UMTA-MA-06-0120-85-2
DOT-TSC-UMTA-85-6

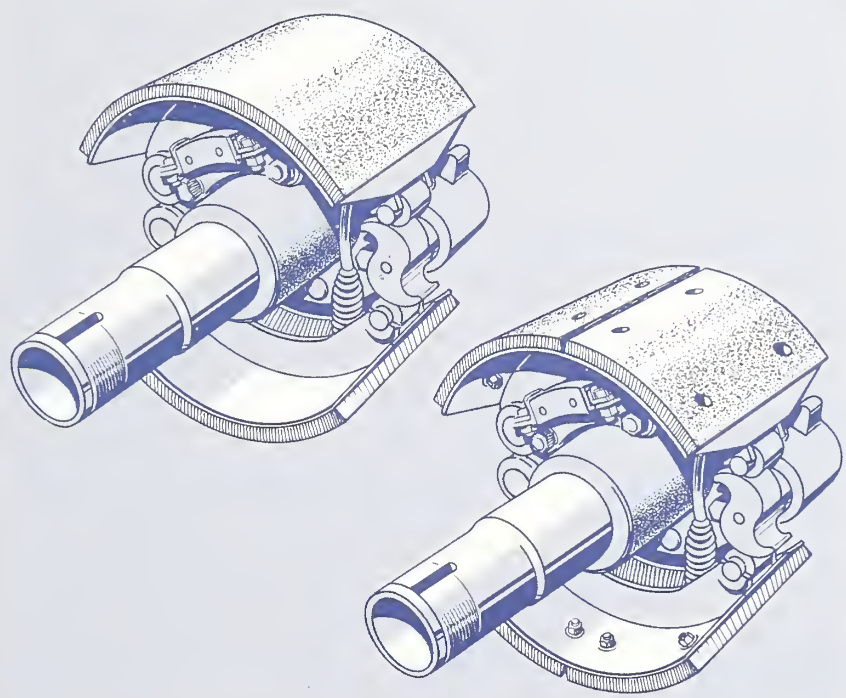
U.S. Department
of Transportation

**Urban Mass
Transportation
Administration**

# Brake Lining for Transit Buses
## Bonded vs. Bolted



Final Report
June 1985



**UMTA Technical Assistance Program**

Technical Report Documentation Page

| 1. Report No. | 2. Government Accession No. | 3. Recipient's Catalog No. |
|---|---|---|
| UMTA-MA-06-0120-85-2 | | |

| | |
|---|---|
| 4. Title and Subtitle<br>BRAKE LINING FOR TRANSIT BUSES - BONDED VS. BOLTED | 5. Report Date<br>June 1985<br>6. Performing Organization Code<br>DTS-63 |
| 7. Author(s)<br>Transit Operations Assistance Division | 8. Performing Organization Report No.<br>DOT-TSC-UMTA-85-6 |
| 9. Performing Organization Name and Address<br>U.S. Department of Transportation<br>Research and Special Programs Administration<br>Transportation Systems Center<br>Cambridge MA 02142 | 10. Work Unit No. (TRAIS)<br>UM562/R5616<br>11. Contract or Grant No. |
| 12. Sponsoring Agency Name and Address<br>U.S. Department of Transportation<br>Urban Mass Transportation<br>Office of Technical Assistance<br>Washington DC 20590 | 13. Type of Report and Period Covered<br>Final Report<br>June 1982 - June 1984<br>14. Sponsoring Agency Code<br>URT-22 |

15. Supplementary Notes



16. Abstract

This report is an examination of the effectiveness of the use of brake bonding on the Advanced Design Bus (ADB). Since the ADB was introduced in 1978, short brake lining life has forced operators to perform frequent and expensive relining. The Detroit Department of Transportation (D-DOT), the Southern California Rapid Transit District (SCRTD) and other transit agencies have recently used adhesive bonds instead of bolted linings to reline brake shoes. Using data from these transit authorities, the study considers factors of safety and cost-effectiveness of bonded brake shoes on S-cam and wedge-type brake systems.

| 17. Key Words | 18. Distribution Statement |
|---|---|
| Brakes, Bonded Lining, S-Cam Foundation, Wedge Brake, Bolted Brakes | DOCUMENT IS AVAILABLE TO THE PUBLIC THROUGH THE NATIONAL TECHNICAL INFORMATION SERVICE, SPRINGFIELD, VIRGINIA 22161 |

| 19. Security Classif. (of this report) | 20. Security Classif. (of this page) | 21. No. of Pages | 22. Price |
|---|---|---|---|
| UNCLASSIFIED | UNCLASSIFIED | 64 | . |

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

# PREFACE

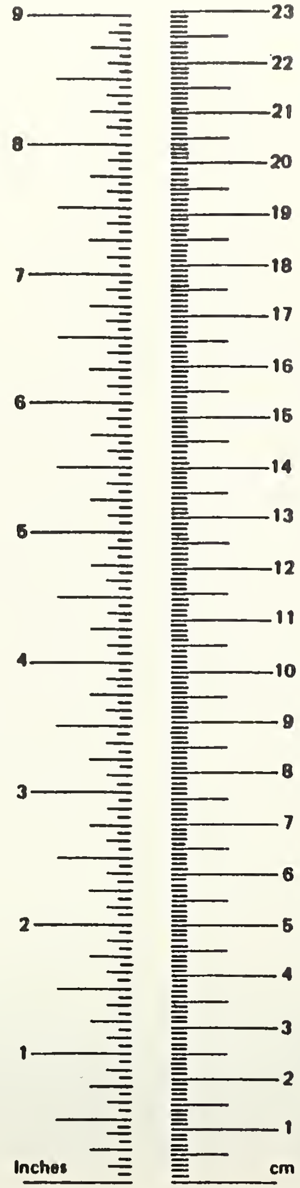
This report, prepared by the Transportation Systems Center (TSC) for the Urban Mass Transportation Administration, Office of Technical Assistance, is an examination of the effectiveness of the use of brake bonding on the Advanced Design Bus (ADB). Since the ADB was introduced in 1978, short brake lining life has forced operators to perform frequent and expensive relining. The Detroit Department of Transportation (D-DOT), the Southern California Rapid Transit District (SCRTD) and other transit agencies have recently used adhesive bonds instead of bolted linings to reline brake shoes. Using data from these transit authorities, the study considers factors of safety and cost-effectiveness of bonded brake shoes on S-cam and wedge-type brake systems.

# METRIC CONVERSION FACTORS

## Approximate Conversions to Metric Measures

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| | **LENGTH** | | | |
| in | inches | *2.5 | centimeters | cm |
| ft | feet | 30 | centimeters | cm |
| yd | yards | 0.9 | meters | m |
| mi | miles | 1.6 | kilometers | km |
| | **AREA** | | | |
| $in^2$ | square inches | 6.5 | square centimeters | $cm^2$ |
| $ft^2$ | square feet | 0.09 | square meters | $m^2$ |
| $yd^2$ | square yards | 0.8 | square meters | $m^2$ |
| $mi^2$ | square miles | 2.6 | square kilometers | $km^2$ |
| | acres | 0.4 | hectares | ha |
| | **MASS (weight)** | | | |
| oz | ounces | 28 | grams | g |
| lb | pounds | 0.45 | kilograms | kg |
| | short tons (2000 lb) | 0.9 | tonnes | t |
| | **VOLUME** | | | |
| tsp | teaspoons | 5 | milliliters | ml |
| Tbsp | tablespoons | 15 | milliliters | ml |
| fl oz | fluid ounces | 30 | milliliters | ml |
| c | cups | 0.24 | liters | l |
| pt | pints | 0.47 | liters | l |
| qt | quarts | 0.95 | liters | l |
| gal | gallons | 3.8 | liters | l |
| $ft^3$ | cubic feet | 0.03 | cubic meters | $m^3$ |
| $yd^3$ | cubic yards | 0.76 | cubic meters | $m^3$ |
| | **TEMPERATURE (exact)** | | | |
| °F | Fahrenheit temperature | 5/9 (after subtracting 32) | Celsius temperature | °C |

*1 in. = 2.54 cm (exactly). For other exact conversions and more detail tables see NBS Misc. Publ. 286. Units of Weight and Measures. Price $2.25 SD Catalog No. C13 10 286.




## Approximate Conversions from Metric Measures

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| | **LENGTH** | | | |
| mm | millimeters | 0.04 | inches | in |
| cm | centimeters | 0.4 | inches | in |
| m | meters | 3.3 | feet | ft |
| m | meters | 1.1 | yards | yd |
| km | kilometers | 0.6 | miles | mi |
| | **AREA** | | | |
| $cm^2$ | square centimeters | 0.16 | square inches | $in^2$ |
| $m^2$ | square meters | 1.2 | square yards | $yd^2$ |
| $km^2$ | square kilometers | 0.4 | square miles | $mi^2$ |
| ha | hectares (10,000 $m^2$) | 2.5 | acres | |
| | **MASS (weight)** | | | |
| g | grams | 0.035 | ounces | oz |
| kg | kilograms | 2.2 | pounds | lb |
| t | tonnes (1000 kg) | 1.1 | short tons | |
| | **VOLUME** | | | |
| ml | milliliters | 0.03 | fluid ounces | fl oz |
| l | liters | 2.1 | pints | pt |
| l | liters | 1.06 | quarts | qt |
| l | liters | 0.26 | gallons | gal |
| $m^3$ | cubic meters | 36 | cubic feet | $ft^3$ |
| $m^3$ | cubic meters | 1.3 | cubic yards | $yd^3$ |
| | **TEMPERATURE (exact)** | | | |
| °C | Celsius temperature | 9/5 (then add 32) | Fahrenheit temperature | °F |

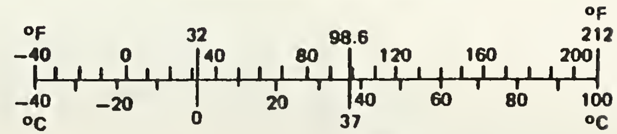


TABLE OF CONTENTS

## LIST OF ILLUSTRATIONS



## LIST OF TABLES

## EXECUTIVE SUMMARY

### BACKGROUND

An often cited complaint from urban transit agencies concerning the Advanced Design Bus (ADB) is the relatively short brake lining life. Despite design improvements made by the equipment supply industry since the introduction of the ADB in 1978, many transit operators and maintenance managers remain dissatisfied with the low mileage between brake relines, especially on ADBs used in downtown service. In order to reduce associated maintenance costs and increase the availability of the vehicles for revenue service, some transit agencies are changing the method of attaching the lining to the brake shoe, using an adhesive bonding process that increases the useable lining thickness by eliminating the need for bolt head space.

A check with selected transit agencies across the country indicates that very few, probably less than ten, have tried brake bonding.

The actual cost-effectiveness of these bonded brake linings has been mixed, primarily due to the influence of a number of variables, including the type of transit service provided, the brake foundation design, the lining material composition and other elements affecting the cost associated with the bonding process. This study identifies cost variables and quantifies the cost-effectiveness of brake bonding at Detroit Department of Transportation (D-DOT) and Southern California Rapid Transit District (SCRTD). The information in this report is to assist other transit agencies in determining whether or not this method of improving brake lining service life is applicable to their operations.

### RESULTS

A summary of results is grouped into two basic areas, safety and cost.

- SAFETY: The principal safety concern is the possibility of a debonding, that is, a separation of the brake shoe and the brake block while the bus is in service. Although debonds have occurred and continue to occur at agencies using this process, it is difficult to assess the frequency or extent of hazard created, since bond integrity is affected by many variables, such as operating conditions, brake material, bonding process or brake system maintenance.

Occasionally, a debond has been observed by the driver as a "slow brake". Usually, however, debonds have been discovered by maintenance personnel during regularly scheduled brake inspections. Typically, when debonds did occur in revenue service, only one wheel was affected and the degrading of the overall brake system was negligible. To minimize the chance of debonding, transit agencies should ensure that proper bonding procedures are followed and be aware that debonds can still occur under certain severe operating conditions. Additionally, when the brake lining wears approximately two-thirds on S-cam brake installations, the cam can actually lock up on the roller or the roller can go over the cam, affecting the braking on that wheel. To allow for the additional depth of the bonded lining, oversize cam rollers are installed at a specified wear point to prevent cam lockup or rollover. This necessary maintenance action can be a major problem and cost for many large transit agencies and could discourage the use of bonded brake linings on buses equipped with S-cam brakes. Buses equipped with wedge-type brakes (General Motors RTS coaches), however, do not use S-cams and therefore do not have the problem of cam rollover or any equivalent wear-related safety concern.

o <u>COST</u>: A cost analysis comparison was conducted to compare total costs associated with brake systems using bonded and bolted brake linings.

