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16. ABSTRACT

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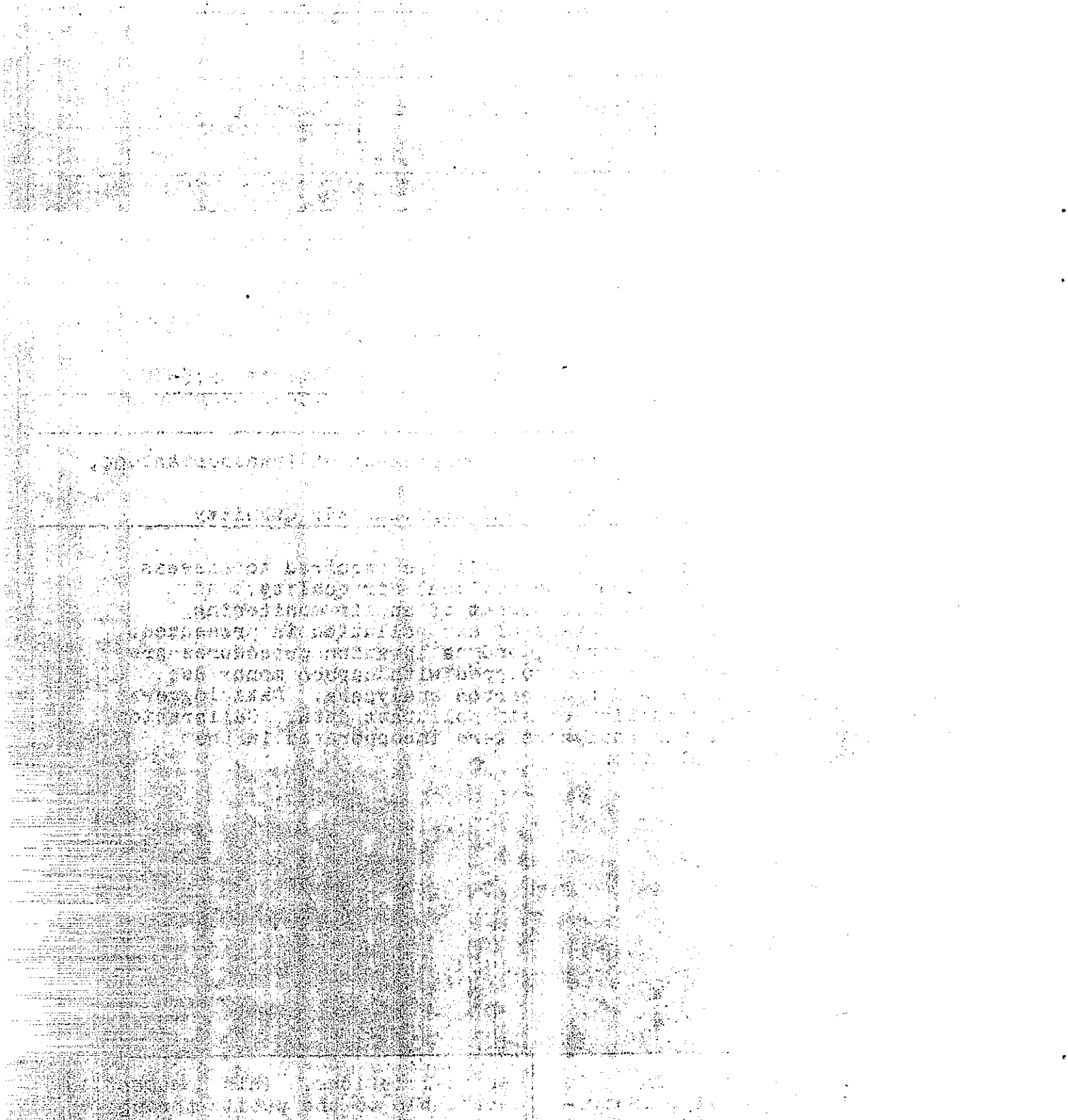

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STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF CONSTRUCTION
OFFICE OF TRANSPORTATION LABORATORY

December 1977

FHWA No. A-8-27
TL No. 657169

Mr. C. E. Forbes
Chief Engineer

Dear Sir:

I have approved and now submit for your information this interim research project report titled:

DESIGN OF AN AIR QUALITY
MONITORING TRAILER FOR
REGIONAL AIR QUALITY ASSESSMENT

Study made by . . . . . Enviro-Chemical Branch

Under the Supervision of . . . . . Earl C. Shirley, P.E.

