGURE 5-9. Existing Extended Bumper for a Unit Rig Truck

# SECTION 6.0

# DESIGN OF A UNIVERSAL EXTENDED BUMPER

## 6.1 LARGE REAR DUMP HAULAGE TRUCK DESIGN CHARACTERISTICS

A review was conducted of the design characteristics of large (100 ton and over) rear dump haulage trucks which affect the design and placement of an extended bumper.

During this study it was determined that there were 11 design dimensions critical to the design of an extended bumper. These critical dimensions are shown in Figure 6-1 and are defined as follows:

$h_b$ = height of rear edge of dump body

$h_p$ = height of operator's platform

$h_c$ = height to the top of cab

$x$ = distance from end of bumper to cab

$y$ = distance from rim to the end of the dump body

$y'$ = distance from tire to the end of the dump body

$y_s$ = distance from rear suspension to the end of dump body

$r$ = radius of loaded tire

$z$ = height to the top of bumper

$z'$ = height to the bottom of bumper

$d$ = distance between the rear wheels

The data for these critical dimensions for 15 different models of trucks produced by six different manufacturers of large haulage trucks are presented in Table 6-1.

This table shows that the characteristics which determine the length and width required for an extended bumper vary just as much between different manufacturers of the same size truck as they do between different sizes of

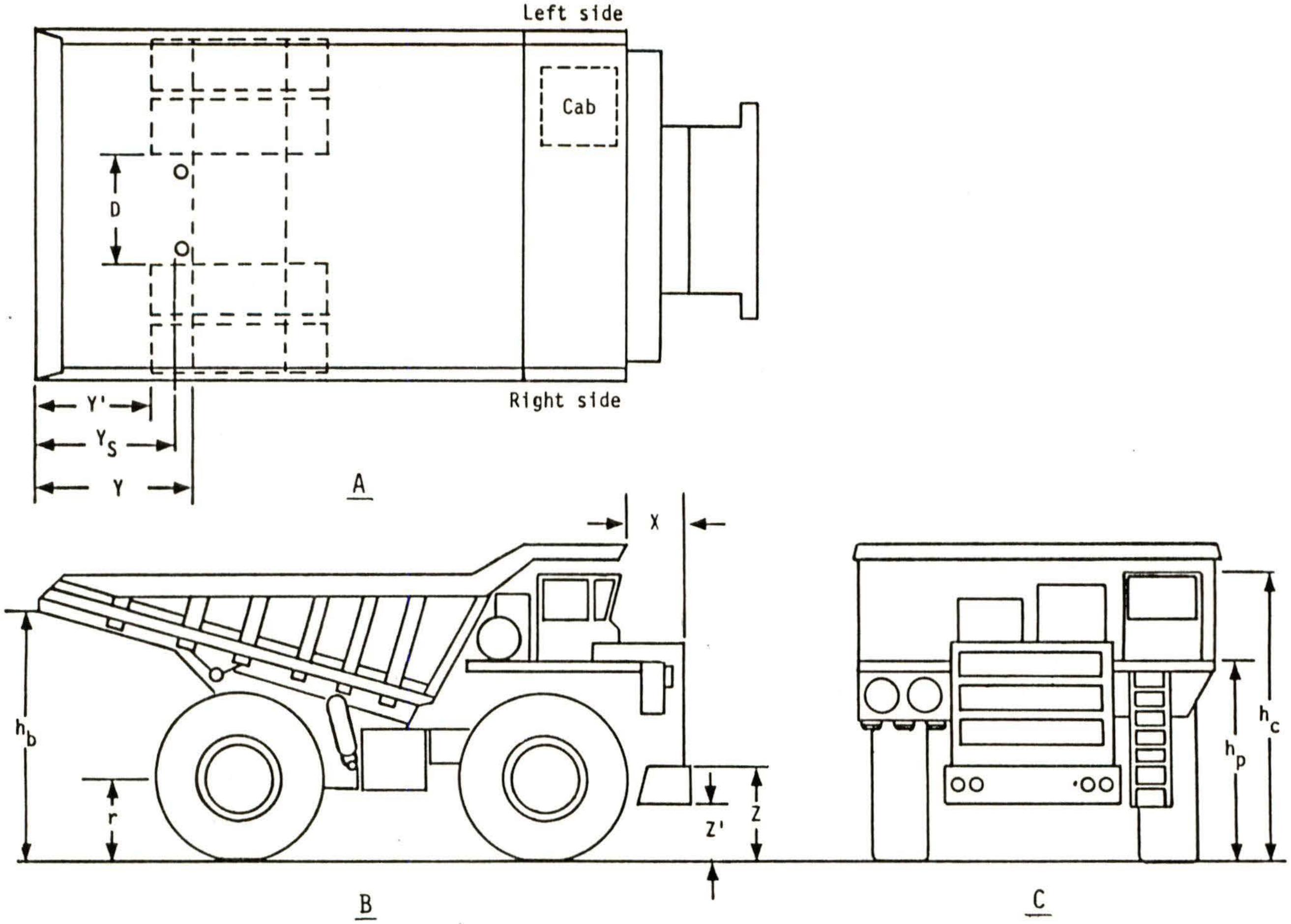


FIGURE 6-1. Critical Truck Dimensions

TABLE 6-1. Large Haulage Truck Extended Bumper Data

| Manufacturer | Model | $h_b$ (ft) | $h_p$ (ft) | $h_c$ (ft) | x (ft) | y (ft) | y' (ft) | r (ft) | z (ft) | z' (ft) | d (ft) | $y_s$ (ft) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dart | 3100 | 11.2 | 10.9 | 15.9 | 4.7 | 8.2 | 6.0 | 4.4 | 6.1 | 3.5 | 7.0 | |
| | 3120 | 12.1 | 11.8 | 16.2 | 5.2 | 8.8 | 6.6 | 4.4 | 6.6 | 3.8 | 7.5 | |
| Euclid | R-100 | 10.9 | 10.0 | 15.3 | 4.0 | 7.0 | 4.6 | 4.0 | 5.2 | 3.5 | 6.6 | |
| | R-120 | 12.8 | 10.8 | 16.3 | 4.5 | 8.2 | 6.0 | 4.4 | 4.3 | 3.2 | 6.3 | |
| | R-170 | 13.3 | 11.5 | 17.0 | 4.9 | 8.3 | 5.9 | 4.8 | 5.1 | 3.8 | 6.5 | 7.4 |
| General Motors of Canada (formerly Terex) | 33-15B | 13.0 | 10.8 | 16.4 | 5.0 | 9.3 | 6.9 | 4.8 | 4.3 | 3.0 | 5.7 | 6.4 |
| | 33-19H | 13.7 | 14.2 | 19.6 | 7.9 | 11.3 | 8.3 | 5.4 | 4.4 | 2.7 | 8.6 | |
| Rimpull | RD-120H | 11.6 | 10.5 | 15.6 | 4.1 | 6.9 | 4.7 | 4.4 | 6.0 | 3.8 | 6.9 | |
| Unit Rig | M-100 | 11.3 | 9.4 | 14.3 | 5.6 | 7.2 | 4.8 | 4.2 | 5.4 | 2.7 | 6.3 | |
| | M-120 -17 | 12.6 | 10.3 | 15.3 | 5.5 | 7.0 | 4.6 | 4.4 | 5.9 | 3.1 | 6.3 | |
| | M-36 | 14.5 | 11.6 | 16.5 | 5.8 | 8.5 | 6.0 | 4.8 | 6.0 | 3.6 | 6.4 | 7.5 |
| | M-200 | 16.9 | 14.4 | 20.0 | 5.5 | 9.1 | 6.1 | 5.4 | 6.7 | 3.8 | 8.6 | |
| WABCO | 120CM | 12.7 | 10.5 | 15.0 | 4.3 | 7.9 | 5.7 | 4.4 | 4.4 | 3.1 | 7.5 | |
| | 120C | 12.7 | 10.5 | 15.0 | 4.3 | 7.9 | 5.7 | 4.4 | 4.4 | 3.1 | 8.25 | |
| | 170C | 13.5 | 11.2 | 16.0 | 4.0 | 8.3 | 5.9 | 4.8 | 5.5 | 3.8 | 7.3 | 7.4 |
| | 3200B | 13.3 | 12.3 | 17.4 | 7.0 | 7.9 | 5.5 | 4.8 | 4.5 | 3.8 | 9.7 | |

trucks. Therefore the dimensions of a bumper designed for 170-ton haulers may be used for a bumper on any of the other size haulers with the exception of the General Motors 33-15B. Using the maximum distance from the end of the dump body to the rear suspension on any of the 170-ton trucks and the minimum distance from the bumper to the cab yields a minimum required bumper length of 3-1/2 feet. However, the actual length of the bumper must be longer in order to provide protection for the operator when the trucks are at an angle to each other. The number of tires the bumper will hit in a collision is dependent upon the width between the tires, the width of the bumper, and the alignment of the haulers. In the event of a straight-on rear-end collision between two haulers the bumper should contact the major portion of at least two tires regardless of the alignment of the haulers. This is important in that the tires must absorb the major portion of the energy of the collision. In order to achieve this the bumper must be as wide as the outside of the inside set of rear tires. For 170-ton trucks this dimension is approximately 13 feet.

## 6.2 DESIGN CRITERIA

As noted in Section 4.0, there are two primary causes of rear-end collisions between haulage trucks. These are loss of control and poor visibility or not seeing the other truck and therefore backing into it. These two types of rear-end collisions have different characteristics with regards to the type of protection required to prevent penetration of the dump body into the cab.

The "loss of control" accidents typically are the result of mechanical failure in either the retarding or braking system. Therefore, the collisions may involve a substantial speed differential between the two trucks. This type of collision usually results in large amounts of tire deflection; the bumper must extend far enough forward to prevent the dump body from entering the cab with the maximum amount of tire deflection.

The "poor visibility" accidents are typically low-speed accidents (under 3 mph) that occur while the haulers are maneuvering in congested areas such as near the shovel or dump site. These collisions create another bumper design problem in that quite often the two trucks are at an angle to each other. It would be very impractical to have a bumper that would eliminate all the hazards from this type of collision because the bumper would have to be wider than the truck. This type of collision also produces significant side loads which the bumper must be able to withstand.

It must be noted that the amount of protection provided by any given bumper is dependent on the angle between the trucks and the way in which the rear tires hit the bumper. As illustrated in Figure 6-2, a collision where the left rear wheels just miss the bumper can allow the dump body to hit the cab. However, if the bumper hits the tire, it would miss the cab (Figure 6-3).

### 6.2.1 Large Haulage Truck Collision Dynamics

The maximum strength of any extended bumper is limited by the strength of the frame. However, the bumper must be sufficiently strong to survive a collision between two haulers at a given speed. While the analysis of the forces generated in a collision between two trucks is extremely complex, certain assumptions can be made in order to determine the maximum forces an extended bumper must support. These assumptions include the following:

- The truck frame is completely rigid (i.e., the bumper will fail before the frame is bent).
- The bumper will only make contact on the rear tires of the other truck (true for most cases except for the Terex 33-15B).
- All of the energy is either absorbed by the tires or dissipated by moving the other truck.
- The rotating inertia due to the mass of the rotating components of a moving truck is 15 percent of its kinetic energy.