Data for this comparison was derived from maintenance records of Detroit Department of Transportation and Southern California Rapid Transit District. The analysis was supported by a Total Life Cost Model developed at the Transportation Systems Center. The cost effectiveness measures used indicate that the use of bonded brake linings can save money, subject to several important site factors. These include the type of foundation brake that is being used (wedge or S-cam), the number of buses in the fleet including the ratio of buses equipped with wedge brakes to buses with S-cam brakes, the number of operating locations, the location of the bonder, the wage rates for transit maintenance personnel, the cost of bonding and brake shoe reconditioning (including debonding used lining and transportation costs), the number of brake relines performed annually and whether brake relines are performed at a central brake shop or at all operating locations.

If brake relines are included as one part of a regularly scheduled brake overhaul program, the use of bonded brake linings can extend the interval between brake overhauls. This is especially true for buses equipped with wedge type foundation brakes. The cost of bringing a vehicle in to install oversize rollers prior to the brake reline date could discourage many larger transit agencies from beginning a bonded brake program for S-cam equipped buses. The extent to which a transit agency can benefit from the use of bonded brake linings will vary with the established brake inspection and maintenance practices at each transit facility and with the brake lining material used. For wedge brake equipped buses, cost savings of $200.00 to $400.00 per bus per year can be realized.

Transit agencies operating S-cam brake buses, however, have to inspect brake lining wear frequently enough to insure that the oversize rollers are installed at the optimum time. Because of this, cost savings on S-cam equipped buses can vary from zero to $200 per bus per year.

# 1. INTRODUCTION

Upon introduction of the advanced design bus (ADB) models, transit maintenance managers began to complain of poor brake performance. More specifically, these complaints were based upon short brake lining life as compared to previous experiences of New Look buses. On the initial set of linings supplied by the manufacturer during ADB bus production, a reported life of 7,000 to 15,000 miles was not uncommon. Many in the transit industry felt that the ADB was designed not to maximize the maintainability of the vehicle but to meet a combination of aesthetic, performance and government regulatory needs. The result of this new set of design criteria was a more powerful, heavier bus, capable of achieving higher speeds between stops, and of stopping in a shorter distance than its predecessor. Unfortunately, all of these innovations in design were made at the expense of brake lining life. This is not to say that such a trade-off was not, overall, a positive development. In fact, while many maintenance managers complained about the ADB's, other sectors of the bus transit community expressed satisfaction with the improvements. However, maintenance experience with ADB's and specifically the associated cost increase has forced many in the transit industry to re-evaluate these priorities.

All other factors being equal, a heavier, more powerful vehicle is more difficult to stop. The added weight of the ADB (increase of 20-25 percent), coupled with the more powerful drivetrain, permits higher acceleration and greater speeds between stops. Since stopping power required varies directly with the vehicle weight and the square of the speed, ADB coaches require a more aggressive braking mechanism to transfer the energy of motion into heat energy.

To a great extent design improvements by both the brake manufacturers and bus companies have begun to alleviate this problem. In some locations brake lining life is reportedly approaching that of the earlier bus designs. In addition to changes in the foundation brake, other retrofit programs, such as the use of different brake lining materials and electric or hydraulic retarders, are being tried by various transit agencies across the country. A few transit agencies have had success in attaching the lining to the brake shoe with a bonding process rather than the traditional bolting method. This bonding method substantially increases the useable lining thickness due to the elimination of the bolt heads. The question remains in any of these modifications as to whether or not the change was cost-effective.

Communication with more than 20 public transit authorities chosen at random (and listed in Table 1-1) indicates that relatively few (4 of 21) have tried brake bonding. Of those few agencies, all discontinued their bonding program for reasons difficult to quantify. Further investigations subsequently uncovered only four additional authorities who used bonded brake linings: Central Ohio Transit Authority (COTA), Southern California Rapid Transit Authority (SCRTD), Southeastern Michigan Transit Authority (SEMTA), and Detroit Department of Transportation (D-DOT). Of these agencies, only D-DOT and SCRTD had available data that were adequate for this analyses. Currently, D-DOT and SEMTA are the only agencies that continue to use bonded brakes to any large degree.

This study examines the bonded brake lining process and, based on available data from transit applications, evaluates and compares the safety, costs and performance with the conventional bolting process. It is hoped that this information will be useful to maintenance managers to evaluate the applicability of brake lining bonding to their operations.

TABLE 1-1. BRAKE BONDING USAGE: TRANSIT AGENCIES REPORTING PAST EXPERIENCES

| AGENCY (Selected at Random) | TRIED BONDED LININGS YES* | NO. OF BUSES | NO |
|---|---|---|---|
| Metropolitan Transit Commission, Minneapolis, MN | | | X |
| Metropolitan Transit System, Baltimore, MD | | | X |
| Milwaukee County Transit System, Milwaukee, WI | X | 3 | |
| Metropolitan Dade County Transit Authority, Miami, FL | | | X |
| Dallas Transit System, Dallas TX | | | X |
| New Orleans Public Service, Inc., New Orleans, LA | X | UNKNOWN | |
| Niagara Frontier Transit Metro System, Buffalo, NY | | | X |
| San Diego Transit Corporation, San Diego, CA | | | X |
| Orange County Transit District, Garden Grove, CA | | | X |
| Indiana Public Transportation Corporation, Indianapolis, IN | | | X |
| Transit Authority of River City, Louisville, KY | X | UNKNOWN | |
| Transit Authority City of Omaha, Omaha, NE | | | X |
| Tidewater Regional Transit, Norfolk, VA | | | X |
| Santa Clara City Transit District, Santa Clara, CA | | | X |
| Toledo Area Regional Transit Authority, Toledo, OH | | | X |
| Broward County Division of Mass Transit, Ft. Lauderdale, FL | | | X |
| Kalamazoo Metro Transit System, Kalamazoo, MI | | | X |
| Kanawha Valley Regional Transportation Authority, Charlestown, WV | | | X |
| Winston-Salem Transit Authority, Winston-Salem, NC | | | X |
| Metropolitan Transit Authority of Wichita, Wichita, CA | | | X |
| City of Salem Transit System, Salem, OR | X | UNKNOWN | |

*These agencies have discontinued brake bonding program.

Source: Telephone communications conducted by Transportation Systems Center (October 1980).

# 2. BUS BRAKE SYSTEMS

There are currently two brake foundation designs for heavy-duty transit buses. The S-cam foundation brake has been used on a majority of full size U.S. transit buses as well as trucks and semi-trailers for many years. With the introduction of the General Motors advanced design bus, a significant design change was made by replacing the <u>S-cam foundation brake</u> with a <u>wedge brake</u> design. These two brake designs have unique performance characteristics that, to varying degrees, can be enhanced by bonded linings. The following sections first discuss the design and operating characteristics of the two brake designs and, secondly, the application of bonded linings.

## 2.1 DESCRIPTION OF BUS BRAKE SYSTEMS AND MATERIALS

The S-cam, illustrated in Figure 2-1, derives its name from the shape of the constant lift cam that forces the brake shoes apart and against the brake drum when the cam shaft is rotated in response to air being applied to a brake chamber. In the brake chamber, air pressure acts upon a diaphragm which forces a push rod to move an adjustable lever called a slack adjuster, which in turn rotates the cam shaft. The cam does not contact the brake shoes directly. The cam action is transmitted to one end of each brake shoe through rollers. The opposite end of each brake shoe pivots on a fixed anchor pin.

One key point to understand about the S-cam brake is the operation of the brake shoe rollers. These rollers facilitate activation of the brake shoes until the brake lining becomes worn sufficiently to permit the roller to pass the high point of the cam. This aspect of the S-cam brake has caused some concern for those contemplating bonded brake linings, and will be discussed in further detail later in this report.