Principal Investigator . . . . . Andrew J. Ranzieri, P.E.
Carl R. Sundquist, P.E.

Report Prepared by . . . . . Kenneth O. Pinkerman, P.E.

Very truly yours,

George A Hill

GEORGE A. HILL
Chief, Office of Transportation Laboratory

KOP:cb

Attachment

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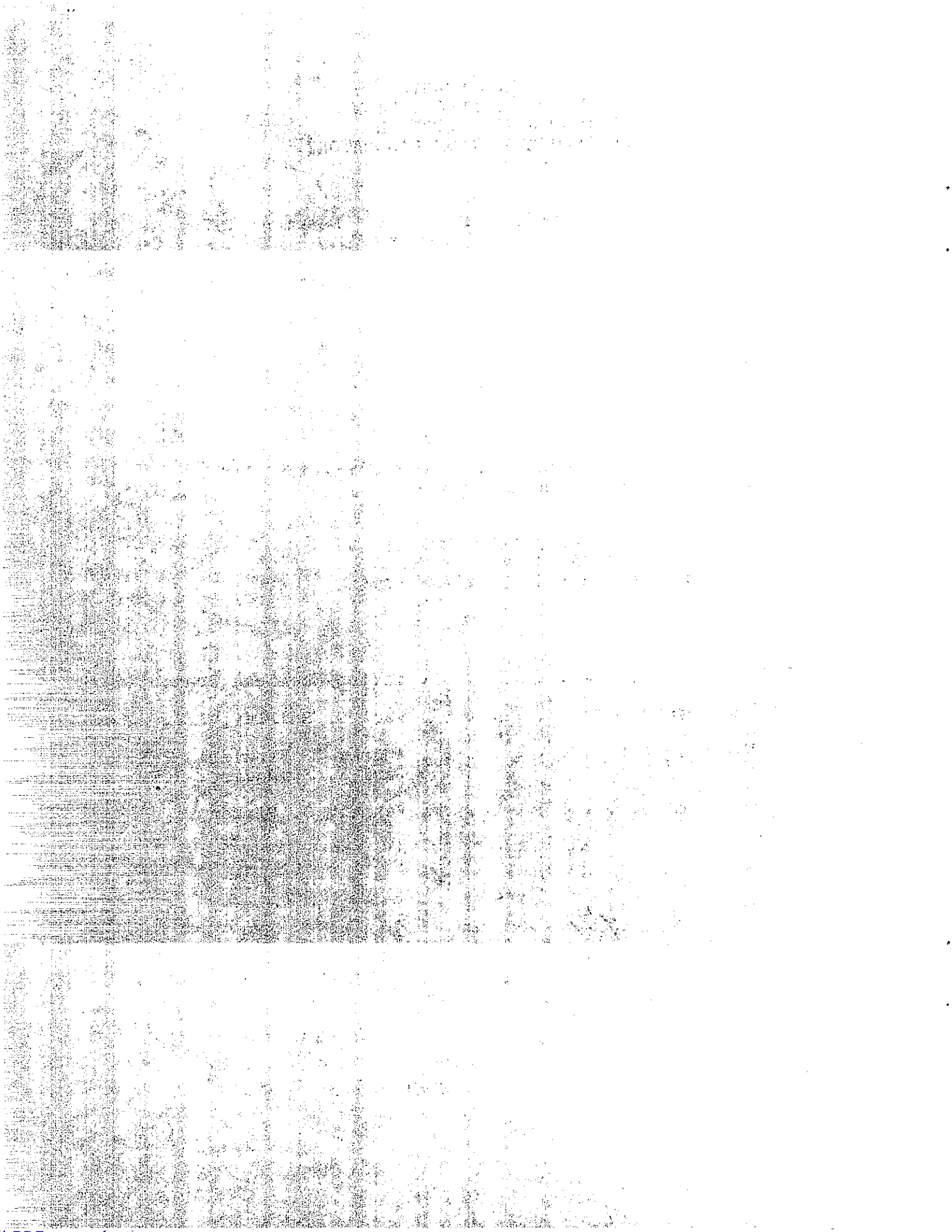

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ACKNOWLEDGEMENTS

Several individuals made significant contributions to the design and construction of the air quality monitoring trailers detailed in this report. The authors thank two outstanding individuals for their assistance on this project, Mr. Robert W. Breazile for layout of the equipment in the trailers and Mr. Orvis D. Box for installation of the analyzers, calibration gases, and air sampling train.