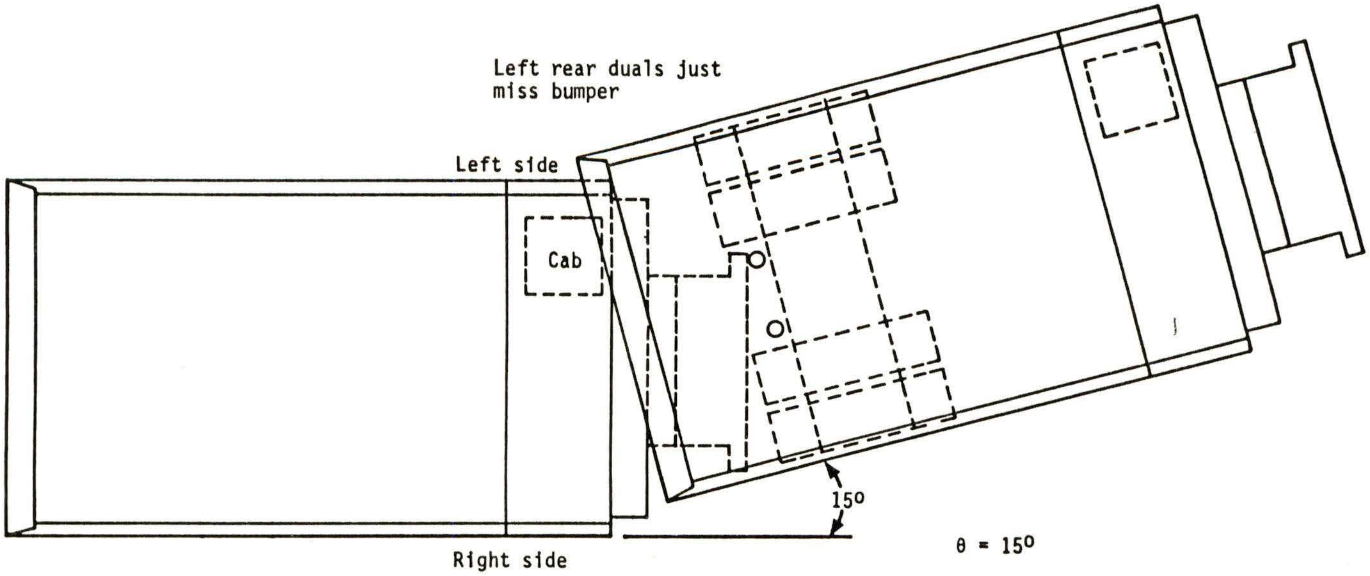


FIGURE 6-2. Rear-End Impact at a 15° Angle — Extended Bumper Misses Tire

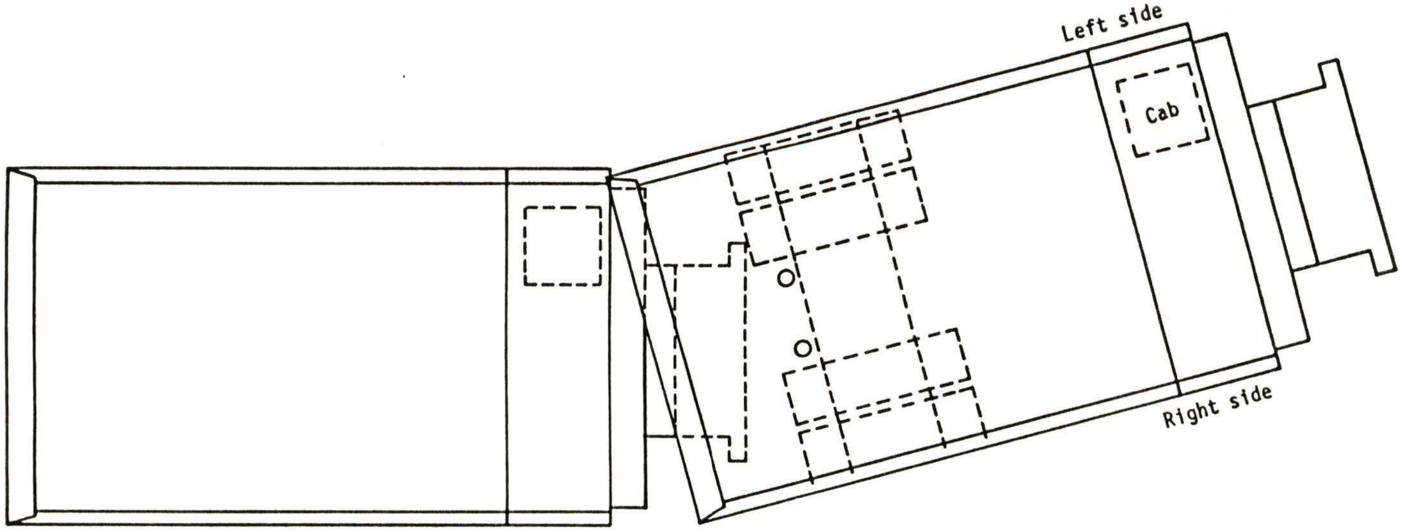


FIGURE 6-3. Rear-End Impact at a 15° Angle — Extended Bumper Hits Tire

In addition to these assumptions there are several critical factors which must be determined in order to analyze the bumper loads including the following:

$K$ = deflection rate of tire

$\mu_s$ = the road adhesion coefficient between the hauler tires and the ground

$X_{max}$ = the maximum deflection of the tires before a solid part of the hauler is impacted

$N$ = number of tires impacted

$\theta$ = angle of impact between the trucks

Virtually all 170-ton trucks are equipped with 36 X 51 type E-3 or E-4 tires. The load deflection rate for a given tire is dependent on the manufacturer, type of construction, and the air pressure. However, since these tires must be able to support the same load without overheating, the load deflection rates of the various tires are fairly similar. But as shown in Figure 6-4, which is the load-deflection curve for a typical 36 X 51 tire, this rate is a linear function and highly dependent on the tire air pressure. The effect on the bumper design is to increase the forces as air pressure is increased and the tire becomes harder. However, if the pressure is low enough to cause the bumper to strike the rear suspension of the truck, the forces on the bumper may be higher than for a hard tire where no solid parts of the truck are hit.

The road adhesion coefficient is a measure of the ability of the tires to grab or adhere to the road surface. As the coefficient is increased the force required to make a stationary truck slide increases. As shown in Table 6-2, the road adhesion coefficient is dependent upon the type and condition of the road surface.

With the exception of the Terex 33-15B, the rear tires extend beyond the frame and rear suspension members. The distance from the back edge of the tire to the rear suspension struts is approximately 18 inches on all of the other 170-ton trucks. On the Terex hauler both the suspension struts and the rear-end housing extend beyond the rear edge of the tires.

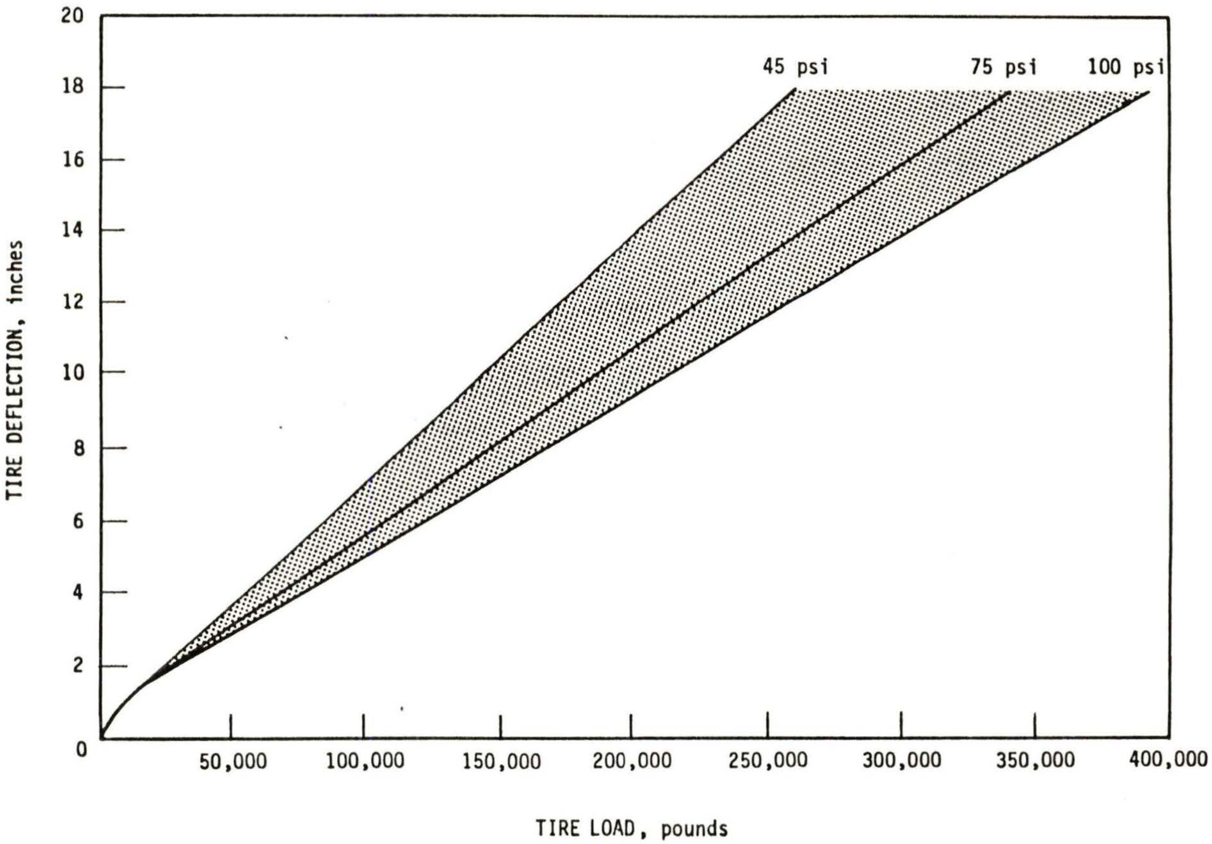


FIGURE 6-4. Typical Load-Deflection Curve for Tires Used on 170-Ton Haul Trucks

TABLE 6-2. Road Adhesion Coefficients

| Road Surface | Road Adhesion Coefficient |
|---|---|
| Gravel | |
| Packed and oiled | 0.55 to 0.85 |
| Loose | 0.40 to 0.70 |
| Wet | 0.40 to 0.80 |
| Rock | |
| Crushed | 0.55 to 0.75 |
| Wet | 0.55 to 0.75 |
| Earth | |
| Firm | 0.55 to 0.70 |
| Loose | 0.40 to 0.60 |
| Wet | 0.40 to 0.55 |
| Clay loam | |
| Dry | 0.50 to 0.80 |
| Rutted | 0.15 to 0.50 |
| Wet | 0.15 to 0.45 |

In certain cases where the haulers are misaligned it is possible to deflect the tires to the rim which is approximately 30 inches.

The angle of impact is important in that as the angle increases the side loads increase and the amount of protection to the operator may decrease. This angle is mostly a matter of circumstances due largely to one operator not seeing the other truck and backing into it. However, it is felt that if the angle between the two trucks is such that any of the second hauler is visible from the center of the rear tires forward in the mirror of the operator who is backing up then there should be no collision. At this angle which is approximately $15^{o}$ or at sharper angles an operator should be able to see a second hauler behind him if he uses his mirrors.

Since both the force required to slide a stationary truck and the energy of a moving truck increase as the weights of the trucks increase, the worst case collision is where a loaded hauler runs into another loaded hauler which is parked with its brakes applied. In order to complete the dynamic analysis of the maximum forces generated during a collision between two haulage trucks, it must be assumed that the energy of the moving truck is conserved. This is the case when there is no bending or breaking of the major components on either truck.