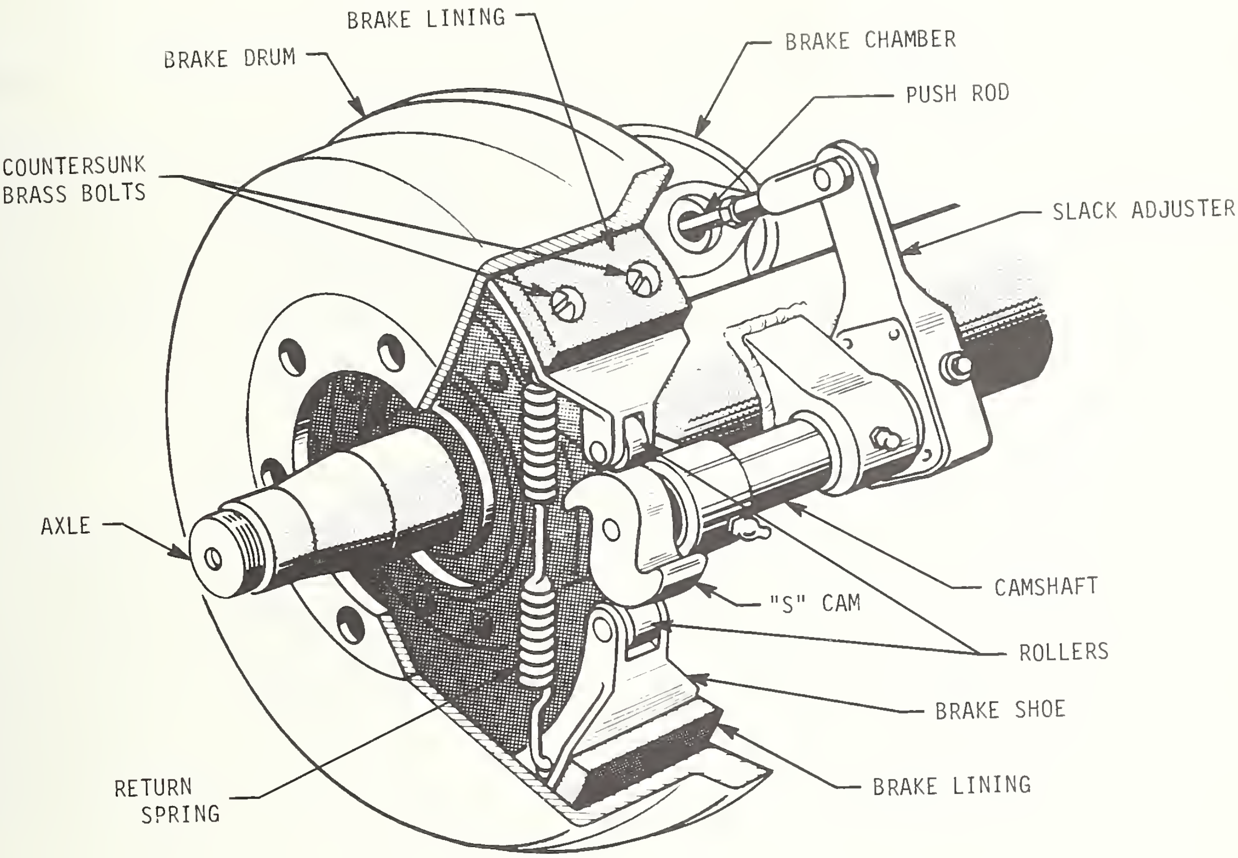


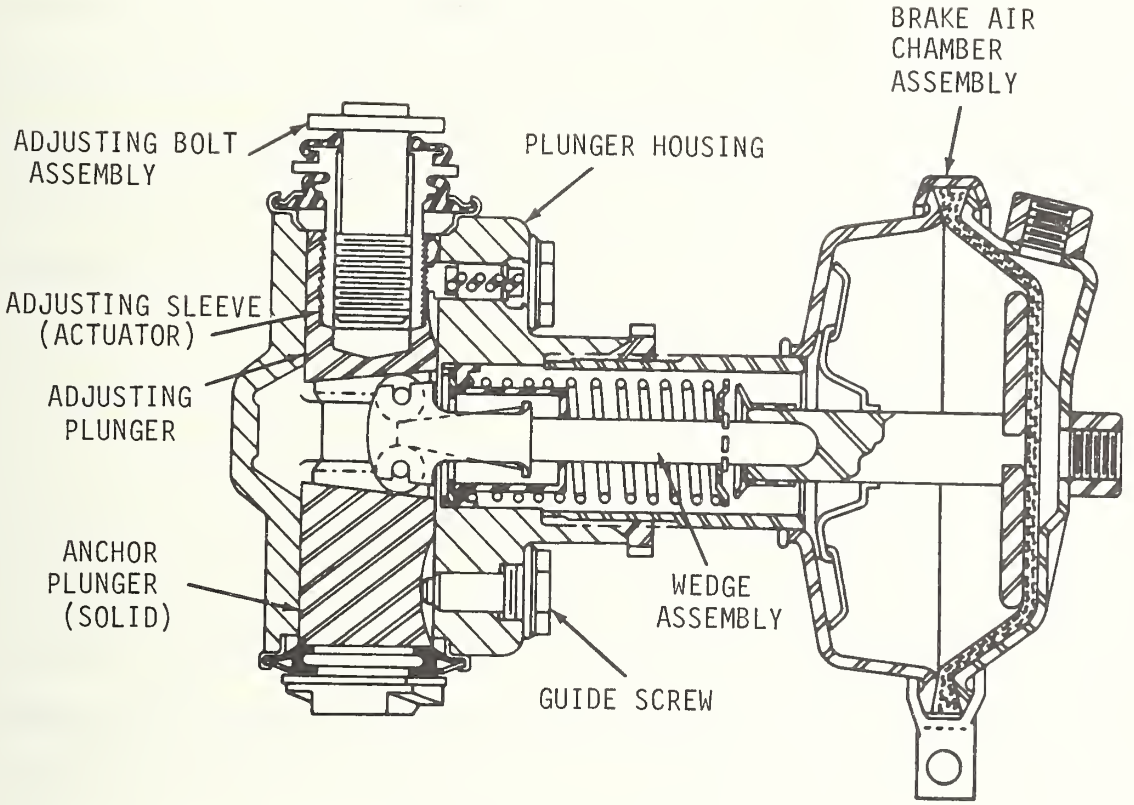

FIGURE 2-1. THE S-CAM BRAKE

The second foundation brake design used on heavy-duty vehicles is the wedge brake, illustrated in Figure 2-2. Originally introduced in the trucking industry, the wedge brake was selected for the General Motors RTS Series ADB because of several factors, including the application of an independent front axle which presented packaging problems for vehicle design using the S-cam brake. The wedge utilizes two brake chambers per wheel, instead of one, mounted directly on the brake spider, perpendicular to the wheel.

The wedge brake is activated when air pressure is applied to the system brake chambers. Each air chamber force is applied to a wedge located in the actuator casting. The wedges push the actuator plungers outward, moving one end of each brake shoe. The forces on the brake shoes are transmitted through the linings to the brake drum. Upon initial application of the brake, one end of each brake shoe moves out to contact the brake drum and the brake shoes are pulled slightly in the direction of drum rotation.

In 1981, GMC began offering a "3rd Generation Brake System", which is basically a modified version of its RTS wedge brake. In order to improve lining life, thicker linings were to be installed, thereby requiring an increased brake drum diameter and modifications to certain minor components. Furthermore, this design modification incorporated a "flat back" drum configuration* to increase the heat sink capacity of the drums.

*See RTS-Coach Service Bulletin No. R-80-I-81 in the appendix of this report for a full description.




Note: The movement of the actuator is sufficient to accommodate additional lining thickness. The actuator bolt was modified to permit full movement (GMC Service Bulletin, R-82-I-5) to permit use of bonded brake linings.

FIGURE 2-2. THE WEDGE BRAKE (ROCKWELL STOPMASTER)

## 2.2 BRAKE LININGS

The fundamental purpose of a friction brake system is to transform energy of motion (the motion of the bus) into heat energy through contact of the brake lining with the brake drum. Due to the mass and motion involved, a significant amount of heat is generated from this energy transformation, heat that must be first absorbed and then dissipated by the brake drum (serving as a heat sink). The lining acts as a heat insulator between the drum and the other components of the foundation brake, thereby protecting them from heat damage. Each time the brake is applied, lining material is "consummed" through this process, gradually resulting in slightly less lining thickness.

Brake linings are manufactured by several companies, and can be formulated to meet a variety of specifications depending upon the application and requirements of the customer. The primary consideration in specifying lining material is its friction character, usually expressed as the coefficient of friction, at specific speeds, temperatures and pressures. Furthermore, it is desirable to obtain lining material with uniform density and friction throughout its composition so that reliable on-the-road performance is realized. Over the years, most bus maintenance managers have developed procurement specifications to meet their own particular performance and maintenance needs. However, new materials and compositions are offered periodically and should be considered in new procurements.

One of the most important considerations in evaluating brake lining performance in transit bus applications is brake fade, that is, the tendency of the lining material to loose its friction characteristics as temperature increases. While brake fade is usually attributed to repeated high-speed stops, it can also occur at lower speeds under certain operating conditions. Frequent stopping does not allowing the brakes to cool sufficiently between stops, and can result in partial loss of braking capability.

Laboratory tests conducted by GMC engineers in the mid-1960's clearly demonstrate this phenomenon. As reported in SAE Publication No. 670510, Burkman and Highley show examples of good and bad brake lining performance in their "Fade and Recovery Tests". Figure 2-3 illustrates good lining performance, showing the test material with a fairly uniform coefficient of friction over the test series. Figure 2-4 illustrates poor lining performance, with excessive fall off in friction in the fade portion as the drum temperature is increased and very low friction values in the early part of the recovery portion.

Of late, combination linings have gained popularity. In a combination lining each shoe is fitted with two different lining materials, with one lining material on the leading half of each shoe and a different material on the trailing half. This approach is advantageous due to the differing forces acting on the four lining segments of each wheel (upper leading, upper trailing, lower leading and lower trailing) and the resultant differences in wear characteristics. The overall objective is to equalize the braking action across all four segments, thereby producing more even lining wear.

## 2.3 BRAKE BONDING

Bonded brake lining has been an accepted practice for automobiles and light duty trucks for many years, replacing the riveted brake lining previously used. However, in medium and heavy duty bus and truck installations, rivets and/or brass bolts are still used to attach the lining to the brake shoes. An agency contemplating a program to evaluate bonded linings should fully understand the technical aspects of the bonding process, quality control procedures and tests and selection criteria for bonding companies.

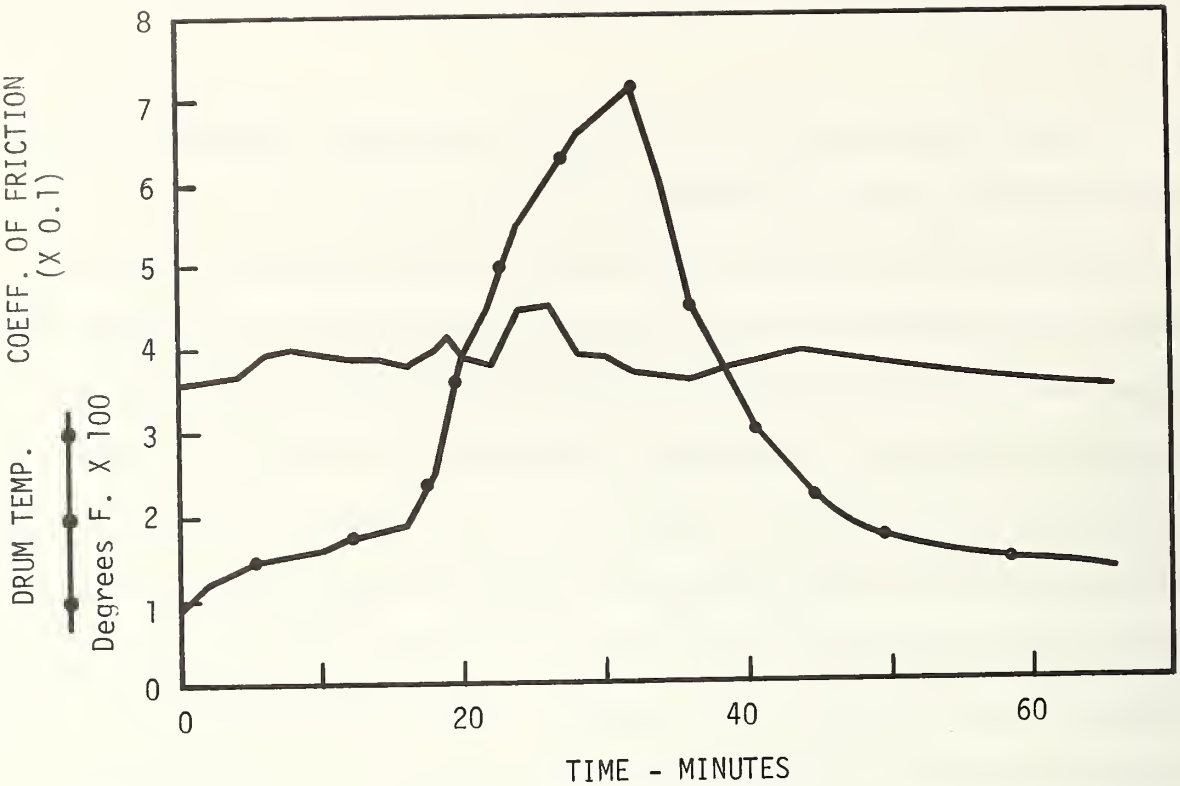



FIGURE 2-3. GOOD PERFORMANCE

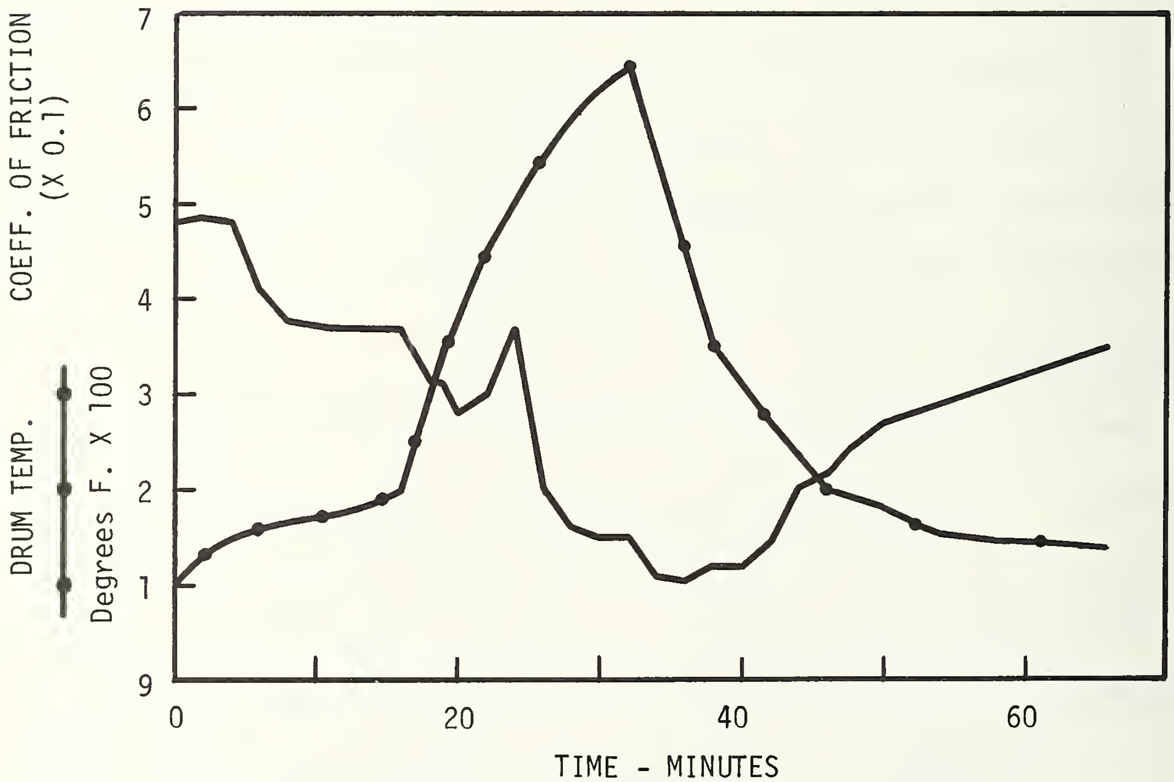



FIGURE 2-4. POOR PERFORMANCE

### 2.3.1 The Bonding Process

During the course of collecting information for this report, three bonders of friction materials in the Detroit area were contacted: Bonded Brakes, Inc. (2222 East Maple, P.O. Box 173, Birmingham, MI 48012), Midwest Brake Bond Company (26255 Groesbeck Highway, Warren, MI 48089), and Uni-Bond, Inc. (1350 Jarvis, Ferndale, MI 48220). Although each differed in scale of operation and particular technical approach for bonding friction material for bus applications, all three utilized the same basic procedure:

1. Remove old lining
2. Clean brake shoe
3. Prepare brake shoe
4. Prepare the lining
5. Apply adhesive
6. Clamp lining to shoe
7. Oven cure
8. Cool bonded shoe
9. Inspect and test
10. Grind bonded linings to proper dimensions.