This study is being conducted under agreement A-8-27 with the Federal Highway Administration titled "Transportation Systems and Regional Air Quality".

The contents of this report reflect the views of the Transportation Laboratory which is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the offical views or policies of the State of California or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

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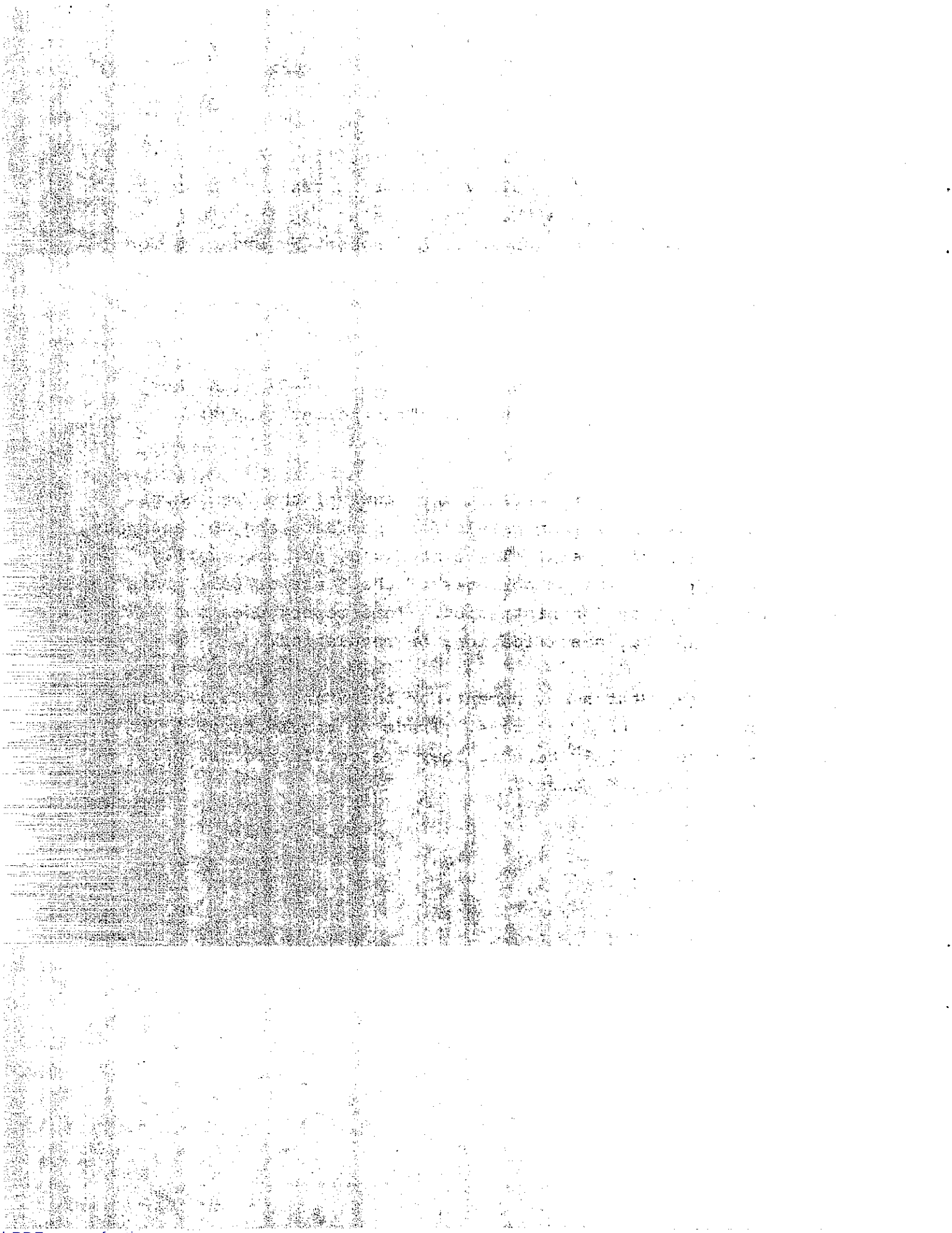