Since energy is conserved, the initial energy of the moving truck (truck 1) is equal to the combined energy of the two trucks at any given time plus the energy dissipated in the rear tires of the second truck plus the energy expended in moving the second truck.

The following terms can be used to express the various energies:

Energy of first truck before impact $= \frac{1}{2} M_1 V_0^2$

Energy of first truck after impact $= \frac{1}{2} M_1 V_1^2$

Energy of second truck after impact $= \frac{1}{2} M_2 V_2^2$

Energy dissipated by moving second truck $= F_f Y$

Energy dissipated into rear tires $= \frac{1}{2} KX^2$

These terms are combined to write the following equation:

$$\frac{1}{2} M_1 V_0^2 = \frac{1}{2} M_1 V_1^2 + \frac{1}{2} M_2 V_2^2 + F_f Y + \frac{1}{2} KX^2 \qquad (1)$$

where $M_1$ = effective mass of truck 1,

$M_2$ = effective mass of truck 2,

$V_0$ = initial velocity of truck 1, ft/sec,

$V_1$ = velocity of truck 1 at any given time after impact, ft/sec,

$V_2$ = velocity of truck 2 at any given time after impact, ft/sec,

$F_f$ = weight of truck in pounds x road adhesion coefficient (frictional force, lbf),

$Y$ = displacement of truck 2, ft,

$K$ = deflection rate of tire(s), lbf/ft,

and $X$ = distance tire(s) deflect, ft.

Figure 6-5 shows a schematic of the impact dynamics.

There are four basic steps in a typical rear-end collision which this equation applies:

- Step 1 — Tire just before impact with truck 1 at a given weight and velocity.
- Step 2 — Time after impact with truck 2 still stationary with an increasing amount of rear tire deflection.
- Step 3 — Time after impact with truck 2 sliding on road with a given adhesion coefficient and an increasing amount of rear tire deflection.
- Step 4 — Time after impact when both trucks come to a rest.

For the case that both trucks are of equal weight:

$$M_1 = M_2 = M \text{ and}$$

$$M = \left(\frac{\text{weight of truck}}{g}\right)(\text{rotational constant}) \qquad (2)$$

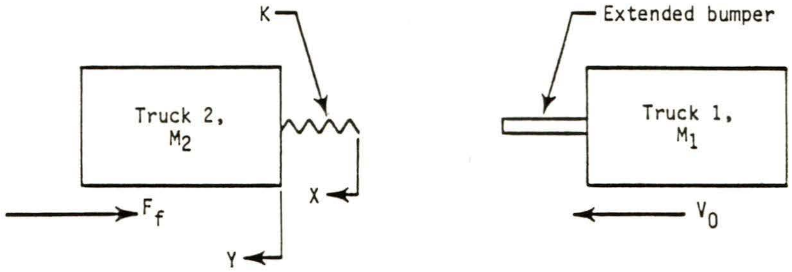
where the rotational constant is due to mass of rotating parts = 1.15.

Equation 1 may then be written as follows:

$$\frac{1}{2}KX^2 = \frac{1}{2}MV_0^2 - \left(\frac{1}{2}M\left(V_1^2 + V_2^2\right) + F_fY\right) \qquad (3)$$

When the trucks have come to rest, $V_1 = V_2 = 0$ and equation 3 can be written as:

$$\frac{1}{2}KX^2 = \frac{1}{2}MV_0^2 - F_fY \qquad (4)$$



K = tire stiffness
X = tire deflection
Y = distance truck 2 slides
$F_f$ = frictional force
$V_0$ = impact velocity

FIGURE 6-5. Schematic of Impact Dynamics

Since the total energy of the system is simply the kinetic energy of truck 1 before impact, the following equation holds true:

$$E_{tot} = \frac{1}{2} MV_0^2 \qquad (5)$$

Equation 4 may be rewritten as follows to find the displacement of truck 2 if X and E totals are known:

$$Y = \frac{E_{tot}}{F_f} - \frac{1}{2}\frac{KX^2}{F_f} \qquad (6)$$

Also, the following relationship between X and Y must hold true:

$$Y = X - X_0 \qquad (7)$$

where $X_0$ is the deflection required for truck 2 to start slide which is determined with the following equation:

$$X_0 = \frac{F_f}{K}$$

For the case of maximum tire deflection the total energy of the system can be determined for any given tire pressure using the following:

$$E_{tot} = F_f(X - X_0) + \frac{1}{2} KX^2 \tag{8}$$

Figure 6-6 shows the relationship of the energy that is absorbed by the tire deflecting and the machine sliding on the ground. The velocity of truck 1 which will deflect the tire(s) to the maximum limit before any metal contact occurs between the two trucks can be determined with the following equation:

$$V = \frac{F_f(X - X_0) + \frac{1}{2} KX^2}{\frac{1}{2} M} \tag{9}$$

Figure 6-7 shows the velocity of truck 1 to deflect two rear tires to the maximum limit as a function of tire air pressure for the case of the heaviest 170-ton truck which has a gross vehicle weight of 575,000 pounds and the highest road adhesion coefficient from Table 6-2 of 0.85.

### 6.2.2 Determination of Impact Forces

The horizontal force on the bumper at any given time is described as follows:

$$F_b = KX$$

where $F_b$ = force on bumper, lb,

$K$ = deflection rate of tire(s),

and $X$ = deflection of tire(s).

Figure 6-8 shows the horizontal bumper force as a function of tire pressure for the case where the bumper impacts two tires. Figure 6-9 shows the horizontal force on the bumper as a function of velocity where the bumper impacts two tires with a given air pressure. For the case where the collision occurs with the two haul trucks at an angle to each other,

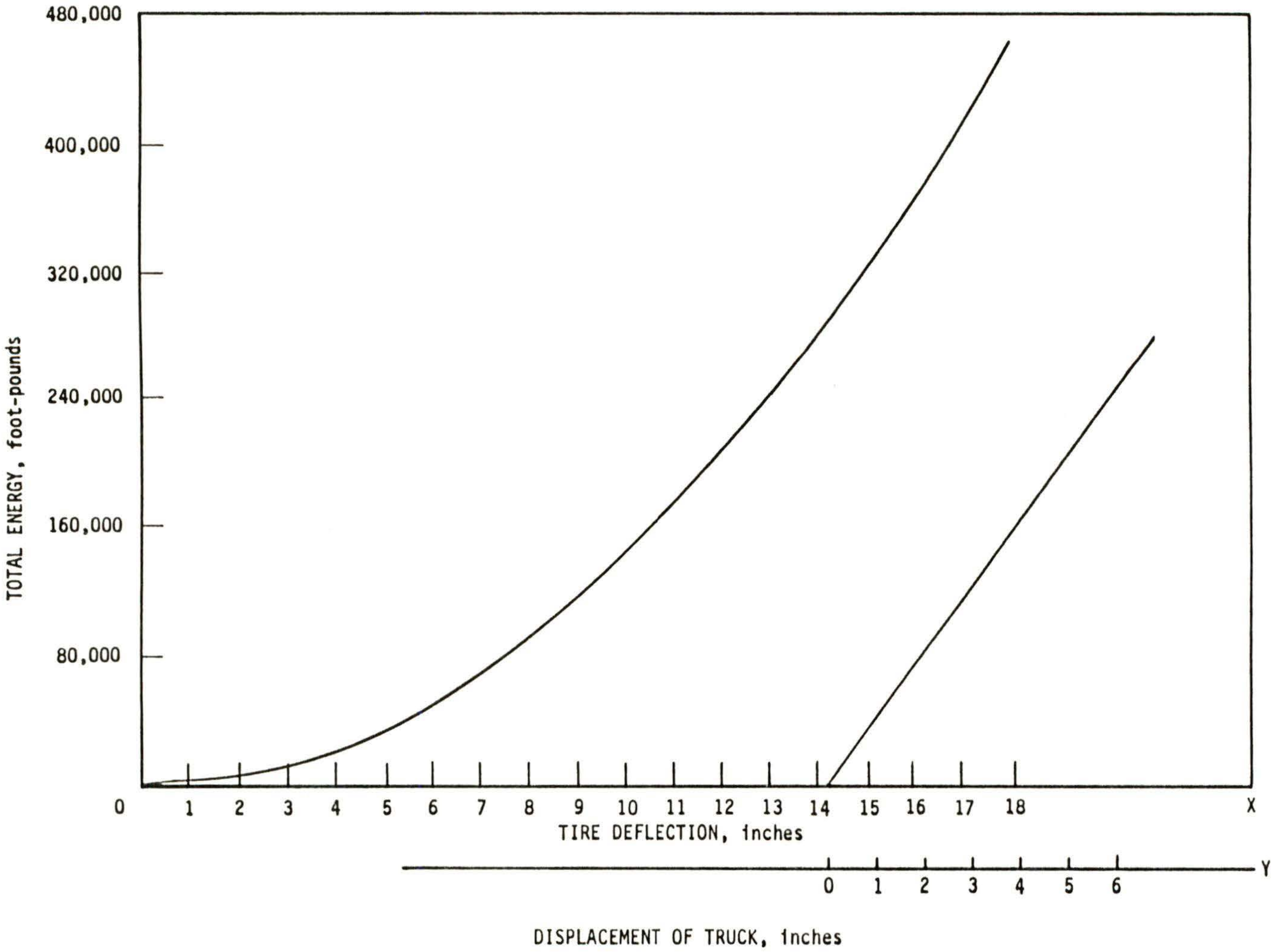


FIGURE 6-6. Tire Deflection and Sliding Distance versus Energy Absorbed

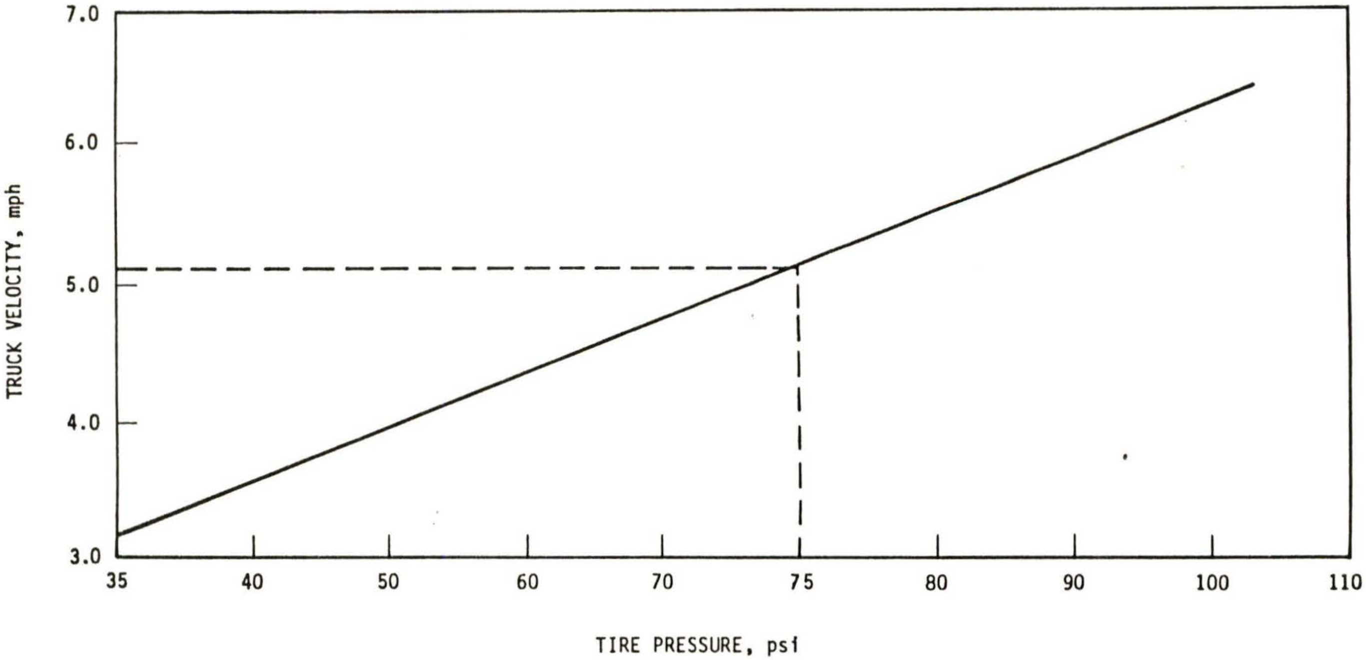


FIGURE 6-7. Impact Velocity to Deflect Tires to Maximum Limit for a Given Tire Inflation Pressure (Two Tires Impacted)