Each of these steps is detailed in the following paragraphs in order to inform and impress the reader with the extent of the process and the degree of monitoring and control that is required.

Remove old linings - For bonded linings, removal is generally accomplished by heating to approximately 700°F (heat above this range could warp the metal brake shoes) and stripping the lining from the shoe. In contrast, bolted linings are removed by removing the bolts, a task typically performed by transit agency personnel.

Clean shoes - Whether new or used, brake shoes must be thoroughly cleaned. New shoes are heated in an oven in order to remove any oil or grease. Used brake shoes, after the remaining worn lining has been removed, are generally cleaned by acid-etching or by grit blasting.

Prepare shoes - In most cases, this step involves the application of a resin coating in order to prepare the shoe surface to accept the bonding adhesive and provide protection against rust. Application methods include dipping or spraying. Finally, just before the application of adhesive, shoes are cleaned once more in order to remove any dust or dirt with either compressed air or by brushing.

Prepare lining - The brake shoe and the lining segments must be properly prepared for bonding. Some brake linings are not compatible with all adhesives because of the porosity of the friction material or because of a coating used to make the brake lining segments easy to remove from the lining manufacturer's molds. Some bonders remove moisture absorbed in the friction material prior to bonding.

Apply adhesive - The adhesive should be applied so as to permit the escape of all solvents. Ambient temperature and humidity affect the drying rate. A variety of adhesives are available, and each specify their own application procedure. In general, adhesives come in either liquid or film form. Both are applied to the lining material and allowed to air-dry to a thickness of about 0.01 inch. Liquid adhesives appear to be the most popular because of their lower cost. Adhesive drying (before the lining is attached) is accomplished through either air-drying for 24 hours or heating at approximately 180°F for about 30 minutes.

Clamp lining to shoe - In this critical step, linings (pre-ground or semi-finished as received from the manufacturer) are temporarily secured to the shoes through some type of pressure device. The brake lining segments must be properly aligned in a fixture that keeps constant pressure on the lining as it is bonded at a pre-determined, closely-controlled temperature. Bonding companies utilize a variety of approaches in this step, but all strive to attain the same basic objective, i.e., produce a constant, uniformly distributed pressure of approximately 75 to 150 psi over the contact plane of the lining and shoe. Whatever clamping devices are used, they must be able to withstand the high oven temperatures needed for the bonding curing.

Oven cure - In order for the bonding adhesive to properly "set", it is necessary for the clamped shoe-lining assembly to be cured in an oven at a specific temperature for a specific time period. Typically, these curing parameters are established through each bonder's experience with particular adhesives and clamping mechanisms. In general, bonding temperatures range between 350° and 400°F. Bonders utilize thermocouples to monitor the temperature at the bonding surface.

Inspect and test - At this point in the bonding process a determination is made concerning the quality of the bond. This can be accomplished in several ways, depending on the practices of the bonding company, recommendations of the adhesive manufacturer and requirements of the transit agency's specifications. A visual inspection will reveal only gross deficiencies in the bond, such as mis-alignment of the lining on the shoe. In most applications some type of strength test should be conducted, such as an axial shear test. Less sophisticated strength tests have been applied in the past (such as a cold chisel test), but have proved to be ineffective in a brake bonding program.

Grind linings - The final step in a brake bonding process is to remove any excess adhesive. Where semifinished linings are used the bonder or the transit agency may perform the final grinding to proper size.

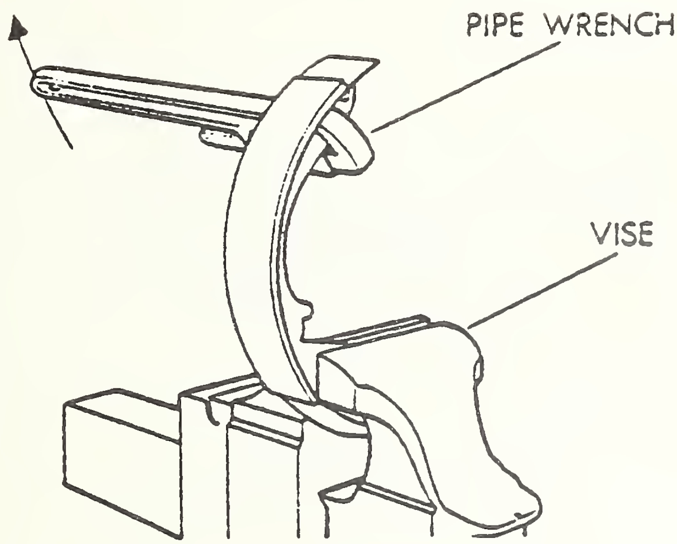
### 2.3.2 Quality Control for Brake Bonding

The most severe problem that could result from poor quality bonding is an in-service bonding failure (separation of the lining from the shoe). However, based on experience to date, such failures are not frequent.

Four commonly employed destructive testing procedures currently used by bonders to determine bond strength are the drop test, twisting test, chisel test and the axial shear test. The drop test is merely an impact test to quickly determine the integrity of the bond. The twisting test as shown in Figure 2-5, checks the elasticity of the bond. The chisel test as shown in Figure 2-6, checks the strength of the bond by examining where the separation occurs. These tests should be applied to samples selected at random to examine the condition of shoe/lining surface at the plane of failure and roughly determine the strength of the bond. A bond is deemed adequate if failure occurred in the lining material rather than at the bond surface.

The most desirable method for testing bond strength is an axial shear test, illustrated in Figure 2-7. With this approach, a load is applied to the lining near the bond plane. The force is increased to the point of destruction or to a predetermined point approximating a set percentage of the ultimate shear

*Because many brake lining products contain asbestos fibers, a known carcinogenic, bonding companies and transit authorities should conform to all applicable OSHA regulations.



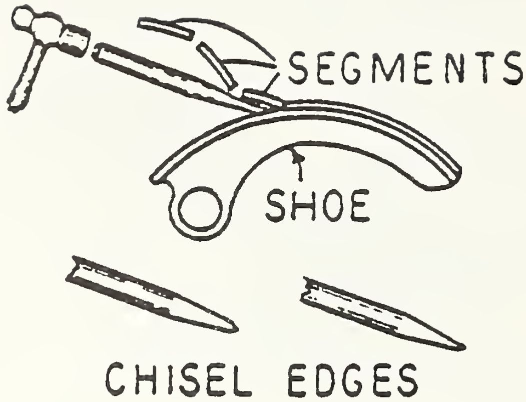

**Purpose**
To determine strength and elasticity of the bonding adhesive. The bond should be capable of absorbing impact. It cannot do this if it is so brittle that it will not withstand twisting. (Plastilock on the lining will not completely 'pop' from shoe - it will fracture into segments.)

**Equipment**
Vise and pipe wrench.

**Procedure**
Select a lightly constructed shoe. One that's 2" or 2-1/4" x 11" is best. Clamp one end of the shoe web in the vise. Tighten the pipe wrench on the opposite end of the web, and twist the shoe at least 90° and up to 180° if possible. For faster, easier testing cool shoes to 40°F. before testing.

**Report Data on Twist Test**
Note pattern of brake lining on shoe face. Did adhesive fail before lining? If adhesive separated onto lining and shoe, lack of impact resistance is indicated.

FIGURE 2-5. BONDED LINING TWISTING TEST (FROM B.F. GOODRICH BRAKE BONDING MANUAL)




CHISEL TEST

**Purpose**
To determine with simple hand tools the strength of a bonded shoe assembly.

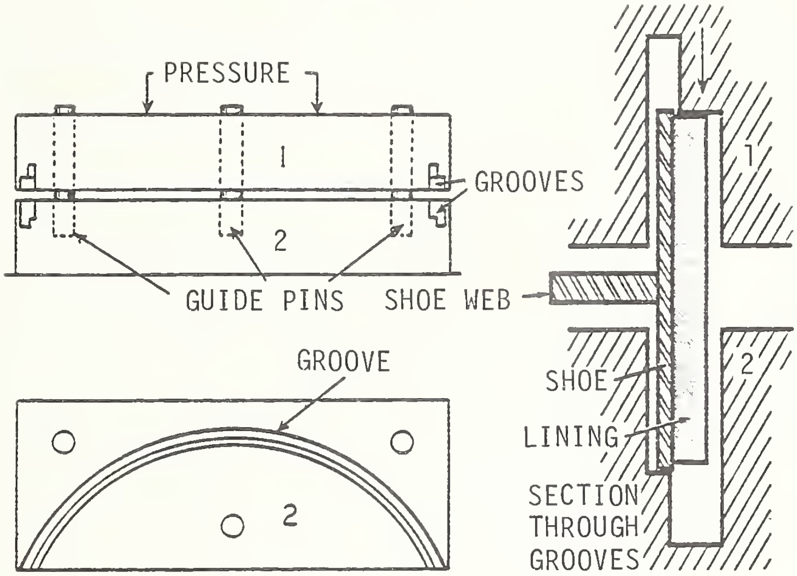
**Equipment**
Sharp cold chisel and hammer or mallet.

**Procedure**
Clamp the shoe assembly in a vise.
Chisel the lining from the shoe, starting at the bond line. Keep as close to shoe face as possible.

**Report Data**
Where did separation of lining from shoe occur?
(Bare metal, lining, or bond line?)
Was lining easy or hard to remove?
Note pattern of lining coverage on the shoe face. Any bare metal showing?

FIGURE 2-6. BONDED LINING GOLD CHISEL TEST (FROM B.F. GOODRICH BRAKE BONDING MANUAL)

AXIAL SHEAR TEST FIXTURE




Source: B.F. Goodrich Brake Bonding Manual

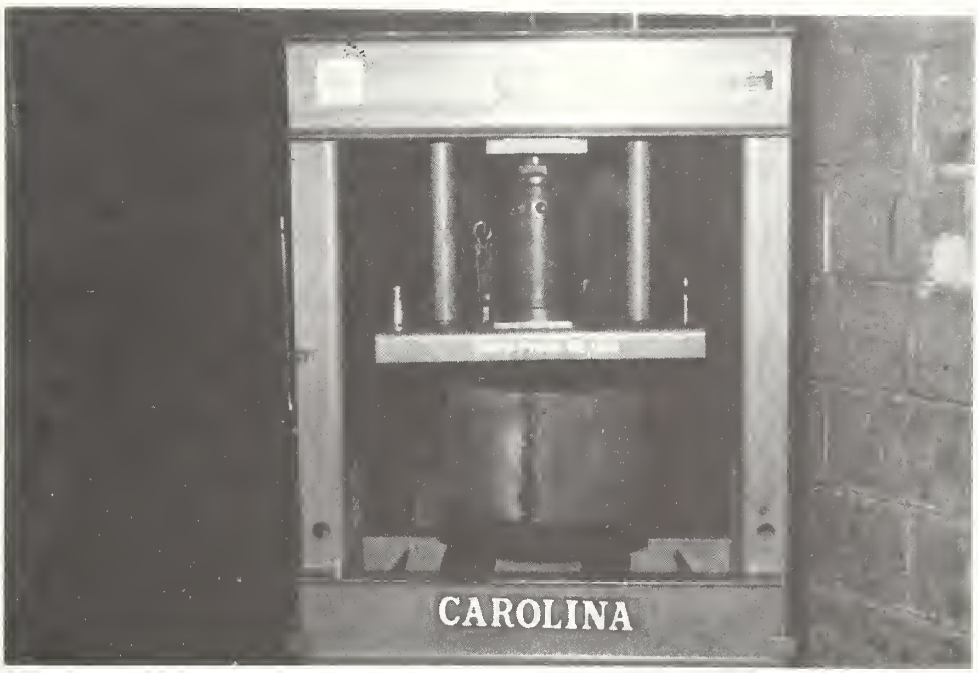



FIGURE 2-7. AXIAL SHEAR TEST FIXTURE (FROM B.F. GOODRICH BRAKE BONDING MANUAL)

strength, or "proof load". In pre-qualifying bidders prior to the award of a bonding contract, it may be useful to test a sample of each batch of shoes/linings for ultimate failure and a portion at the proof load level.