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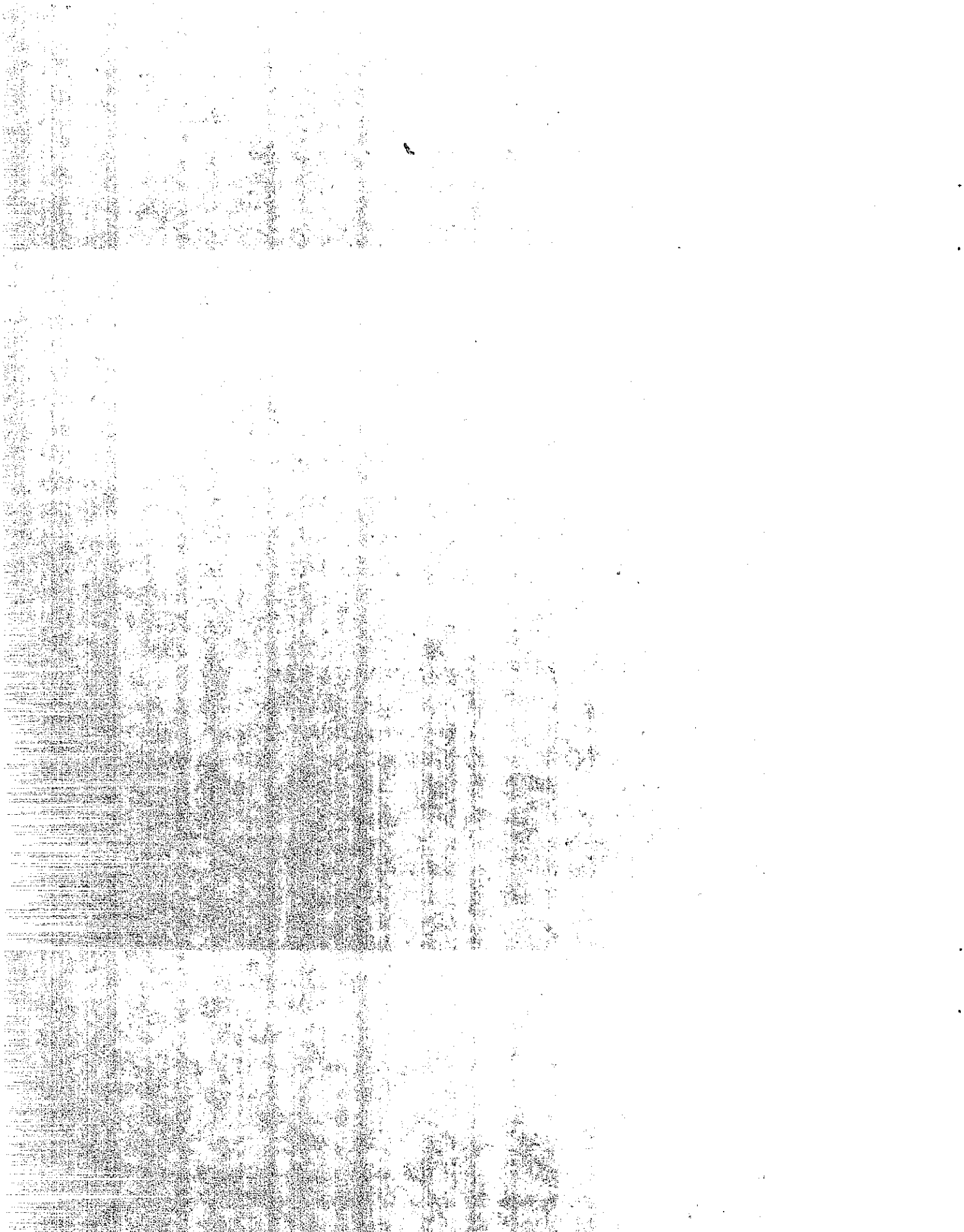

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INTRODUCTION

Three trailers were equipped with analyzers and allied equipment to detect ambient levels of primary and secondary air pollutants. They were designed to provide a semi-fixed monitoring package to obtain data for regional air quality modeling. Total hydrocarbons (THC), methane (CH_4), non-methane hydrocarbons (NMC)(THC-CH_4), oxides of nitrogen (NO_x, NO, NO_2), ozone (O_3), and carbon monoxide (CO) can be measured with these monitoring packages.

These trailer units have been used to obtain two extensive air quality data bases. The first use was in San Diego where data were obtained for use in the regional modeling activity utilizing Science Applications Incorporated's model MADCAP (Model of Advection, Diffusion and Chemistry of Air Pollution). The other use was in Sacramento where the data will be used to validate System Applications Incorporated's regional model (SAI Photochemical Air Shed Model). When the trailer units are in use they are located in widely separated areas to obtain data for temporal and spatial air pollutant distribution representative of a specific study area. Climatological and source strength (traffic) conditions are considered in locating the trailer units in various study areas.