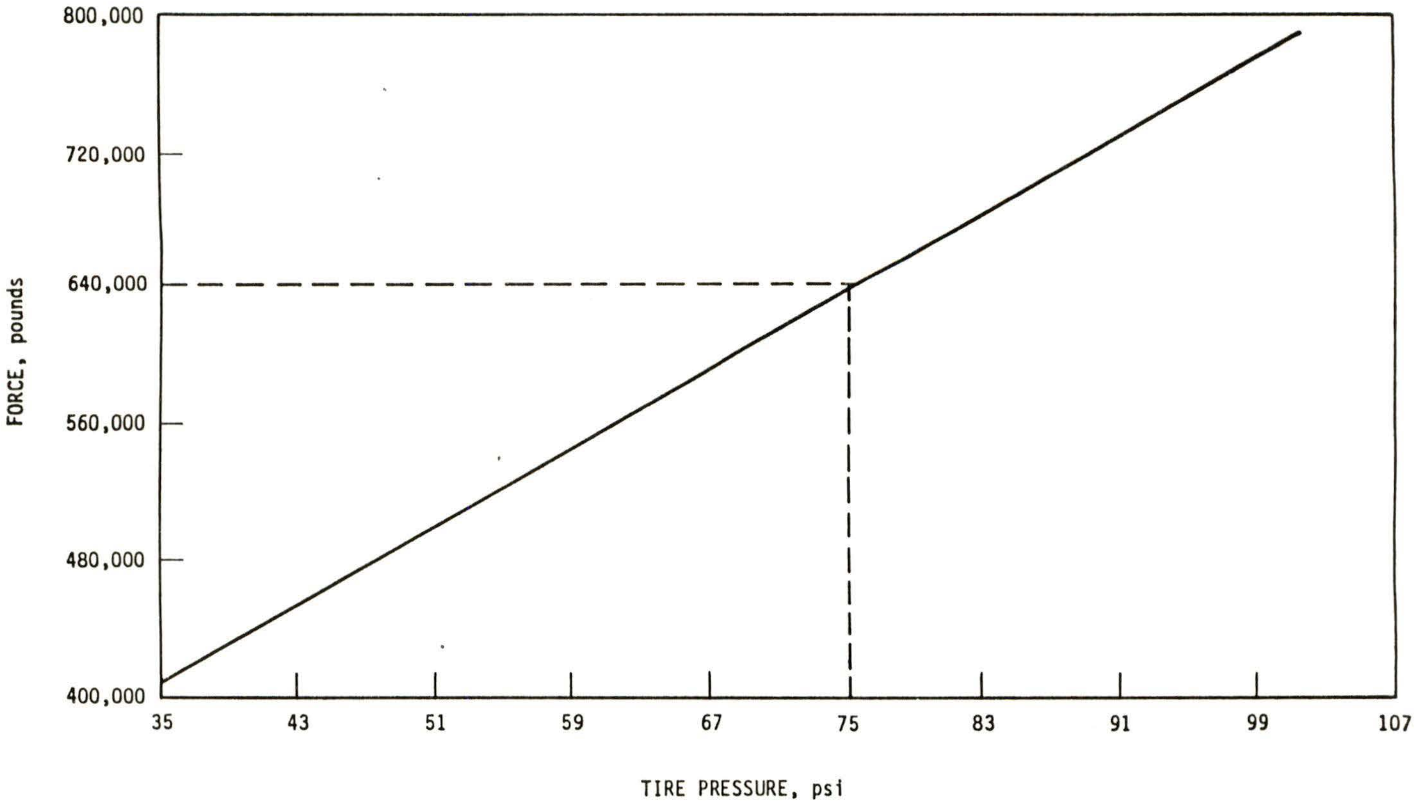


FIGURE 6-8. Maximum Bumper Force Developed versus Tire Inflation Pressure (Two Tires Impacted)

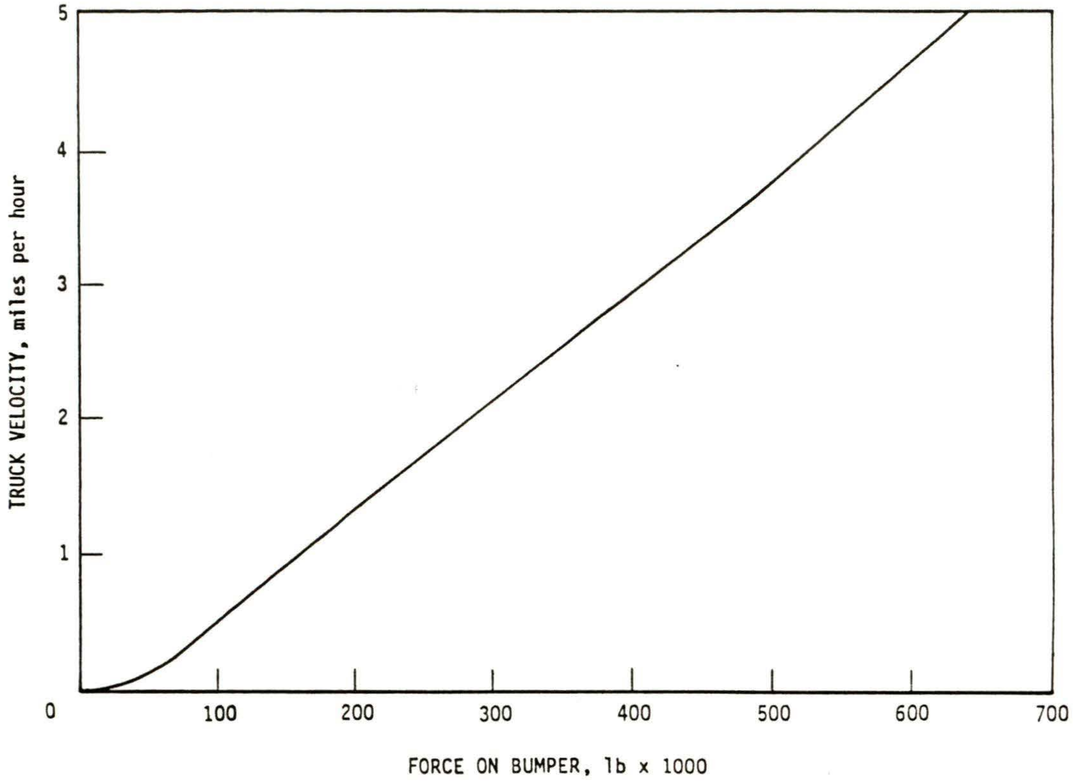


FIGURE 6-9. Impact Velocity versus Resulting Bumper Force

a side load is introduced onto the bumper. For this type of collision the forces acting on the bumper can be broken down as follows:

$$F_b \text{ side} = F_b \sin 0 \quad \text{and}$$

$$F_b \text{ front} = F_b \text{ cosine } 0$$

where 0 = angle between the trucks, deg

and $F_b$ = force due to tire deflection.

Any vertical loads on the bumper are the result of the trucks being at an angle to each other or vertical misalignment between the bumper and the rear tires. As illustrated in Figure 6-9, the only bumper which would normally not make contact with the center of the rear tire is the Terex 33-15B since the top of its bumper is approximately 4 inches lower than the center of the tire. This amount of misalignment would result in a vertical load of 6 percent of the frontal load. For a 640,000-pound frontal load the resultant vertical load due to misalignment is 38,400 pounds.

# SECTION 7.0

# CONFIGURATION OF THE UNIVERSAL EXTENDED BUMPERS

## 7.1 EXTENDED BUMPER REQUIREMENTS

The basic design of the bumper must be such that it can be adapted to any 170-ton truck with only minor modifications to it. In order to minimize damage to the hauler and to properly support the extended bumper on impact the bumper's main structural supports must be attached directly in line with the frame rails of the hauler. The bumper design must also be such that it doesn't interfere with the normal maintenance procedures to the hauler.

As previously discussed the extended bumper must be 4 feet long and 13 feet wide at the front. It must be capable of supporting a 640,000-pound frontal load, a 75,000-pound side load, and a 38,400-pound vertical load.

## 7.2 TRUCK FRAME AND BUMPER SPECIFICATIONS

Since the main supports of the extended bumper must line up directly with the frame rails of the truck, it is critical that the dimensions of the frame rails on any truck are known before an extended bumper can be designed.

### 7.2.1 Euclid R-170 Frame Specifications

The frame rails on the Euclid R-170 consist of a 12-inch high by 10-inch wide fabricated box section. The top and bottom plates are approximately 1-inch thick with the side plates being 5/8-inch thick. The frame is constructed using high-strength alloy steel with a yield strength of 100,000 psi. The distance between the inside edges of the frame is 92 inches. The front edge of each frame rail flares into the bumper and is approximately 2 feet wide at the rear of the bumper. The bumper consists of a box beam section 14 inches high by 8-1/2 inches wide.

In order to mount an extended bumper on this truck the front and top of the existing bumper would have to be reinforced to prevent it from collapsing from the impact loads. This can be accomplished by using plate to form a pad on which the extended bumper main supports would be welded.

### 7.2.2 Titan 33-15B Frame Specifications

The frame rails on the Titan 33-15B consist of a 20-inch high by 8-inch wide fabricated box section. The top and bottom plates are 1-inch thick while the side plates are 1/2-inch. The distance between the inside edges of the frame rails is approximately 68 inches. The frame is constructed using a medium-strength steel alloy with a yield strength of 45,000 psi. The front bumper is bolted to the frame rails in order that it can be removed whenever the power module must be removed from the truck.

The original bumper on this truck will have to be reinforced in order to install an extended bumper. In addition, since the bumper must remain removable any accessories mounted on the bumper must be able to be easily disconnected from the hauler.

### 7.2.3 Unit Rig Mark 36 Frame Specifications

The front frame rails on the Mark 36 consist of a fabricated tapered box section with a distance of 90 inches between the inside edges. At the front the frame is 11 inches high by 3 inches wide with 5/8-inch top and bottom plates and 7/16-inch side plates. The frame rails which are constructed from 100,000-psi yield strength steel form the outer sides of the front bumper. The bumper is fabricated from 3/8-inch plate with the lower part supporting the steering pivots. Only minor reinforcement of the bumper would be required to mount an extended bumper on the Mark 36 since the frame rails extend to the front of the bumper.