The Society of Automotive Engineers has developed a formal procedure for this type of shear test - SAE Recommended Practice J840c. Although it is usually applied to automotive and truck brake shoes, it has been found to be effective for bus brake shoes as well.

If an axial shear test procedure is used, an examination of selected samples should be made of those shoes/linings loaded to destruction in order to determine whether the failure occurred in the lining material or at the bond surface. As much as feasible, this examination should be made by personnel of the transit agency.

### 2.3.3 Selection of Bonding Companies

In many cities in this country there are companies that have the capability for the bonding of friction materials to brake or clutch pads. These companies presently provide bonding services to a wide variety of industrial and automotive customers and, under the proper set of circumstances, should be willing and able to apply their expertise to bus brake bonding. There are a few important considerations to be addressed in those areas where brake bonding has not been established for bus application so that inferior bonding services are not inadvertently obtained. All of these questions can be resolved by the transit agency through conducting a pre-bid qualification process.

First, the bonding company must be able to demonstrate that it possesses adequate facilities for proper bus brake bonding, including ovens, clamping devices and test equipment. Second, the bonder should also have experience in bonding brake lining material of similar characteristics with that used for bus brakes. Third, all potential contractors must be able to demonstrate that they can handle the required volume of work for shipping, bonding and storage to meet the transit agency's needs.

For a startup program as many bonding companies as possible should be solicited for participation in a small-scale test program. The transit agency should determine if the bonder can perform in accordance with the program requirement and the bonded linings meet minimum strength criteria. After this pre-bid qualification process has been conducted, formal bids can be obtained.

# 3. COMPARISON OF BONDED VERSUS BOLTED BRAKES

In this section, bonded and bolted brakes are compared with regard to safety, performance, maintenance, supply and inventory, and costs. The structure of this analysis, as well as the data used, should be useful to maintenance managers to assess the potential value of bonded brakes at their agencies.

## 3.1 SAFETY

For both S-cam and wedge brakes, the major safety concern is that of an in-service debonding, i.e., the lining detaches from the shoe as a result of bond failure. This concern is presented here in terms of two considerations, namely the causes and consequences of such occurrences.

In-service debonds can generally be grouped into two areas: Those debonds that relate to bonding procedures and those debonds that are related to excessive brake temperature. Contributing causes of debonds resulting from improper bonding procedures or poor quality control, include, but are not limited to:

1. Use of lining material that is not suitable for bonding, such as some metallic linings;
2. Use of friction materials where mold release agent has not been adequately removed from contact surface;
3. Improper alignment of the lining on the shoe;
4. Use of damaged or improperly prepared shoes;
5. Use of lining containing excessive moisture;
6. Use of improper adhesive;
7. Improper application of adhesive;
8. Inadequate or uneven clamping pressures;
9. Inadequate time or temperature for bonding curing.

Debonds attributable to quality control problems did occur during the early years of testing at Detroit-DOT (then known as Detroit Street Railway) but with no adverse safety consequences. Bond failures were usually discovered when the driver wrote a defect report for slow brakes or a mechanic found the debond during scheduled inspection. However, as recently as 1983-84 data from an UMTA-sponsored bonded brake program at the Southeastern Michigan Transportation Authority (SEMTA) indicates that of five test buses, three experienced debonding. SEMTA personnel attributed these debonds to quality control problems.

While the previous causes of debond are related to the bonding process, debonds can also occur as a result of certain transit operating conditions. Such conditions, although difficult to quantify, involve a combination of excessively high temperatures for sustained time periods and high braking torques.

It is well recognized that the energy of a moving vehicle is translated into heat in the braking system. Brake drum temperatures of 500-600°F are not abnormal in transit operations with frequent stops, heavy loads and braking from high speeds. Kinetic energy is a function of the square of the vehicle speed ($KE = 1/2\ MV^2$) and in the foundation brake this kinetic energy is converted directly to heat.*

As part of its testing of vehicle retarders, D-DOT obtained measurements of brake lining temperatures on one of its in-service buses without a retarder in operation during August, 1982. In spite of high passenger loads, frequent stops, and +90°F ambient conditions, brake lining temperatures measured at the bond plane remained below 350°F. Temperatures at the bond plane would be substantially lower than drum temperatures because of the insulating effect of the friction material.

*Heat in BTUs = Kinetic Energy divided by 778 foot-pounds.

In 1977 Rockwell International conducted dynomometer tests to determine the relationship of drum temperatures and bond line temperatures for Mack Trucks, Inc. The test data, shown below, demonstrated that debonding occurred at a bond line temperature of 940°F with a brake drum temperature of 1100°F.

TABLE 3-1. BOND LINE VS. DRUM TEMPERATURE

| Drum Temperatures | | Bond Line Temperatures |
|---|---|---|
| 300°F | | 240°F |
| 400°F | | 320°F |
| 500°F | | 410°F |
| 600°F | | 500°F |
| 700°F | | 600°F |
| 800°F | | 660°F |
| 900°F | | 720°F |
| 1000°F | | 840°F |
| 1100°F | --- (Debond occurred) --- | 940°F |

Source: Correspondence (6/10/77) from Rockwell International

The friction material itself acts as an insulator against heat transfer between the drum and the bond plane. The insulation effect decreases, however, as the lining wears. A more meaningful test result conducted at that time by Rockwell demonstrated that the bonded brake operated safely in a test using the SAE-J840C procedures. This procedure requires 50 stops from speeds of 70 mph at 155 fpsps with bond line temperatures sustained at 650°F. These test results obviously represent a specific set of conditions, including the quality of the bonding, the thickness and composition of the lining, and the adhesive used.

Transit agencies should ensure that proper bonding procedures are followed and be aware that debonds can still occur under certain operating conditions.

For the S-cam brake there is an additional safety concern - brake malfunction due to "cam lockup" or "cam rollover". Either could occur if the cam rotated too far as a result of an excessively high cam ride on the roller. Cam lockup is when the roller reaches a high point on the cam just as the lining contacts the drum, causing the brake to lock on. Cam rollover is the condition when the roller travels past the high point of the cam causing the loss of braking in that wheel. Either condition can occur if the linings wear sufficiently and are not replaced in time.

Although cam lockup can occur on S-cam brakes with conventional bolted linings, there is a greater tendency for lockup with bonded linings. The cam is designed to force the brake shoe against the drum for a specific depth of lining, after which the bolt heads begin contacting the drum. On bonded brakes without installation of an oversized roller, the additional lining available for wear permits the roller to ride up on the cam and lock the brake on. Detroit DOT reports modifying the shape of the S-cam to reduce the possibility of cam lockup with bonded brakes. This modification required grinding down the trailing ends of the S-cam. No data is currently available to assess the effectiveness of this modification.

Since bonding allows extended wear of the lining material, the brake shoes must be able to move farther out as the lining wears in order to continue to contact the brake drum for braking applications. To accommodate the additional useful thickness made available by bonding, oversize cam rollers must be installed at about the same point in lining wear that a bolted lining would be removed. The greater diameter of the larger rollers satisfies the additional radial movement requirement of the bonded brake shoes, and allows the S-cam mechanism to function as it was designed for an extended period. In instances where brake lining wear varies between the front and rear axle, it may be necessary to install the rollers at different mileage intervals. The need to install oversize rollers at the optimum wear point emphasizes the increased safety requirement for a proper brake inspection program when bonded linings are used on S-cam brakes.

## 3.2 PERFORMANCE

In general buses equipped with bonded linings appear to exhibit no measurable difference in braking performance, such as stopping ability, compared to similar coaches equipped with bolted lining of the same composition and thickness. The manner in which the lining is attached to the shoe does not influence how the foundation brake functions in terms of applied forces and heat generation given similar operating environments. The assumption is that there is no change in the friction characteristics of the bonded lining material with extended wear-down and exposure to break heat.

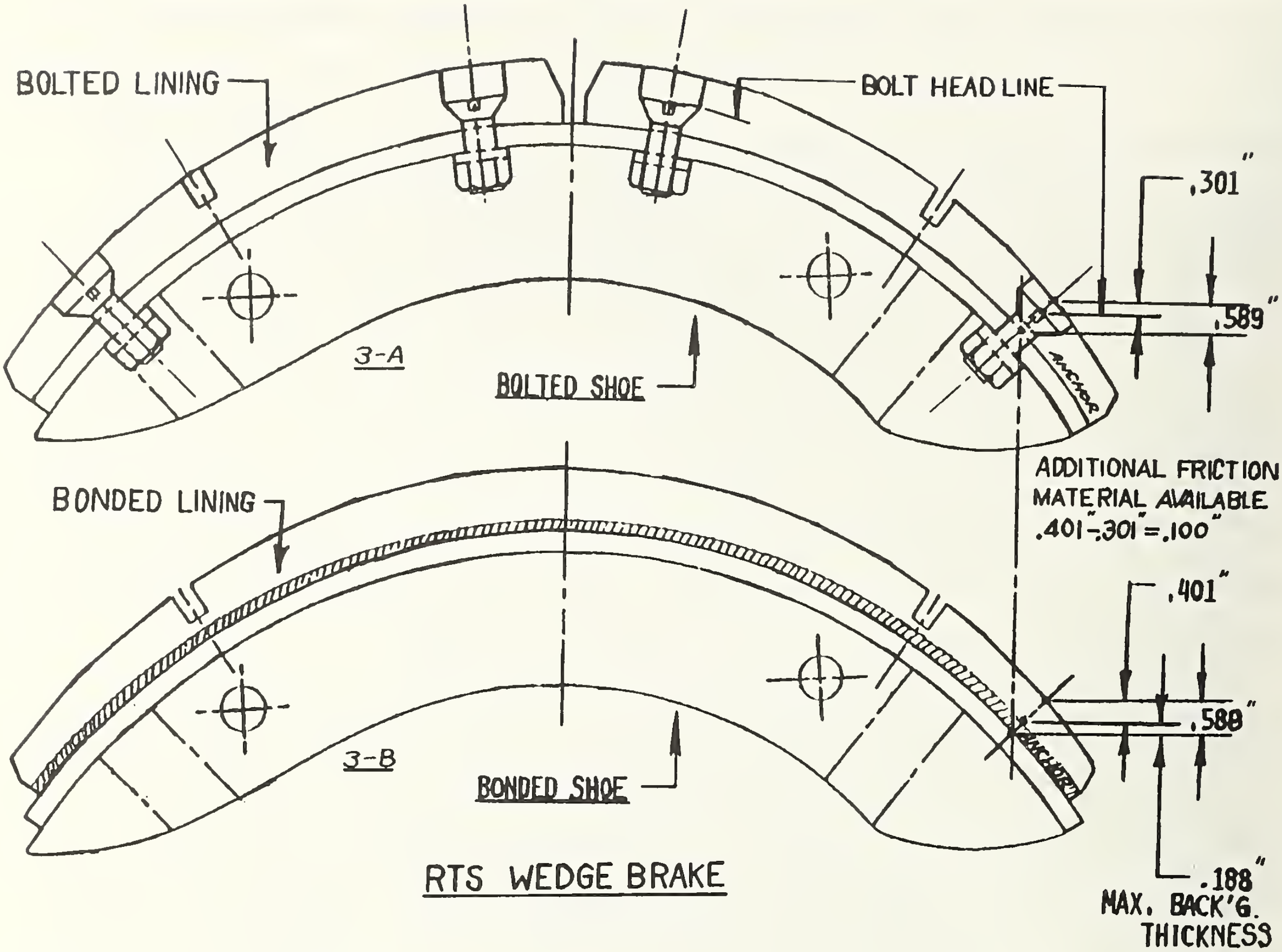
D-DOT reports that the braking efficiency of a bonded brake that has had oversize rollers installed with the original lining retained is initially higher than a brake that has a new lining because a wear-in period is not needed. Normally, a new lining goes through a wear-in period until its entire surface is "seated". In contrast, when only oversize rollers are installed on brake shoes with partially worn linings, the original wear pattern is not disturbed and the brake retains its efficiency. The use of bonded linings demands a superior brake maintenance program with frequent inspections to insure that lining wear-down is not allowed to progress to the extent that brake performance deteriorates and the steel brake shoe contacts and changes the brake drum. This is especially important since uneven brake wear readily occurs.