The trailers are used in conjunction with air pollution control district (APCD) fixed stations to obtain pollutant concentration data. Mechanical weather stations are located in the area to supplement any acceptable permanent meteorological stations such as airports, and National Weather Service stations.

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DISCUSSION

The trailer units were selected to compliment the other air quality monitoring equipment fabricated by Caltrans. Mobile vans have been equipped with air quality analyzers and most districts have carbon monoxide analyzers in their laboratories for bag sample analysis. The trailer units have been very effective for their intended use during the first two applications.

Trailers

To provide a relatively inexpensive means of housing the air monitoring equipment, the Caltrans Transportation Laboratory selected a commercially available trailer. This 22 foot (6.71 m) long by 8 foot (2.44 m) wide office trailer was typical of mobile home construction being finished inside with paneling, fluorescent lights, wall-mounted receptacles, wall mounted heater/air conditioner, and equipped to handle 110 volt AC power. The total power load was calculated to be 30 amps of 110 VAC power and all monitoring sites have the requirement of access to this type power.

The interior of the trailer was modified with the addition of one 4 foot (1.22 m) base cabinet with plywood top, one Budd 70 inch (178 cm) instrument rack, cylinder anchor chains mounted to the rear wall, and a frame and panel for the recorders (see Figures 1 and 2).

The cabinet provides a surface to mount the carbon monoxide analyzer and gives storage drawers, etc. The instrument rack is fastened to the floor and to the wall studs. It is the container for the other analyzers and some support equipment for the hydrocarbon analyzer.

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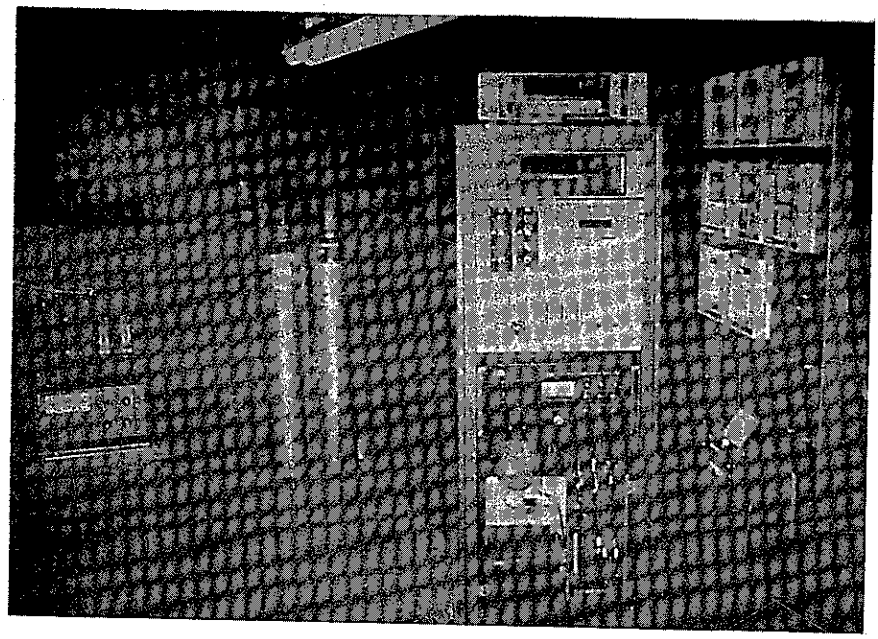

Fig. 1 Trailer interior. Rack right center holds analyzers for ozone, oxides of nitrogen, and hydrocarbons.