### 7.2.4 WABCO 170C Frame Specifications

The WABCO 170C frame consists of a fabricated box section 17 inches high by 4-1/2 inches wide with 1-1/2 inch top and bottom plates and 5/8 inch side plates. The distance between the frame rails on this truck is only

57 inches. The 170C frame is constructed out of a high-strength steel alloy with a yield strength of 100,000 psi.

The front bumper which is fabricated from 1/4-inch plate has a removable center section for removing the power module. This feature must be incorporated into the design of the extended bumper. Only minor reinforcement of the existing bumper will be required in order to mount an extended bumper since the frame rails extend to the front of the bumper.

## 7.3 EXTENDED BUMPER DESIGNS

In order to use the same basic bumper structure on all of the different 170-ton trucks, the design must incorporate the following:

- Maximum height for main support structures of 18 inches.
- Front bumper cross beam must be able to be mounted on the front, the bottom, or top of the main support structures as required for the bumper to impact near the center of the rear tires during a collision.
- Distance between the main support structures must be variable.
- All cross bracing in center section must be below the main structural supports.
- Main structural members must be weaker than the truck frame.
- The overall extended bumper weight should not substantially exceed the weight of the existing design.

Table 7-1 shows a comparison of the strength of the extended bumper design to the frame strengths for each truck. In all cases but one the bumper strength is substantially less than the frame strength. The side capability of the bumper design is about 10 percent stronger than the side capability of the Unit Rig frame. However, this is relatively insignificant amount.

TABLE 7-1. Comparison of
Extended Bumper and Truck Frame Strengths

| Frame | Elastic Bending Moment Capability (in.-lb) | |
|---|---|---|
| | Vertical | Side |
| Extended bumper | $2.3 \times 10^6$ | $1.2 \times 10^6$ |
| Euclid | $12.3 \times 10^6$ | $7.3 \times 10^6$ |
| Terex | $8.7 \times 10^6$ | $3.8 \times 10^6$ |
| Unit Rig | $3.1 \times 10^6$ | $1.1 \times 10^6$ |
| WABCO | $12.9 \times 10^6$ | $4.0 \times 10^6$ |

It is estimated that the narrow frame design for WABCO and Terex trucks weighs approximately 1,900 pounds and costs approximately $3,000. The wide frame design weighs approximately 1,500 pounds and costs approximately $2,500. These costs and materials do not include the actual installation of the extended bumpers. Since the same basic bumper design is used for all trucks in order to obtain the same capability, the bumper attachments to the frame for each truck will be different and should be considered at the time of installation. This would allow mine personnel to evaluate the types of modifications they prefer for installation.

The computer program PLASTIC CANOPY, described in the U.S. Bureau of Mines Information Circular 8795, was used to evaluate the structural capacity of the extended bumper design, as well as the existing designs, for the three load cases. The WAI extended bumpers were specifically designed to meet the three load case criteria. The drawings for these designs are included in Appendices A through D.

Of the existing designs the design for the Unit Rig truck has the lowest structural capability. This is due to the fact that the 10 x 6 x 1/2 inch tube is not directly welded to the I-beams. Also, the I-beams cannot carry a substantial load.

The two extended bumper designs for the WABCO truck also do not meet the developed criteria. However, the design 1 has proven itself in a documented rear-end collision.

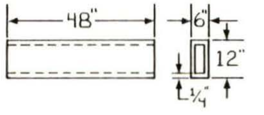
The structural capability of the extended bumpers was summarized in Table 2-1.

# APPENDIX A

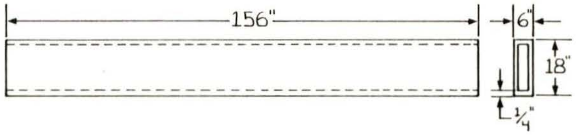
# EXTENDED BUMPER DESIGN FOR A WABCO 170-TON TRUCK

| REVISIONS | | | | |
|---|---|---|---|---|
| ZONE | LTR | DESCRIPTION | DATE | APPROVED |

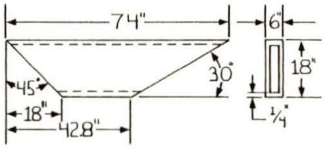
NOTES:



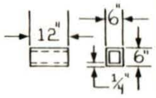
ITEM 1
2 REQ'D



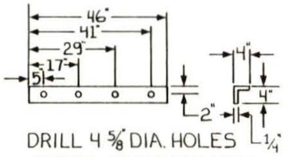
ITEM 2
1 REQ'D



ITEM 3
2 REQ'D

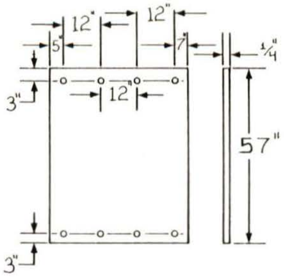


ITEM 4
2 REQ'D



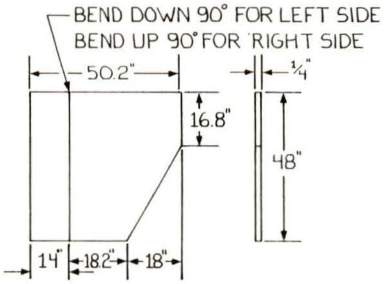
DRILL 4 ⅝" DIA. HOLES AFTER ASSEMBLY TO MATCH ITEM 6

ITEM 5
2 REQ'D

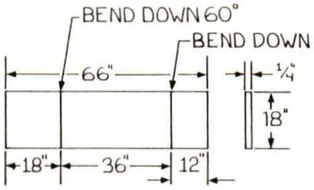


DRILL 8 ⅝" DIA. HOLES

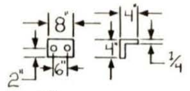
ITEM 6
1 REQ'D



ITEM 7
2 REQ'D - 1 LEFT - 1 RIGHT

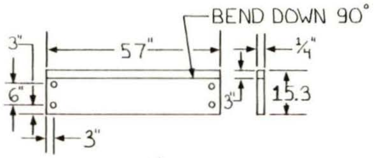


ITEM 8
1 REQ'D



DRILL 2 ⅝" DIA. HOLES AFTER ASSEMBLY TO FIT ITEM 9

ITEM 10
2 REQ'D



DRILL 4 ⅝" DIA. HOLES

ITEM 9
1 REQ'D

| ITEM | QTY | DESCRIPTION | WT |
|---|---|---|---|
| 10 | 2 | 4"x4"x¼" ANGLE | 5 |
| 9 | 1 | ¼" PLATE | 62 |
| 8 | 2 | ¼" PLATE | 84 |
| 7 | 2 | ¼" PLATE | 151 |
| 6 | 1 | ¼" PLATE | 240 |
| 5 | 2 | 4"x4"x¼" ANGLE | 25 |
| 4 | 2 | 6"x6"x¼" 46 Ksi YIELD | 19 |
| 3 | 2 | 18"x6"x¼" 46 Ksi YIELD | 167 |
| 2 | 1 | 18"x6"x¼" 46 Ksi YIELD | 510 |
| 1 | 2 | 12"x6"x¼" 46 Ksi YIELD | 120 |

CONTR
DRAWN
DESIGNER
CHECK
STRESS
L. ENGR
P.A.
RELEASE

WOODWARD ASSOCIATES, INC.

EXTENDED BUMPER DESIGN FOR A WABCO 170 TON TRUCK

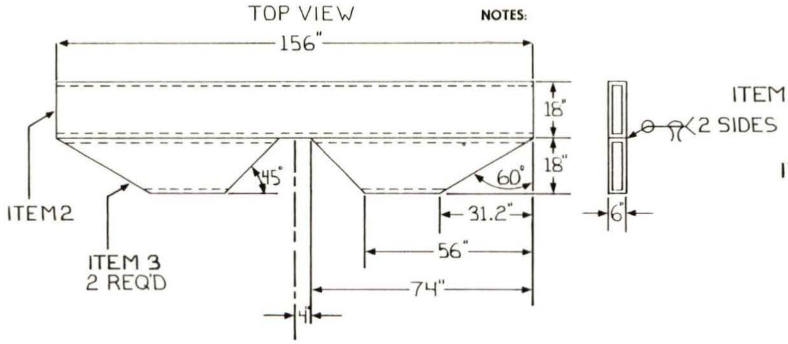
| SIZE | CODE IDENT NO. | DRAWING NO. |
|---|---|---|
| C | | 149-101 |

SCALE
SHEET 1 OF 3

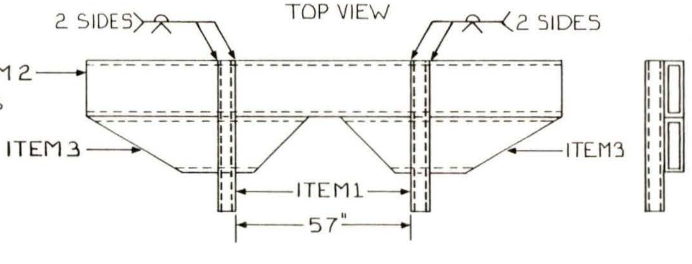
FORM NO LPC 1039-8 C

| REVISIONS | | | | |
|---|---|---|---|---|
| ZONE | LTR | DESCRIPTION | DATE | APPROVED |

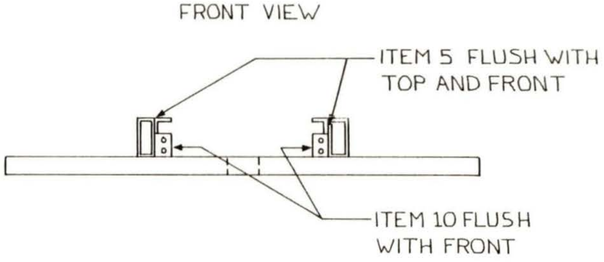
NOTES:



ITEM 11
1 REQ'D



ITEM 12
1 REQ'D



ITEM 13
1 REQ'D

| | | |
|---|---|---|
| CONTR | | |
| DRAWN | | |
| DESIGNER | | |
| CHECK | | |
| STRESS | | |
| L. ENGR | | |
| P.A. | | |
| RELEASE | | |

WA WOODWARD ASSOCIATES, INC.