## 3.3 MAINTENANCE

The most significant maintenance difference between bonded brakes and bolted brakes is the extended lining life made possible by bonding. Figure 3-1 illustrates the increase in available lining thickness of the bonded linings. The more miles that can be accumulated on a set of linings, the fewer brake relines will be required over the life of the bus. Since a brake reline is a significant maintenance/undertaking, a reduction in the total number of brake reline occurrences is cost effective. However, if bonded linings are removed before the additional friction material gained through bonding is used, this cost advantage is lost. Reasons for premature removal of brake shoes include maintenance practices requiring maintenance on both axles when only one axle requires brake reline, brake replacement when wear approaches the scribe line on bolted linings, or misadjustments or misalignments of other components of the brake system. Figure 3-2 illustrates worn bonded shoes received at the bonder for debonding with significant friction material remaining.

In addition to the cost considerations associated with fewer brake relines, such reductions in maintenance requirements have impact on bus downtime and mechanic work distribution. Based on the increased thickness of friction material available for braking with bonded linings and the reported experiences of Detroit DOT it is estimated that mileage between brake relines can be extended 20-40 percent.

Another distinction in maintenance practices between bonded and bolted linings is the mechanic training and implementation of brake inspection procedures needed to ensure roller replacement at the appropriate time in S-cam brake systems. All bus transit maintenance departments conduct some form of periodic bus brake inspection and adjustment activity. This is usually performed at one to two week intervals depending on service profiles and other operating conditions and usually takes no more than fifteen minutes per vehicle.




Source: Presentation by GMC Truck and Coach to Bus Technology Committee, April 25, 1980.

FIGURE 3-1. COMPARISON OF AVAILABLE LINING THICKNESS: BOLTED SHOE AND BONDED SHOE INSTALLATION

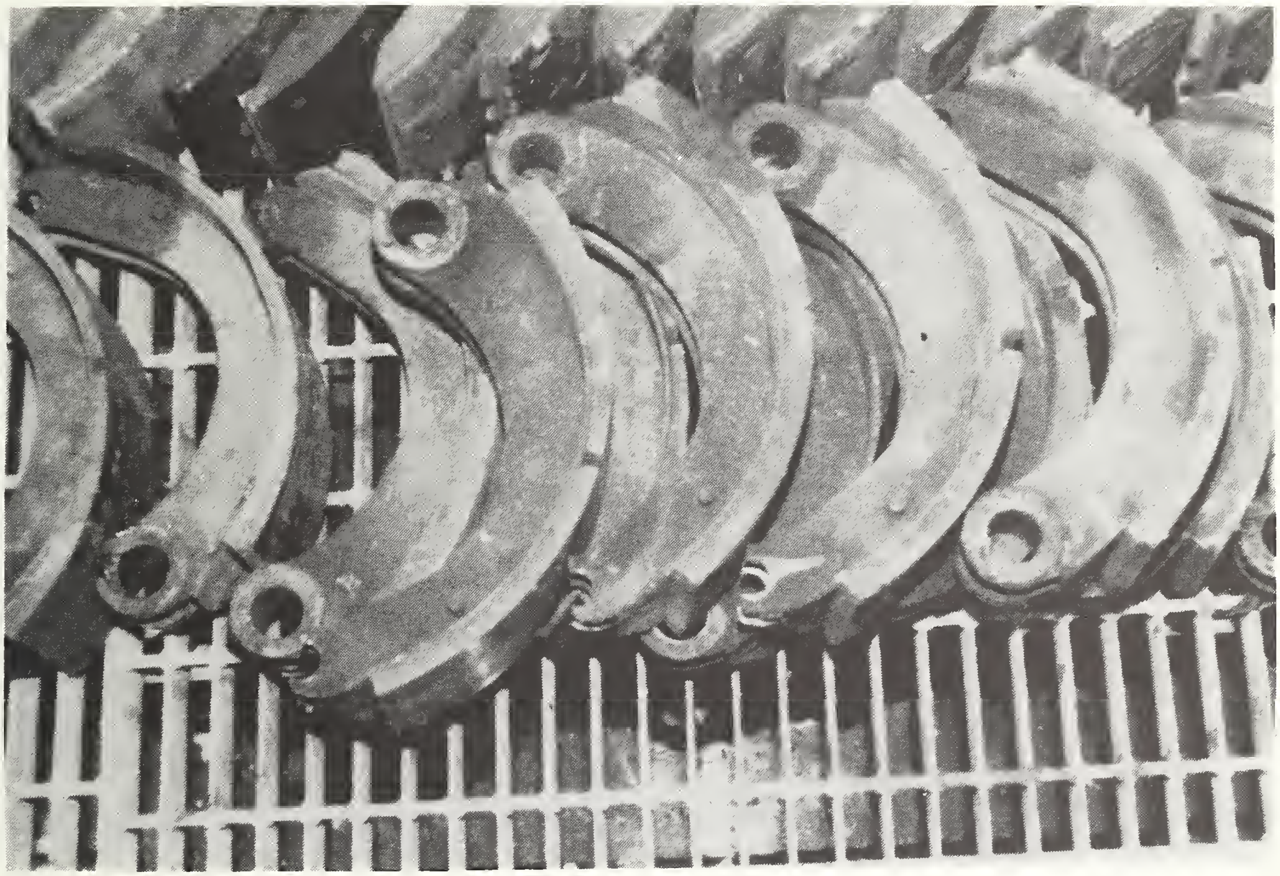


FIGURE 3-2. USED BONDED BRAKE SHOES READY FOR DEBONDING

Furthermore, most maintenance organizations utilize this time to check for brake lining wear.

In a bonded lining program for S-cam brakes, it is necessary to install oversize brake rollers before the cam angle excees 60 percent of its total lift. Detroit DOT incorporated the inspection for this cam angle into their regular weekly brake inspection cycle and a D-DOT designed cam position indicator was used to measure brake wear. Whenever an inspecting mechanic determined that the cam angle had exceeded its allowable limit, the bus was sent to the brake repair section of that garage or shop for installation of oversize rollers, a maintenance task requiring about six hours of mechanic time. Further information on use of the D-DOT Brake Cam Position Indicator is provided as Figure 3-3.

Bonded linings on the wedge brake do not require any increased inspection or maintenance activities as does the S-cam brake. It is still necessary, however, to ensure that the bonded lining on the wedge brake does not wear to a point where the lining fractures, the friction characteristics are diminished or the shoe contacts the drum. A potential advantage of bonded linings on wedge brakes is that bonding permits scheduled overhaul/rebuild of the foundation brake to coincide with the brake reline.

## 3.4 SUPPLY AND INVENTORY

Whether or not brake overhaul work is done at a central shop or at an operating garage, certain basic work must be accomplished, i.e., machining brake drums to match brake linings and rebuilding major foundation brake components. For those agencies with only single spindle drum lathes, brake drums must be cut to predetermined sizes corresponding to three factory-ground brake lining thicknesses: standard, first oversize, and second oversize. For those transit

## BRAKE CAM POSITION GAGE

**Designed and made in DSR shops, this gage indicates the position of the brake cam at any time; and shows the proper time to install oversize brake shoe rollers to obtain full wear from bonded lining.**

**Installation:**

1 — Back off rear brake shoes completely. Each brake cam must be in "zero" position for proper installation of gage (figure 1).

2 — Remove slack adjuster retaining washer.

3 — Install cam gage (which also takes the place of the retaining washer). To properly align the pointer of the gage, use the template as shown in figure 1. Template is stamped L.H. (left hand) or R.H. (right hand). When the Cam Gage is properly installed, the pointer (figure 2) will always point to the rear of coach with S-cam in "zero" position.

4 — Re-adjust the brakes.

As brake lining wears and brakes are adjusted the pointer will move to a position approximately ½ in. before the guide rivet (figure 3). The oversize rollers should be installed at this time. Subsequent lining wear and brake adjustments will bring the pointer to the "high cam" position (figure 4).

When checking or adjusting brakes and the pointer is near either position, (for oversize roller installation or "high cam"), adjust brake shoes tight against the drum and use the template (figure 1) to determine exact position of pointer. The installation procedures must be followed closely to assure proper operation of cam position gage.

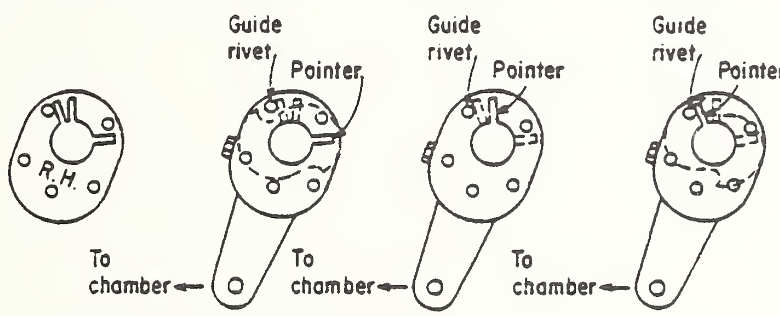



Fig. 1 Template | Fig. 2 "Zero" position | Fig. 3 Install O/S rollers | Fig.4 High cam position

FIGURE 3-3. D-DOT BRAKE CAM POSITION INDICATOR agencies with dual spindle brake lathes, brake drums and the linings can be machined together by transit maintenance personnel at the site of brake reline, thereby allowing for an infinite number of drum diameters and lining thicknesses (up to a predetermined maximum).

If transit agencies were to substitute bonded brake linings for bolted linings, a few additional considerations would have to be made. First, a larger inventory of brake shoes would have to be maintained in order to allow the bonder time to process the bonded shoes and return them to the transit agency and, more importantly, to have sufficient inventory of bonded linings to match available brake drums. More bonded shoe and lining sets are required if brake drums are not custom turned with matching linings on double spindle lathes. As an example of increased inventory a rule of thumb developed at D-DOT indicates that a 10 percent spare factor should be on site, and 12 to 15 percent consigned to the bonder.

Secondly, a bonded lining program necessitates the establishment of an inventory of oversize brake shoe rollers for those transit agencies planning to install bonded linings on buses using S-cam brakes. At D-DOT, it was determined that the quantity of oversize brake shoe rollers should be equivalent to the bonder's shoe inventory, or 12 to 15 percent of the total shoe requirement for each type bus.

Detroit DOT reports that over the course of its bonded lining program, varying degrees of centralization of maintenance activities have existed. However, none of these organizational structures presented any significant problem with inventory, installing or maintaining bonded linings.

## 3.5 COSTS

The final, and probably most important, criterion for an evaluation of bonded versus bolted brakes is costs. Many of the criteria described in the previous paragraphs can be expressed in terms of dollars, thereby permitting a quantitative comparison. In this section, relevant costs, some of which are typically neglected in bus maintenance cost-effectiveness analyses are identified and analyzed on the basis of life cycle costs.

For the purposes of this analysis, it is assumed there are no cost-related differences between the safety and braking performance of bonded and bolted brake linings. Hence, all cost differences relate primarily to capital costs and brake maintenance activities. The analysis in this section of the report will be made in terms of changes to be expected from implementing a bonded program. The data used for the cost comparison was obtained from Detroit DOT and Southern California Rapid Transit District (SCRTD). The bonded brake programs conducted at these agencies are described in the appendix.