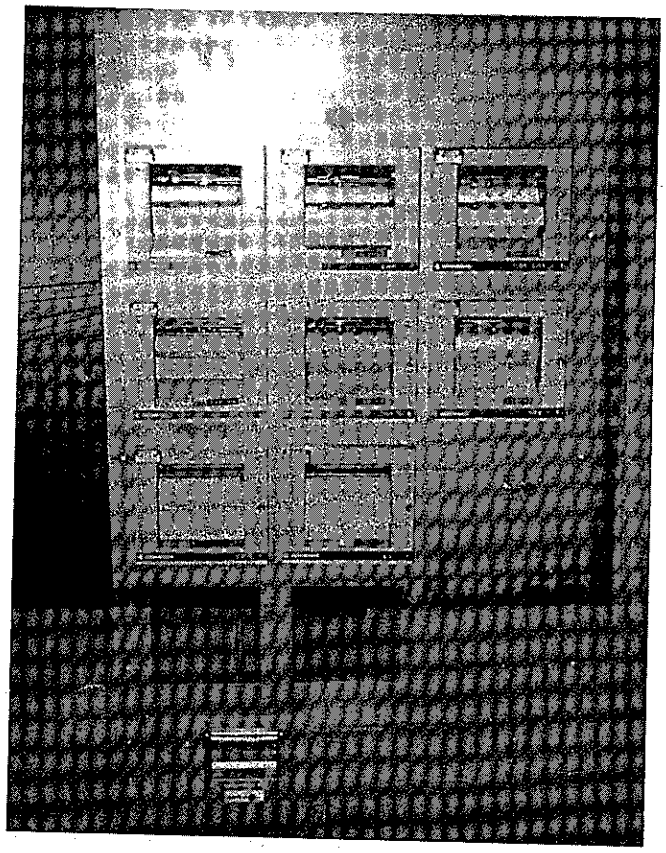

Fig. 2 Recorder package and data acquisition (Cassette Magnetic Tape)

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Other support items such as the air compressor and related air driers are mounted directly to the floor and the wall.

Due to the size of original wiring, an additional circuit was installed leading to the instrument rack location with conduit and a surface mounted 4 receptacle box.

Exterior Power Connection

The trailer was modified to meet all OSHA safety requirements for exterior wiring. A 220 VAC heavy duty cord and breaker box were installed. The pigtail end has a standard 4 prong male connector for 220 VAC power with a weatherproof box (shielded female receptacle) for post mounting supplied for hard wiring at each trailer site.

Sampling System

These trailers are a basic assembly of analyzers and support systems, and utilize the simplest sampling system possible. Each analyzer has its own 1/4" (0.64 cm) teflon sample supply line from outside the trailer. They are bundled in one piece of conduit that raises 8 feet (2.44 m) above the trailer and ends in an upside down plastic beaker (see Figure 3) for rain protection. Each line enters the wall through a stainless steel bulk head fitting and travels directly to the analyzer (see Figure 4). Therefore, the analyzer pump is the only sample supply component required.

Carbon Monoxide

The Carbon Monoxide Analyzer is a Beckman Model 865 NDIR, which is a short path infrared absorption method instrument with a flowing reference. The flowing reference is a replacement for a sealed, nitrogen filled, reference previously used in CO analyzer instruments. It consists of ambient air scrubbed of Carbon

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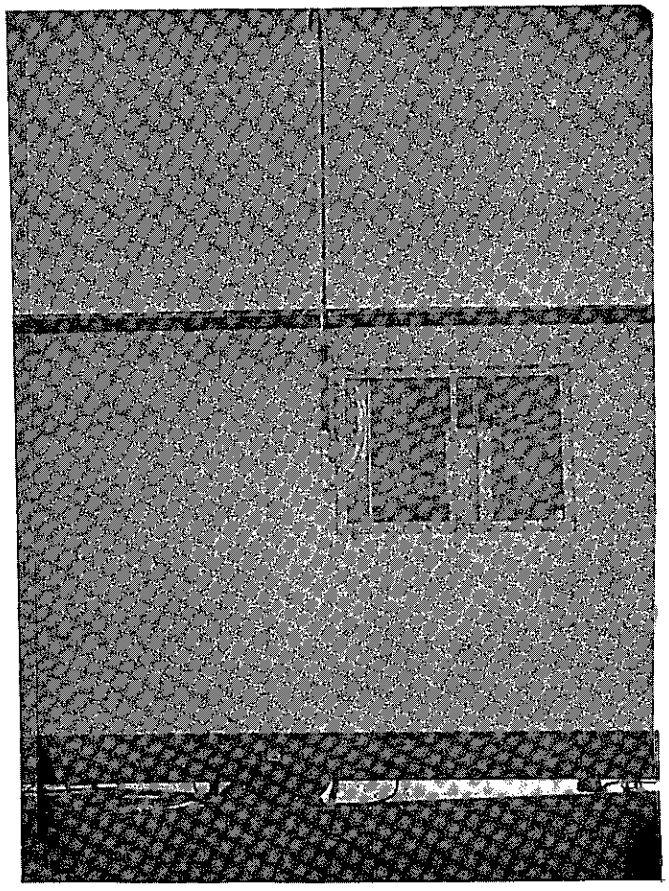