EXTENDED BUMPER DESIGN FOR A
WABCO 170 TON TRUCK

| SIZE | CODE IDENT NO. | DRAWING NO. |
|---|---|---|
| C | | 149-101 |

SCALE SHEET 2 OF 3

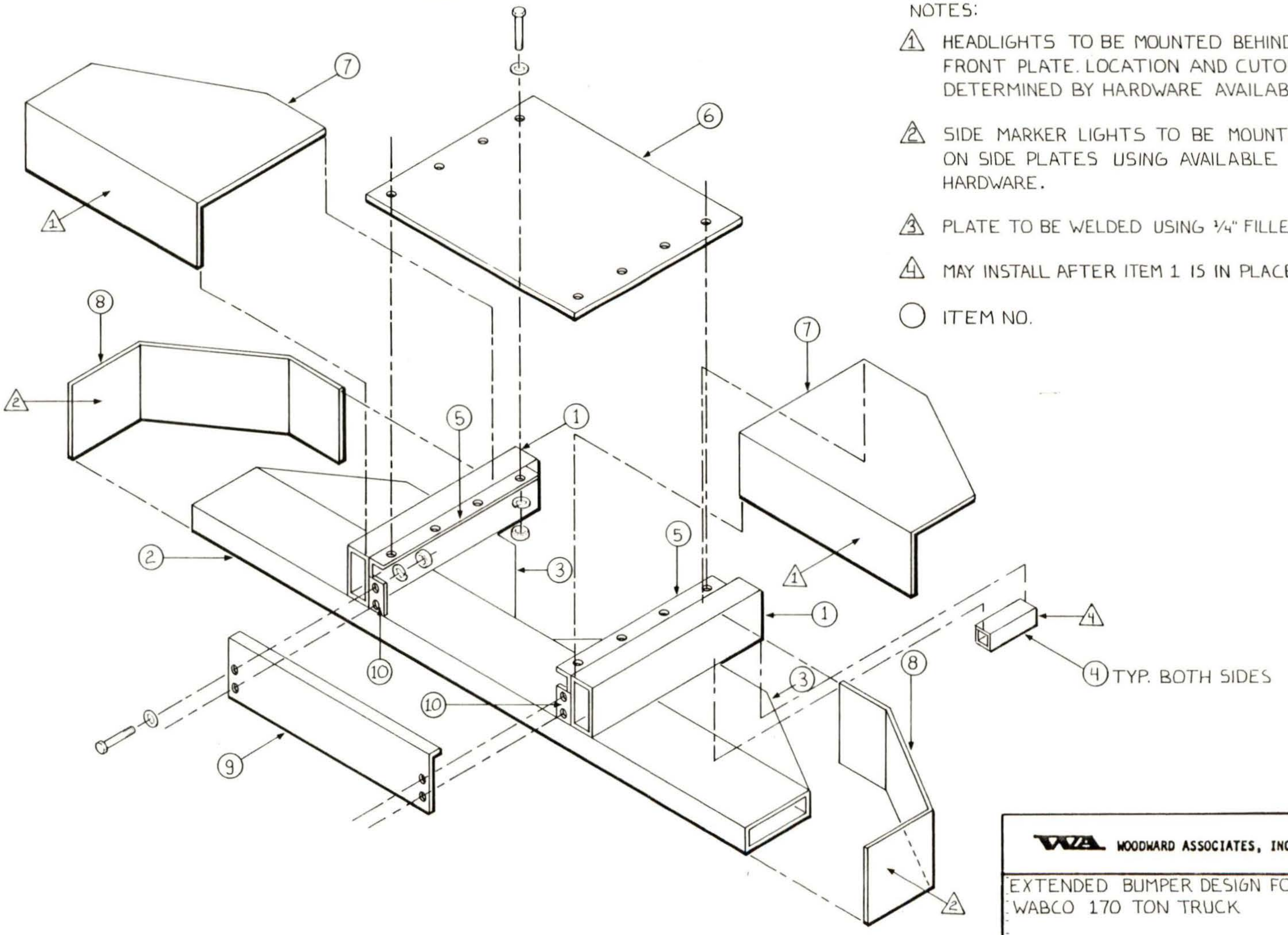
FORM NO LPC 1038-2 C

FORM

**REVISIONS**

| ZONE | LTR | DESCRIPTION | DATE | APPROVED |
|---|---|---|---|---|

NOTES:



NOTES:

1. HEADLIGHTS TO BE MOUNTED BEHIND FRONT PLATE. LOCATION AND CUTOUT DETERMINED BY HARDWARE AVAILABLE.
2. SIDE MARKER LIGHTS TO BE MOUNTED ON SIDE PLATES USING AVAILABLE HARDWARE.
3. PLATE TO BE WELDED USING 1/4" FILLET.
4. MAY INSTALL AFTER ITEM 1 IS IN PLACE.

○ ITEM NO.

**WOODWARD ASSOCIATES, INC.**

EXTENDED BUMPER DESIGN FOR A
WABCO 170 TON TRUCK

| SIZE | CODE IDENT NO. | DRAWING NO. |
|---|---|---|
| C | | 149-101 |

SCALE

SHEET 3 OF 3

FORM NO LPC 1039-2 C

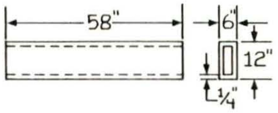
FORM

# APPENDIX B

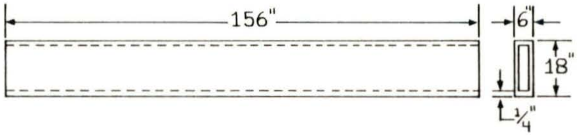
# EXTENDED BUMPER DESIGN FOR A TEREX 170-TON TRUCK

| REVISIONS | | | | |
|---|---|---|---|---|
| ZONE | LTR | DESCRIPTION | DATE | APPROVED |

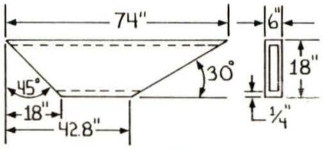
NOTES:



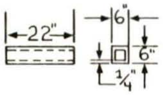
ITEM 1
2 REQ'D



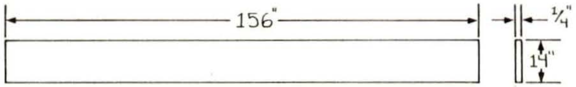
ITEM 2
1 REQD



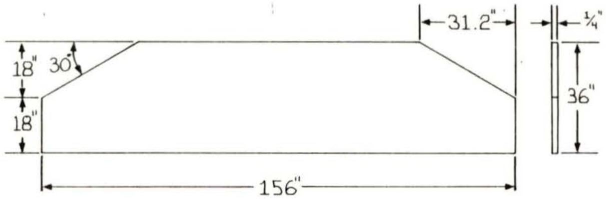
ITEM 3
2 REQ'D



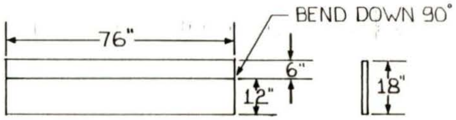
ITEM 4
2 REQ'D



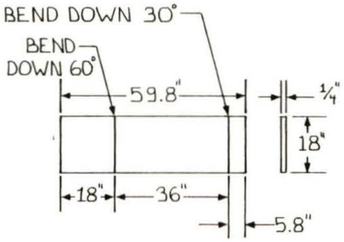
ITEM 5
1 REQ'D



ITEM 6
1 REQ'D



ITEM 7
1 REQ'D



ITEM 8
2 REQ'D

| ITEM | QTY | DESCRIPTION | WT |
|---|---|---|---|
| 8 | 2 | 1/4" PLATE | 76 |
| 7 | 1 | 1/4" PLATE | 97 |
| 6 | 1 | 1/4" PLATE | 358 |
| 5 | 1 | 1/4" PLATE | 155 |
| 4 | 2 | 6x6x1/4" 46 Ksi YIELD | 35 |
| 3 | 2 | 18x6x1/4" 46 Ksi YIELD | 167 |
| 2 | 1 | 18x6x1/4" 46 Ksi YIELD | 510 |
| 1 | 2 | 12x6x1/4" 46 Ksi YIELD | 190 |

CONTR
DRAWN
DESIGNER
CHECK
STRESS
L. ENGR
P.A.
RELEASE

WA WOODWARD ASSOCIATES, INC.

EXTENDED BUMPER DESIGN FOR A
TEREX 170 TON TRUCK

| SIZE | CODE IDENT NO. | DRAWING NO. |
|---|---|---|
| C | | 149 - 102 |

SCALE
SHEET 1 OF 3

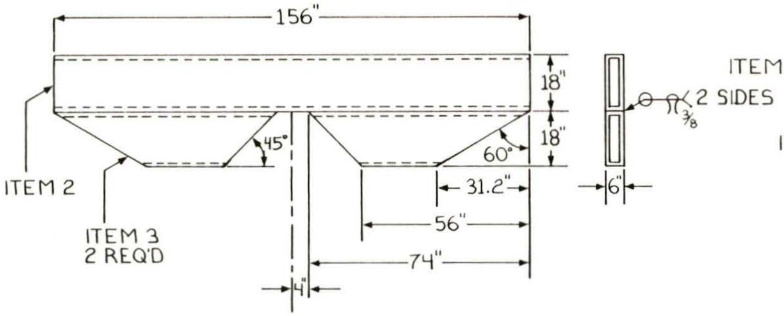
FORM NO LPC 1039-E C

FORM

| REVISIONS | | | | |
|---|---|---|---|---|
| ZONE | LTR | DESCRIPTION | DATE | APPROVED |

TOP VIEW

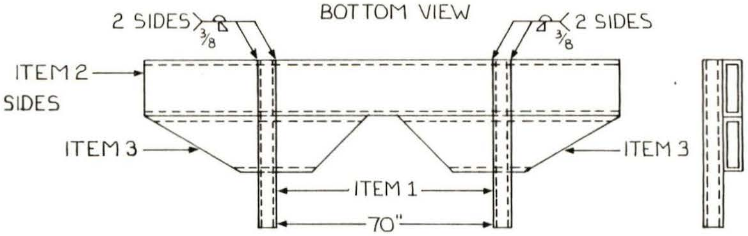
NOTES:



ITEM 9

1 REQ'D

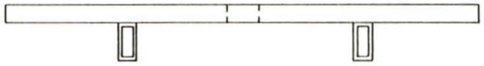
BOTTOM VIEW



ITEM 10

1 REQ'D

FRONT VIEW



ITEM 11

1 REQ'D

| | | |
|---|---|---|
| CONTR | | |
| DRAWN | | |
| DESIGNER | | |
| CHECK | | |
| STRESS | | |
| L. ENGR | | |
| P.A. | | |
| RELEASE | | |

WOODWARD ASSOCIATES, INC.