First of all, there are those costs associated with developing and establishing a procurement methodology to obtain the bonding service. In most cases, this would involve refinements to an existing set of specifications and, perhaps, inspecting local bonding facilities as part of a pre-qualification process. Cost considerations related to these activities are primarily administrative and, to a lesser degree, engineering. In terms of scale these activities are no different than many other product and service procurements and most transit agencies are well-equipped to meet these initial start-up needs, especially if they are accustomed to contracting out some of their maintenance work (e.g., unit rebuilding).

Secondly, an extra inventory of brake shoes must be purchased to allow for sufficient stock of lining sizes on hand at the agency, in process at the bonders and in shipment. As mentioned earlier, a total of about 25 percent more shoes would be required to meet this need - 10 percent on the agency's property and about 15 percent at the bonder. For S-cam brakes, an inventory of oversize rollers must also be established, representing about 15 percent of the total shoe requirement. Shortages of this equipment at the transit agency could result in additional out-of-service time.

Up to this point, all cost considerations listed have been one-time only expenditures. The following paragraphs describe those cost factors that are job-specific, and recurring. A cost analysis and comparison of bonded and bolted brake linings is performed for both wedge brake and S-cam brake foundations.

Table 3-2 lists the labor, materials and downtime cost factors associated with a typical 4-wheel bolted brake reline maintenance action on a wedge brake system. These factors were derived from test and maintenance records of D-DOT and SCRTD, and are presented in terms of minor and major brake overhauls.

TABLE 3-2. BOLTED BRAKE RELINE COST FACTORS (WEDGE BRAKE)

Labor Cost Factors-Minor Overhaul
- L1. Bus moving and positioning
- L2. Remove & replace (R&R) brake components (minor)
- L3. Moving and cleaning drums
- L4. Turning drums
- L5. Removing old linings
- L6. Sandblasting and painting shoes
- L7. Bolting on new linings

Labor Cost Factors-Major Overhaul
- L1 through L7 from above
- L8. R&R brake components (major)

Material Cost Factors-Minor Overhaul
- M1. 1/3 Brake drums*
- M2. Retainer springs
- M3. Brake block (drilled)
- M4. Bolts and nuts

Material Cost Factors-Major Overhaul
- M1 through M4 from above
- M5. Major brake components

Downtime Cost Factor-Minor and Major
- D1. Out of service for brake reline

*Each drum is assumed to last through three or four sets of linings before replacement.

Table 3-3 shows the labor, materials and downtime cost factors associated with a bonded reline of a wedge brake system. This breakdown assumes that the bonding company is responsible for procuring brake block material and delivering the bonded lining/shoes to the transit agency's brake maintenance location. The same information sources were used as those for Table 3-2.

TABLE 3-3. BONDED BRAKE RELINE COST FACTORS (WEDGE BRAKE)

Labor Cost Factors-Minor Overhaul
- L1. Bus moving and positioning
- L2. Remove & replace (R&R) brake components (minor)
- L3. Moving and cleaning drums
- L4. Turning drums

Labor Cost Factors-Major Overhaul
- L1 through L4 from above
- L5. R&R brake components (major)

Material Cost Factors-Minor Overhaul
- M1. 1/3 Brake drums
- M2. Retainer springs
- M3. Bonded lining/shoes

Material Cost Factors-Major Overhaul
- M1 through M3 from above
- M4. Major brake components

Downtime Cost Factor-Minor and Major
- D1. Out of service for brake reline

For S-cam brakes, the additional labor and material cost factors associated with installing oversize rollers must be considered.

At this point, the basic format of each type of brake reline task has been identified. Since we are concerned with only the differences between the two approaches, it may appear acceptable to eliminate those factors common to both. However, because the frequency of these maintenance tasks must be taken into account, such a simplification is not possible without affecting the cost-effectiveness analysis.

The values for labor and material unit costs will vary among transit agencies. In some cases, specific procedures may vary from those factors listed in Tables 3-2 and 3-3, resulting in differing cost-effectiveness calculations. For example, sandblasting and painting brake shoes is an important task for a northern transit operation where buses are subjected to a corrosive environment. Such precautions may not be applicable to a southern operation. Differences between transit agencies in their brake reline procedures, labor rates, and material costs must be taken into account when undertaking a cost-effective evaluation for a specific operation. For the purposes of this report, labor and material costs from the D-DOT and SCRTD test experiences will be utilized, thereby providing a range of analysis results. For the SCRTD coaches the bonded brakes were purchased as original equipment. At D-DOT, because of the close proximity of the bonder, there were no shipping charges. Agencies at other locations should consider these additional costs.

Applying labor rates, labor hours and material costs from D-DOT and SCRTD maintenance information, expenses for each of these major cost factor categories were calculated and are presented in Table 3-4 for RTS-II wedge brake overhauls. The differences in costs between the two transit organizations reflect varying labor rates, material procurement and brake overhaul practices. For the D-DOT data, costs for a minor and major overhaul are combined into a weighted average since their experience shows that a major overhaul is required following every two minor overhauls. Data was not available from SCRTD concerning expenses associated with major brake overhauls, hence its cost-effectiveness analysis is based soley on minor overhauls.

TABLE 3-4. BRAKE RELINE EXPENSES FOR D-DOT AND SCRTD (WEDGE)

| | TOTAL EXPENSES PER BUS RELINE | |
|---|---|---|
| | Bonded | Bolted |
| D-DOT Minor Overhaul | | |
| Labor | $ 266.91 | $ 266.91 |
| Material | 359.15 | 349.15 |
| Downtime | 480.00 | 480.00 |
| Total | $1,106.06 | $1,096.06 |
| D-DOT Major Overhaul | | |
| Labor | $ 398.10 | $ 398.10 |
| Material | 697.31 | 687.31 |
| Downtime | 480.00 | 480.00 |
| Total | $1,575.41 | $1,565.41 |
| D-DOT Weighted Averages | $1,262.51 | $1,252.51 |
| SCRTD Minor Overhaul (Michigan Bonded Linings) | | |
| Labor | $ 271.60 | $ 271.60 |
| Material | 535.64 | 404.01 |
| Downtime | 480.00 | 480.00 |
| Total | $1,287.24 | $1,155.61 |
| SCRTD Minor Overhaul (West Coast Bonded Linings) | | |
| Labor | $ 271.60 | $ 271.60 |
| Material | 491.64 | 404.01 |
| Downtime | 480.00 | 480.00 |
| Total | $1,243.24 | $1,155.61 |

Table 3-5 combines the cost data from above with mileage experiences of the D-DOT and SCRTD in-service bonded brake lining test programs (descriptions of these test programs are provided in the appendix of this report). Cost-effectiveness measures are then calculated.

TABLE 3-5. BONDED VS BOLTED COST-EFFECTIVE MEASURES (WEDGE)

| | COST PER BUS RELINE (1981 $) | | |
|---|---|---|---|
| | Bonded-Michigan | Bonded-West* | Bolted |
| D-DOT | | | |
| Miles/Reline | 19,400 | NA | 16,600 |
| Total Cost/Reline | $1,263 | NA | $1,253 |
| Cost/1,000 Miles | $65.10 | NA | $75.48 |
| SCRTD | | | |
| Miles/Reline | 28,250 | 28,250 | 22,500 |
| Total Cost/Reline | $1,287 | $1,243 | $1,156 |
| Cost/1,000 Miles | $45.56 | $44.00 | $51.38 |

*Estimated cost only. No bonding was performed for SCRTD by a West Coast bonding company.

The figures shown in Table 3-5 indicate cost savings of $7.38 and $5.82 per 1,000 miles for local and out-of-state bonding, respectively, for the SCRTD test program. For the D-DOT case, savings of $10.38 per 1,000 miles were realized through brake lining bonding. Such savings are significant, especially when applied over the life of the bus.

Concerning cost savings for S-cam brakes, only data from D-DOT's late 1960's test are available. The analysis conducted by D-DOT staff at that time is summarized in Table 3-6, and shows savings in excess of 30 percent realized through the use of bonded linings due primarily to the significant improvement in mileage between relines.

TABLE 3-6. D-DOT BRAKE OVERHAUL COSTS FOR COMPLETE BUS (S-CAM) BONDED VERSUS BOLTED LINING (January 23, 1970)

| | COST PER BUS RELINE (1970 $) | | |
|---|---|---|---|
| | Bonded Lining | Bolted Lining | |
| Labor Costs | | | |
| Transferring Coach | $ 5.01 | $ 5.01 | |
| Shop Overhaul | 110.12 | 110.12 | |
| Moving & Cleaning Drums | 5.17 | 5.17 | |
| Turning Drums | 15.08 | 15.08 | |
| Cutting Wear Lines | .89 | .89 | |
| Removing Old Linings | --- | 2.69 | |
| Sandblasting & Painting Shoes | --- | 2.15 | |
| Bolting on New Linings | --- | 2.69 | |
| Building Up Brake Chambers | 3.58 | 3.58 | |
| Installing Oversize Rollers | 21.48 | --- | |
| Total Labor Costs | $161.33 | $147.38 | |
| Material Costs | | | |
| Seals & Springs | $ 11.44 | $ 11.44 | |
| Brake Block (Drilled) | --- | 32.24 | |
| Brake Block (Undrilled) | 30.96 | --- | |
| Nuts & Bolts | --- | 3.84 | |
| Brake Drums (1/3 Cost) | 39.66 | 39.66 | |
| Bonding Service | 16.00 | --- | |
| Total Material Costs | $ 98.06 | $ 87.18 | |
| Total Costs | $259.39 | $234.56 | |
| Average Brake Life (Miles) | 58,732 | 36,788 | |
| Cost/1,000 Miles | $ 4.42 | $ 6.38 | (potential 31% improvement) |

## 4. CONCLUSIONS

Bonding brake linings can be cost-effective for many bus maintenance operations. Circumstances important to a safe and cost-effective brake bonding program include:

1. Local capability for heavy-duty brake bonding.
2. Comprehensive procurement specifications, including rigid quality assurance procedures.
3. Proper operation of foundation brake components.
4. Capability for handling increased volume of shoes, linings, and roller inventories.
5. For S-cam equipment, provisions for inspection and subsequent installation of oversize rollers at the optimum lining wear point.

If the above conditions can be met, maintenance managers can expect cost savings on the order of ten to thirty percent compared with conventional bolted linings, depending on factors, such as type of foundation brake, severity of service, and brake maintenance practices.

Bonded brake linings have been tried at various bus authorities, including COTA (Ohio), SCRTD (Los Angeles), SEMTA and D-DOT (Detroit). General Motors recommended the use of bonded brake linings in response to transit agency complaints of poor brake lining life on early RTS coaches. With the exception of test installations, SEMTA and D-DOT appear to be the only transit agencies that at this time continue to maintain a bonded brake program for transit coaches.

Some transit operations and maintenance personnel have expressed a general reluctance to permit brake lining wear beyond that point traditionally established by bolted brake lining without significant cost savings - an apparent perception of too much to lose and not enough to gain. The non-availability of local, competent companies with bonding capability is another, although lesser, issue in expanding the use of bonded brake linings for bus operations. Some in the brake bonding business feel that adequate local bonding capabilties could evolve as the markets for bonded brake linings are established across the country.

The principal safety concern is the possibility of a separation of the brake lining from the brake shoe while the bus is in service. In-service debonds can be traced to either problems in the bonding or excessive brake temperatures. Specifications that include a rigid quality control program can minimize debonds that are the result of improper bonding procedures. However, debonds can still occur under certain operating conditions where unusually high brake temperatures are sustained for extended periods. In actual practice debonds are normally detected either by the driver who reports a slow brake or the mechanic during regularly scheduled brake inspections. However, because bonding permits lining wear beyond that attained with bolted linings, operating conditions can arise where excessively worn linings can debond or fracture, possibly causing brake lockup or loss of brake in one or more wheels.

Additionally, when the brake lining wears approximately two-thirds on S-cam brake installations, cam lockup and/or rollover can occur, affecting the brake action on that wheel. To allow for the additional depth of the bonded lining, oversize cam rollers are installed at this wear point to prevent cam lockup and/or rollover. This necessary maintenance action can be a major problem and cost for many large transit agencies and could discourage the use of bonded brake linings on buses equipped with S-cam brakes.

Many transit and truck operators have found that the wedge foundation brake, with its automatic adjustment feature, can provide extended trouble free operation provided the complete foundation brake assembly is rebuilt periodically. Therefore, bonding a quality lining on the wedge brake can significantly extend mileage between relines and can offer the opportunity to combine lining replacement with scheduled brake rebuild. This appears to be the most cost-effective application of bonded linings.