Fig. 3 Sample Mast with Rain Shield

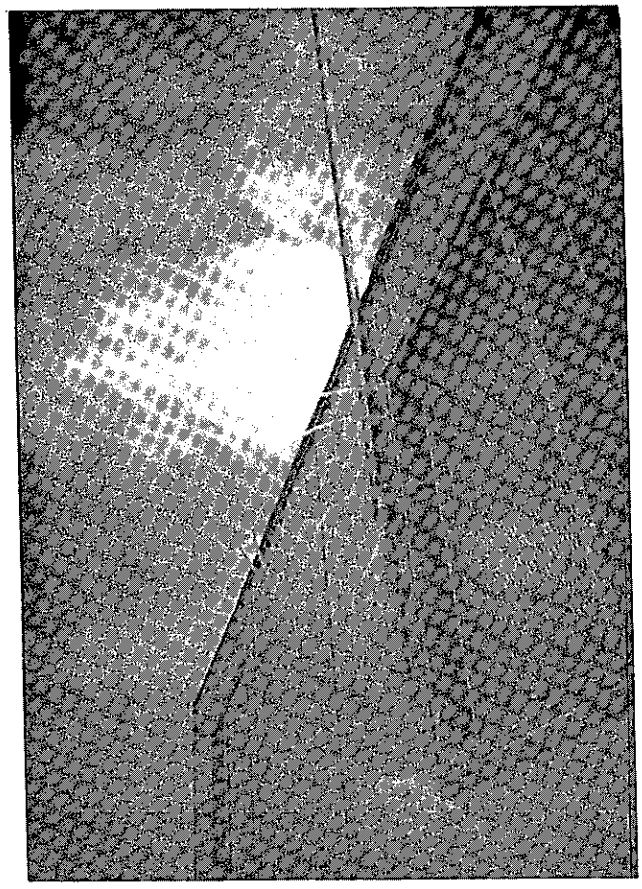

Fig. 4 Sample Lines Inlet

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Monoxide and then passes at the same flow rate as the sample cell of 1 liter/minute (0.035 ft^3/min.) This reduces Carbon Dioxide and water vapor interference due to the fact that both sides of the detection system see the same concentrations of the interfering gases. The same CO scrubber system is used for zeroing the instrument. Therefore, all the analyzer requires for support is a sample pump, lines, and proper span gases (see Figure 5). The analyzer flow system is diagrammed in the Appendix Figures 8 and 9.

This analyzer has proven to be very sensitive to vibration and requires desensitizing to damp out compressor cycling, door closing, foot steps, etc., eventhough the trailer is supported on its wheels and 4 corner jacks (see Figure 6). If these analyzers are to be used in the future in trailers or vans, an adequate shock mounting system or isolation must be devised. The manufacturer's solution was to desensitize the electronics yet have repeatability and accuracy.

Ozone

Ozone analysis is accomplished by the ultraviolet light absorption method. The analyzer selected is a Dasibi Model 1003AH Ozone Analyzer which is diagrammed in the Appendix Figure 10. This device requires no outside support equipment or gases. It is a very stable instrument and will operate satisfactorily for 2 to 3 months between calibrations. Electronic checks are built into the detection system and allow the operator to check for lamp degradation and clouding of the optics. The main problem is this system is a relatively rapid build up of dirt in the absorption chamber which reduces the effectiveness of the instrument. Ambient levels of ozone are affected by filter materials. Because of this, filters are not used in the sample system and dirt passes through. A solution to this may be some type of collector or settling chamber to prevent carry through and settling out in the optical absorption chamber.