EXTENDED BUMPER DESIGN FOR A
TEREX 170 TON TRUCK

| SIZE | CODE IDENT NO. | DRAWING NO. |
|---|---|---|
| C | 06491 | 149-102 |
| SCALE | | SHEET 2 OF 3 |

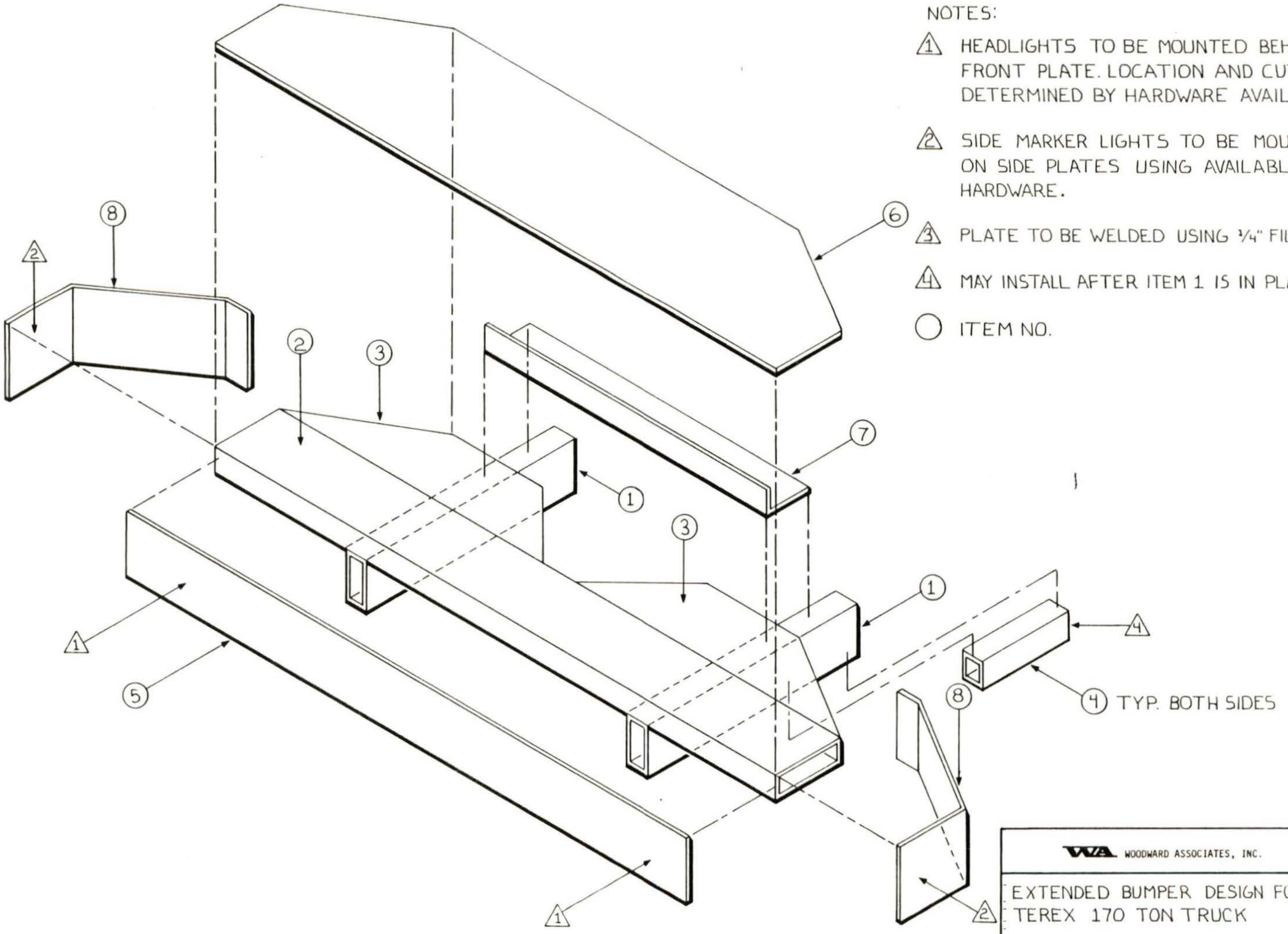
FORM NO LPC 1036-2 C

FORM

**NOTES:**

**REVISIONS**

| ZONE | LTR | DESCRIPTION | DATE | APPROVED |
|---|---|---|---|---|
| | | | | |



NOTES:

- △1 HEADLIGHTS TO BE MOUNTED BEHIND FRONT PLATE. LOCATION AND CUTOUT DETERMINED BY HARDWARE AVAILABLE.
- △2 SIDE MARKER LIGHTS TO BE MOUNTED ON SIDE PLATES USING AVAILABLE HARDWARE.
- △3 PLATE TO BE WELDED USING 1/4" FILLET.
- △4 MAY INSTALL AFTER ITEM 1 IS IN PLACE.
- ○ ITEM NO.

**WA** WOODWARD ASSOCIATES, INC.

EXTENDED BUMPER DESIGN FOR A
TEREX 170 TON TRUCK

| SIZE | CODE IDENT NO. | DRAWING NO. |
|---|---|---|
| C | 06491 | 149-102 |

SCALE
SHEET 3 OF 3

FORM NO LPC 1039-2 C

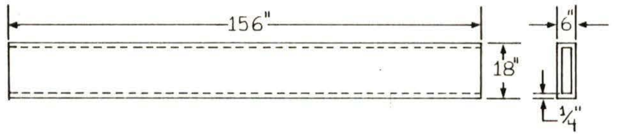
FORM

# APPENDIX C

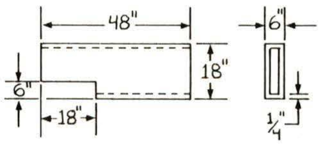
# EXTENDED BUMPER DESIGN FOR A EUCLID 170-TON TRUCK

| REVISIONS | | | | |
|---|---|---|---|---|
| ZONE | LTR | DESCRIPTION | DATE | APPROVED |

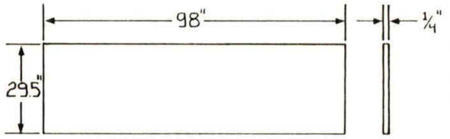
NOTES:



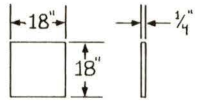
ITEM 1
1 REQ'D



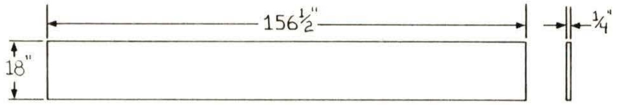
ITEM 2
2 REQ'D



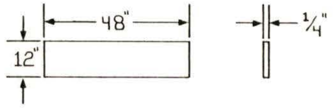
ITEM 3
1 REQ'D



ITEM 4
2 REQ'D



ITEM 5
1 REQ'D



ITEM 6
1 REQ'D

| ITEM | QTY | DESCRIPTION | WT |
|---|---|---|---|
| 6 | 1 | ¼" PLATE | 41 |
| 5 | 1 | ¼" PLATE | 200 |
| 4 | 2 | ¼" PLATE | 23 |
| 3 | 1 | ¼" PLATE | 205 |
| 2 | 2 | 18"x 6"x ¼" 46 Ksi YIELD | 150 |
| 1 | 1 | 18"x 6"x ¼" 46 Ksi YIELD | 510 |

CONTR
DRAWN
DESIGNER
CHECK
STRESS
L. ENGR
P.A.
RELEASE

WA WOODWARD ASSOCIATES, INC.

EXTENDED BUMPER DESIGN FOR A
EUCLID 170 TON TRUCK

| SIZE | CODE IDENT NO. | DRAWING NO. |
|---|---|---|
| C | 06491 | 149-201 |

SCALE
SHEET 1 OF 3

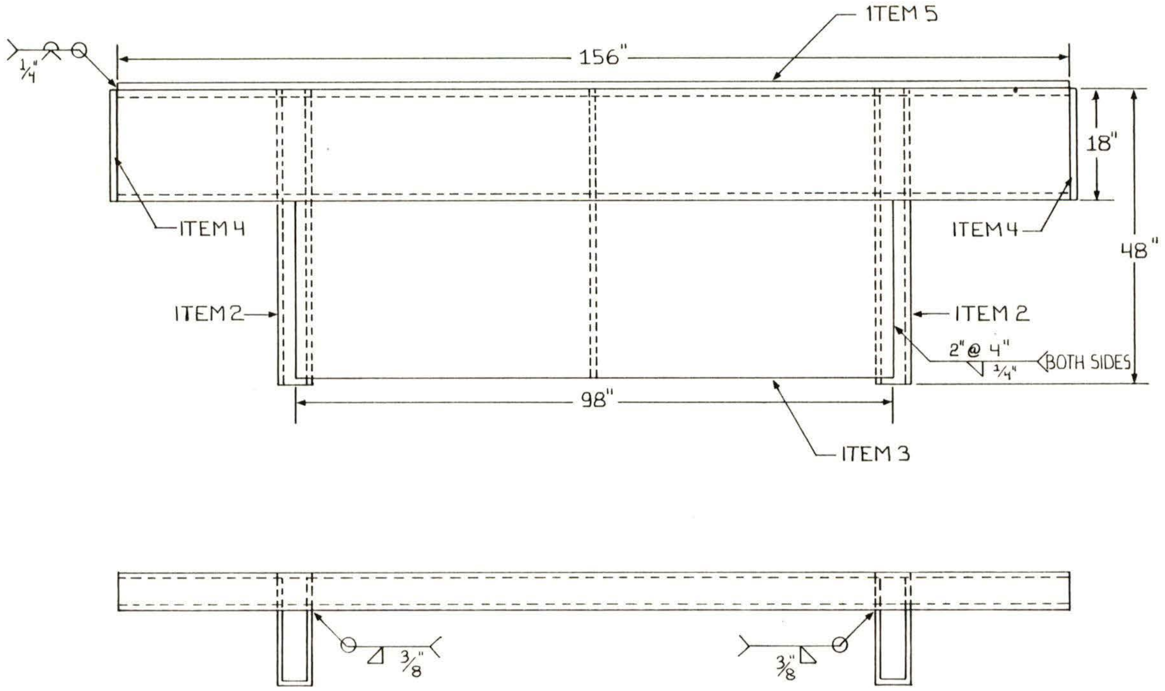
FORM NO. LPC 1039-8 C

FORM

REVISIONS

| ZONE | LTR | DESCRIPTION | DATE | APPROVED |
|---|---|---|---|---|

NOTES:



FRONT VIEW

CONTR
DRAWN
DESIGNER
CHECK
STRESS
L. ENGR
P.A.
RELEASE

**WOODWARD ASSOCIATES, INC.**

EXTENDED BUMPER DESIGN FOR A
EUCLID 170 TON TRUCK

| SIZE | CODE IDENT NO. | DRAWING NO. |
|---|---|---|
| C | | 149-201 |

SCALE

SHEET 2 OF 3

FORM NO LPC 1039-2 C

FORM

**REVISIONS**

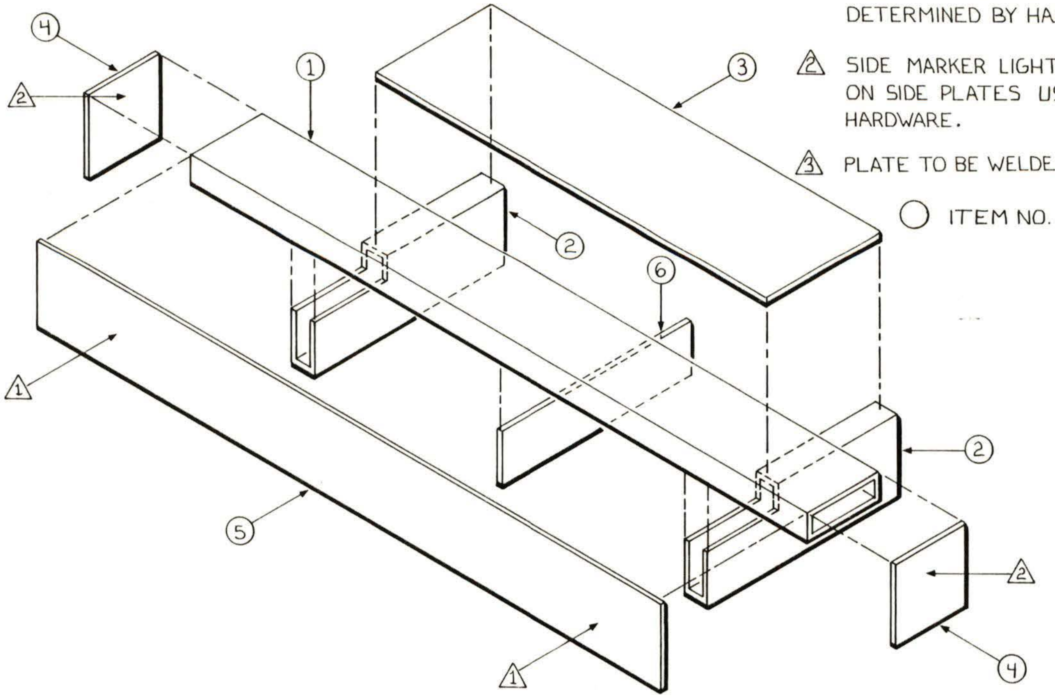
| ZONE | LTR | DESCRIPTION | DATE | APPROVED |
|---|---|---|---|---|

**NOTES:**

NOTES:

1. △ HEADLIGHTS TO BE MOUNTED BEHIND FRONT PLATE. LOCATION AND CUTOUT DETERMINED BY HARDWARE AVAILABLE.
2. △ SIDE MARKER LIGHTS TO BE MOUNTED ON SIDE PLATES USING AVAILABLE HARDWARE.
3. △ PLATE TO BE WELDED USING ¼" FILLET.