APPENDIX
TRANSIT INDUSTRY EXPERIENCE WITH BONDED BRAKES:
DETROIT DEPARTMENT OF TRANSPORTATION AND SOUTHERN CALIFORNIA RAPID TRANSIT DISTRICT

## A.1 INTRODUCTION

In the mid-1960's, Detroit Department of Transportation (D-DOT) implemented bonded brake linings on its GMC New Look fleet (equipped with S-cam foundation brakes). D-DOT's system-wide conversion to bonded linings continued until the late 1970's when the bonding program was temporarily suspended because of procurement problems. D-DOT re-initiated the brake bonding program when the agency began experiencing short lining life on their new RTS-II fleet. From that time until the present, bonded brake linings have been the standard at D-DOT.

At SCRTD, on the otherhand, a revenue service test of bonded versus bolted linings was initiated in 1981 with the delivery of new GMC-RTS-II coaches. General Motors Truck and Coach in cooperation with SCRTD was interested in determining the cost effectiveness of bonded brake linings.

Before these two projects are presented in more detail, a general comment should be made concerning the inherent limitations of evaluating brake lining life for in-service buses. Due to the nature in which buses are operated and maintained in most urban transit operations, it is extremely difficult to obtain a complete picture of the causes of brake lining wear. Brake imbalance, differing service profiles and varient driver characteristics represent some of the variables that are difficult to control and almost never measured in brake lining wear tests. Furthermore, most transit agencies reline brakes on at least one axle at a time, as determined by the maximum lining wear on either wheel on that axle in order to reduce overall maintenance costs and minimize bus out-of-service time. This results in the removal of linings from the lesser worn wheel on the same axle that could have many miles of service remaining.

The overall result of these conditions and practices is that "mileage between relines" is not always an accurate measure of brake lining wear. It is, however, the most frequently utilized criterion for evaluation. This measure can be a meaningful indicator in an in-service test program only if a large number of buses are involved and the test is conducted over a long period of time. The D-DOT and SCRTD test programs were conducted in this manner.

## A.2 DETROIT DOT'S BONDED BRAKE PROGRAM

In December 1963, D-DOT began testing bonded brake linings on ten GMC New Look buses, using the same lining material as in its bolted brake program - Worldbestos ZAM 159, a medium friction material. The bonder selected was Midwest Bonding Co., a local firm with substantial bonding expertise for industrial and automotive applications.

Initially, several problems were encountered. In order to protect against cam rollover, D-DOT maintenance engineers developed special procedures to guide mechanics in inspecting for "high" cams during weekly brake checks. More specifically, they designed and fabricated a special gauge that enables a mechanic to determine how close the brake is to the high cam condition. Figure 3-3 shows this gauge.

Most problems with D-DOT's initial test program were related to the quality of the bonding. In some cases, linings broke away from shoes while in the process of being installed on the bus. It was determined that the release agent used by the lining manufacturer in his molds had not been cleaned from the linings resulting in an unclean surface and a poor bond. This was corrected by requiring the lining manufacturer to abrade the lining of all dirt and other impurities prior to bonding. Another early bond quality problem related to improperly formulated cement, and was corrected by the adhesive manufacturer.

As a result of these bond failures, D-DOT and the bonder instituted a shear test procedure, wherein a sample of each batch of bonded linings was subjected to a cold chisel test. Later, bond quality testing utilized an axial shear load test fixture.

At the time of the initial test of bonded brake linings, D-DOT had been averaging 35,000 miles of service life for bolted linings. The useable life for the bonded linings being tested averaged over 58,000 miles, an improvement of more than 65 percent. After all initial program start-up problems were resolved between the bonding company, the lining manufacturer and the adhesive manufacturer, D-DOT converted its entire brake reline operation to bonded brake linings, reporting the following cost advantages:

- o Material savings in the omission of nuts and bolts used to bolt on predrilled lining.
- o Labor savings in the elimination of sandblasting and painting of shoes by D-DOT personnel.
- o Material savings in the purchase of brake lining material due to the elimination of the pre-drilled, counterbored bolt holes.
- o Longer drum life.
- o Extended lining life.
- o Elimination of drum scoring by bolt heads contacting the drum on worn linings.
- o Elimination of break-in or burnishing period at the time of oversize roller installation, because of the continued use of worn-in bonded brake linings.

- Elimination of scaling or corroding of brake shoes under bolted linings.
- Overall reduction in brake labor cost by at least 60 percent due to fewer brake overhauls and elimination of debolting and bolting brake linings.

The disadvantages of brake bonding, as cited by D-DOT maintenance personnel, were a scarcity of bonding companies and the increased possibility of cam rollover, and the potential of an in-service debond. Clearly, D-DOT managers have felt that the advantages far outweigh the disadvantages in light of their continued support of bonding over bolting.

In 1970, D-DOT maintenance staff completed an updated cost analysis of their bonding program as compared with a bolted lining program. At that time, it was determined that a savings of 31 percent per 4-wheel brake overhaul was being realized through bonding. In 1970 dollars the savings were $1.96 per 1,000 miles per bus for every 4-wheel brake overhaul. When such savings were applied to D-DOT's fleet of buses, numbering at least 1000 at that time, the overall cost-effectiveness was substantial. A summary of these costs is presented in Table 3-6.

More recently, D-DOT has had the opportunity to collect comparative data on bonding and bolted brake linings for their fleet of RTS-II buses equipped with. wedge brakes. Because of procurement difficulties, D-DOT was forced to temporarily return to bolted linings in 1980. As they gradually resumed the bonded lining program, there was a time period when part of the fleet was equipped with bolted linings and part was equipped with bonded linings. A summary of these data is provided below.

TABLE A-1. D-DOT BRAKE OVERHAUL REPORT FOR RTS FLEET
FEBRUARY, 1981
SUMMARY OF BONDED VERSUS BOLTED LINING MILEAGES

| Lining Type | 4-Wheel | Rear Axle | Average* |
|---|---|---|---|
| Bonded | 22,128 | 16,654 | 20,300 |
| Bolted | 19,036 | 14,162 | 17,400 |

*Weighted average between 4-wheel and rear only

These figures show an improvement of about 17 percent in the bonded lining mileages as compared with that obtained with bolted linings, D-DOT felt that the difference was sufficient enough to warrent continuation of brake bonding at D-DOT.

Due to the proximity of the Southeastern Michigan Transportation Authority (SEMTA) to D-DOT, and because of exchanges in maintenance information and personnel between the two organizations, SEMTA began using bonded brake linings in the mid-1970's. Although formal, documented comparative evaluations have not been completed at SEMTA as of this time, SEMTA has renewed the use of bonded brake linings on most of their bus fleet after a brief haitus because of a question as to the cause of a bus wheel fire.

## A.3 SCRTD's BONDED BRAKE PROGRAM

In 1981 the Southern California Rapid Transit District (SCRTD), Los Angeles, California, awarded a contract for 940 new transit buses to General Motors Corporation's (GMC) Truck and Coach Division. GMC proposed that the last 200 of the 940 new RTS-II buses to be delivered would be equipped with bonded brake linings. The bonding was performed by Unibond, Inc. of Ferndale, Michigan, and installed on the buses at the GMC Truck and Coach plant in Pontiac, Michigan. All buses were to have the same lining material. Two hundred of the 740 buses delivered earlier to SCRTD would be used as control buses. SCRTD was to establish an inventory of replacement brake shoes with bonded linings for the first reline of the 200 test buses with bonded brakes. These linings and shoes were to come from Rockwell's Ashtabula, Ohio, brake manufacturing plant. A local Los Angeles distributor of automotive friction materials was set up to handle the return of worn bonded linings and brake shoes to Unibond, Inc. in Michigan. Unibond, Inc. would remove the remaining used linings and rebond the brake shoes with new lining material before returning the shoes to the local west coast distributor. If the test of bonded linings was successful and SCRTD expanded its use of bonded brake linings, the west coast distributor would prepare to perform the debonding and bonding locally. This would eliminate the cost of shipping worn and rebonded brake shoes back and forth between Los Angeles, California and Ferndale, Michigan. The test program was monitored both by SCRTD and GMC Truck and Coach service representatives. After the test buses with bonded linings had been in service, a number of deficiencies were discovered. Most of the bonded linings installed on the buses and the replacement linings had hairline fractures throughout the material. In service the bonded linings were flaking which resulted in road calls for tight brakes. Other test buses exhibited uneven wear patterns and brake drum scoring. SCRTD also encountered problems in obtaining replacement bonded linings in the oversizes needed for relines. As a result the bonded linings were removed as they failed and were replaced with conventional bolted linings. Because of the premature failures of the bonded brake linings, the original 200 test buses was gradually reduced to a small number of buses operating out of SCRTD divisions where heavy freeway driving was common. In this operation some test buses accumulated 25,000 to 30,000 miles on the original bonded linings.

Because a few of the original 200 test buses with bonded brake linings did achieve extended brake lining life (those assigned to freeway routes), SCRTD, in cooperation with UMTA, made plans for a second test of bonded versus bolted brake linings. This second test was expanded to include operational testing of both asbestos and non-asbestos brake linings from three manufacturers of friction materials and new brake drums from three manufacturers. Two Michigan bonders were used to bond the mix of 30 bus sets of asbestos and non-abestos linings to the brake shoes. A similar mix of asbestos and non-asbestos brake linings was bolted to the brake shoes of another 30 buses by SCRTD. At the conclusion of the 104 week test period the results obtained indicated that non-asbestos bonded linings outperformed all other lining combinations. Unfortunately, because of the problems SCRTD again experienced with bonded linings, SCRTD reports that "the District could not at this time recommend the use of bonded linings."

Of the total 480 brake shoes bonded, 260 bonded shoes were rejected by the lining manufacturer. Some of the problems which rendered the bonded shoes unuseable included the following:

- Incorrect spacing between the primary and secondary brake blocks (linings)
- Reversal of the primary and secondary brake blocks on the shoes
- Bonding of two primary or two secondary brake blocks on the same shoe
- Improper alignment of brake blocks on the shoe table.

Since buses with bonded linings had to be relined when the lining wore to the "scribe line" thickness, and because of the problems of quality control with bonding companies, SCRTD determined that the use of bonded brake linings was not cost-effective.

REFERENCES

1. Porcaro, Harrington, and Carberry, "Bonded Vs. Bolted Brake Lining for Urban Bus Application," TSC Project Memorandum (December 1980).

2. Bendix Corporation, Bendix Products Automotive Division, "Bendix 15 Wedge Actuated Heavy Duty Brakes" (November 1965).

3. "Braking: Disc Brakes, On the Inside Track This Time," Fleet Owner (July 1980).

4. Burkman and Highley, "Laboratory Evaluation of Brake Lining Materials," Society of Automotive Engineers No. 670510 (May 1967).

5. "B.F. Goodrich Brake Bonding Manual," IPC No. 63-7.

6. "Evaluation of Retarders for Transit Buses - Interim Report," UMTA (June 1983).

7. Rockwell International, Internal Letter, "15" x 4" Bonded Lining for Mack Trucks, Inc." (June 1977).

8. Alexander, Ted (Superintendant of Rolling Stock, Detroit Street Railway, now Detroit DOT), "The DSR's Bonded Lining Program," Internal Report (c. 1970).

9. Swanger, W. "D-DOT Brake Maintenance Cost Breakdown," Staff Report (March 1983).

10. Waite, D., "Cost Per Mile Projected for Drum Life - RTS II Brake Lining," SCRTD Staff Report (September 1981).

11. "4 Wheel Brake Overhaul - Total Cost, Bonded Versus Bolted Lining," D-DOT Staff Report (January 1970).

12. "D-DOT Brake Report for RTS Coaches," D-DOT Staff Report (February 1981).

13. GMC Truck and Coach and SCRTD Test Reports (1981 - 1983).

14. Detroit Department of Transportation, "Service and Maintenance Bulletin."

200 copies



☆ U. S. GOVERNMENT PRINTING OFFICE: 1985--501-858--20,066

For additional copies of this publication, please contact:

U. S. Department of Transportation
Transportation Systems Center — Code 31
Kendall Square
Cambridge, Massachusetts 02142
(617) 494-2486