○ ITEM NO.



CONTR
DRAWN
DESIGNER
CHECK
STRESS
L. ENGR
P.A.
RELEASE

WOODWARD ASSOCIATES, INC.

EXTENDED BUMPER DESIGN FOR A EUCLID 170 TON TRUCK

| SIZE | CODE IDENT NO. | DRAWING NO. |
|---|---|---|
| C | | 149-201 |

SCALE
SHEET 3 OF 3

FORM NO LPC 1030-2 C

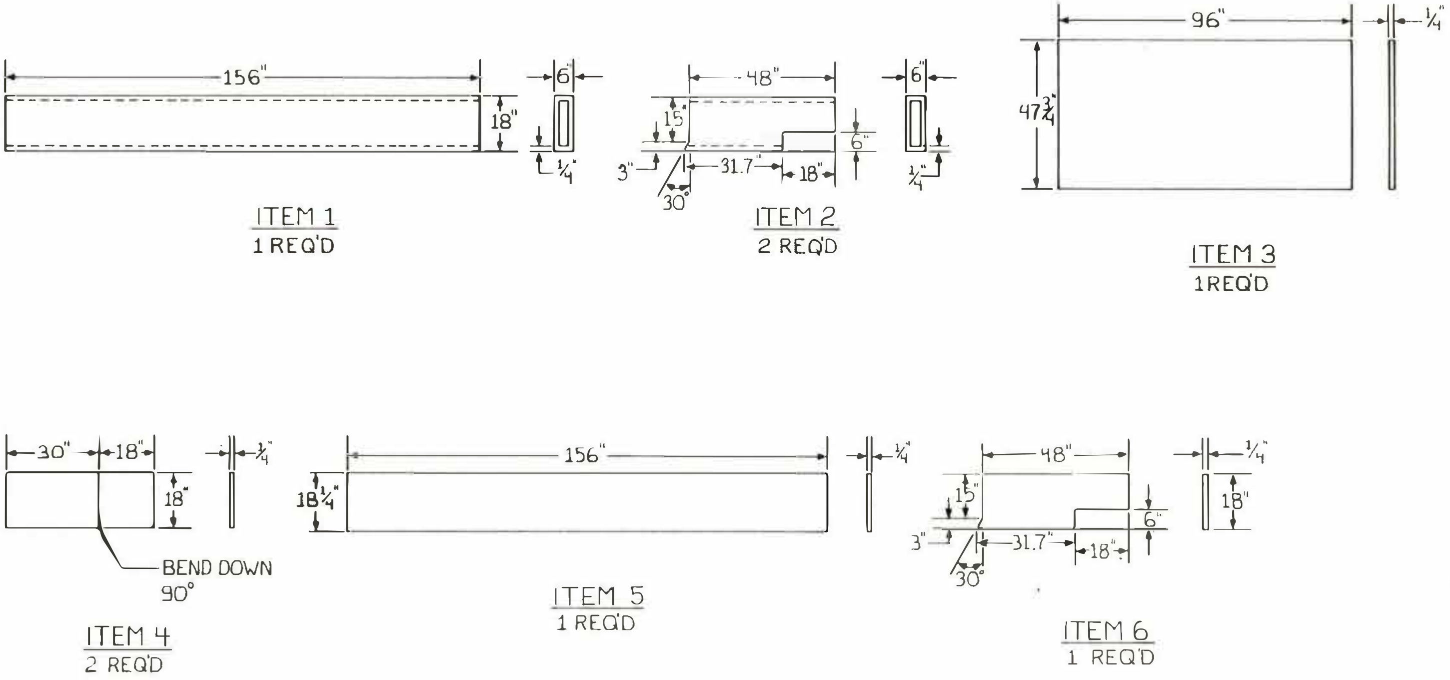
FORM

# APPENDIX D

# EXTENDED BUMPER DESIGN FOR A UNIT RIG 170-TON TRUCK

| REVISIONS | | | | |
|---|---|---|---|---|
| ZONE | LTR | DESCRIPTION | DATE | APPROVED |

NOTES:



| | | | |
|---|---|---|---|
| ¼" PLATE | 62 | 1 | 6 |
| ¼" PLATE | 200 | 1 | 5 |
| ¼" PLATE | 60 | 2 | 4 |
| ¼" PLATE | 325 | 1 | 3 |
| 18"x 6"x ¼" 46 ksi YIELD | 150 | 2 | 2 |
| 18"x 6"x ¼" 46 Ksi YIELD | 510 | 1 | 1 |
| DESCRIPTION | WT | QTY | ITEM NO. |

CONTR
DRAWN
DESIGNER
CHECK
STRESS
L. ENGR
P.A.
RELEASE

WA WOODWARD ASSOCIATES, INC.

EXTENDED BUMPER DESIGN
FOR A UNIT RIG 170 TON TRUCK

| SIZE | CODE IDENT NO. | DRAWING NO. |
|---|---|---|
| C | | 149-202 |

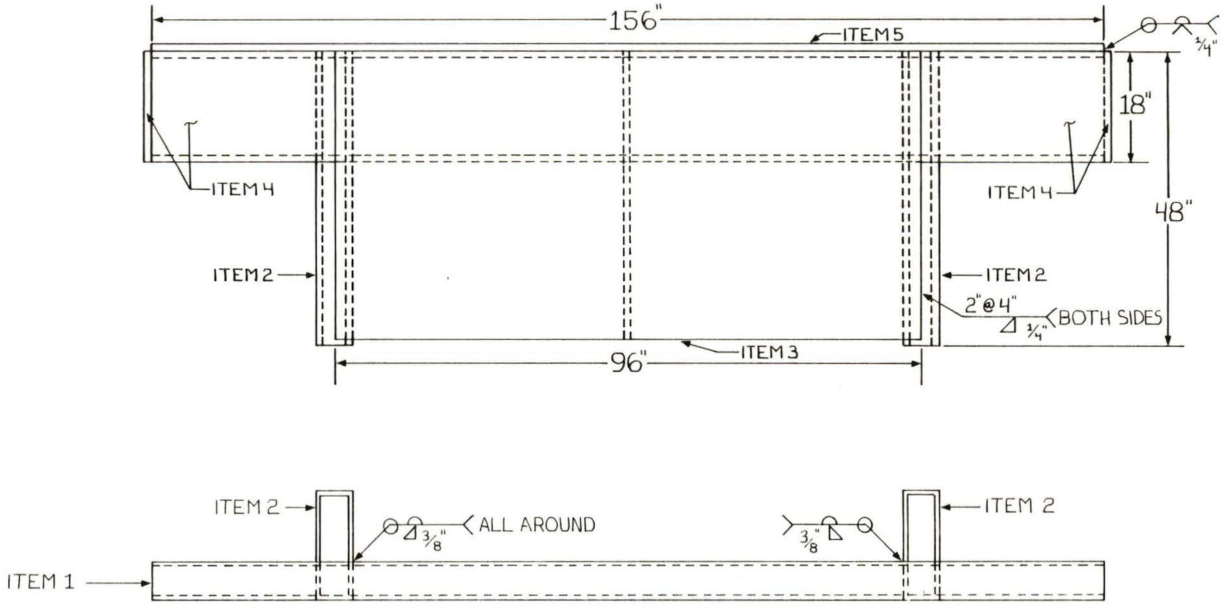
SCALE
SHEET 1 OF 3

FORM NO LPC 1039-2

FORM

| REVISIONS | | | | |
|---|---|---|---|---|
| ZONE | LTR | DESCRIPTION | DATE | APPROVED |

NOTES:



FRONT VIEW

ITEM 7
1 REQ'D

CONTR
DRAWN
DESIGNER
CHECK
STRESS
L. ENGR
P.A.
RELEASE

WOODWARD ASSOCIATES, INC.

EXTENDED BUMPER DESIGN FOR A
UNIT RIG 170 TON TRUCK

SIZE C
CODE IDENT NO.
DRAWING NO. 149-202
SCALE
SHEET 2 OF 3

FORM NO LPC 1039-2 C

FORM

**REVISIONS**

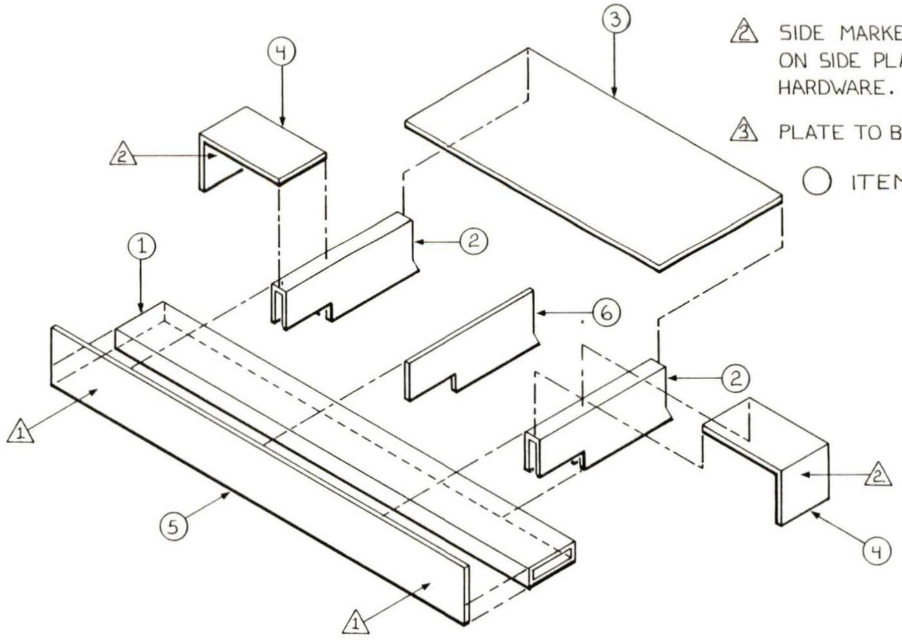
| ZONE | LTR | DESCRIPTION | DATE | APPROVED |
|---|---|---|---|---|

NOTES:

NOTES:

1. HEADLIGHTS TO BE MOUNTED BEHIND FRONT PLATE. LOCATION AND CUTOUT DETERMINED BY HARDWARE AVAILABLE.
2. SIDE MARKER LIGHTS TO BE MOUNTED ON SIDE PLATES USING AVAILABLE HARDWARE.
3. PLATE TO BE WELDED USING 1/4" FILLET.

○ ITEM NO.



CONTR
DRAWN
DESIGNER
CHECK
STRESS
L. ENGR
P.A.
RELEASE

**WOODWARD ASSOCIATES, INC.**

EXTENDED BUMPER DESIGN FOR A
UNIT RIG 170 TON TRUCK

SIZE C
CODE IDENT NO.
DRAWING NO. 149-202
SCALE
SHEET 3 OF 3

FORM NO LPC 1039-2 C

FORM