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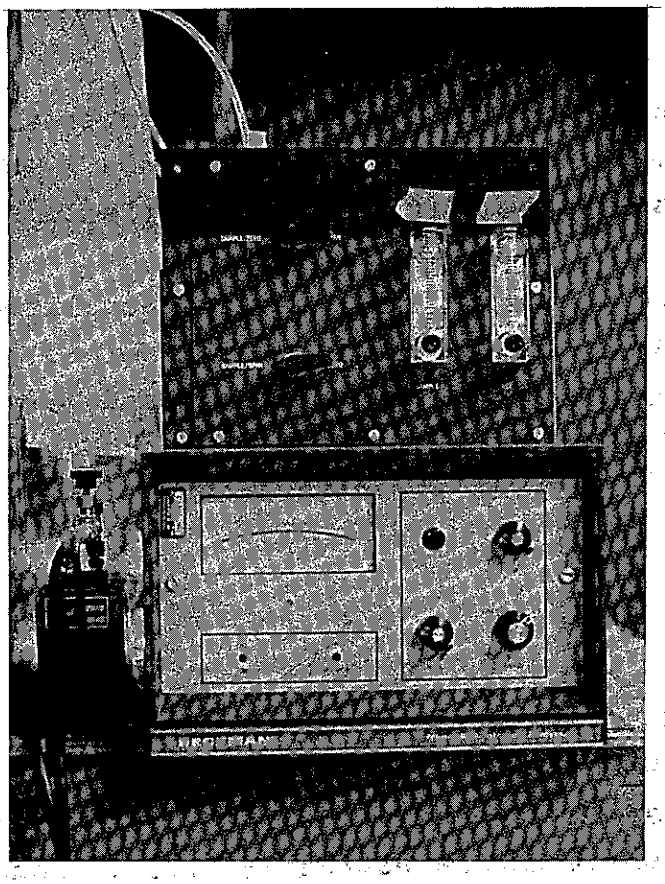

Fig. 5 Carbon Monoxide Analyzer and Sample Pump

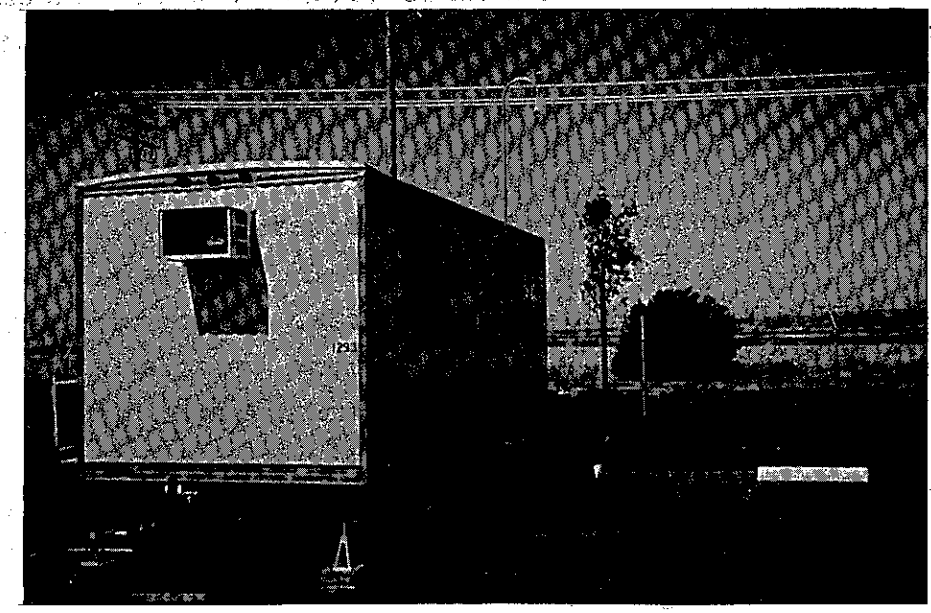

Fig. 6. Air Monitoring Trailer
Typical Site Location

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In the trailers, as constructed, disassembly and cleaning of the optic absorption chamber are required on a 1-1/2 month to 2 month basis. This is not a difficult job but is time-consuming.

Calibration of the ozone analyzer is accomplished with an ozone generator and cross checked with wet chemical analysis methods (absorption by 1% buffered potassium iodide). The resulting color is read with a Spectrometer. Recent methods utilize a Dasibi Reference Analyzer with primary calibration by a long path photometer.

Hydrocarbons

Hydrocarbons are measured as total (THC), methane (CH_4), and non-methane (NMHC) for a reactive hydrocarbon reading. The instrument used is a Bendix Model 8201 Gas Chromatograph (G.C.) using Flame Ionization Detection (F.I.D.). The schematic diagrams for this analyzer are Figures 11, 12, and 13 in the Appendix. This analyzer is specifically designed to measure ambient levels of hydrocarbons. It separates CH_4 from the total by absorption and sequential release of compounds from the G.C. columns. The F.I.D. gives a signal corresponding to the peak height for each compound which is proportional to the amount of that pollutant in the air sample.

This analyzer is calibrated with cylinders of span gases. Methane (4-5 ppm) in air is the gas mixture used for spanning. It is important that all support gases, carrier air, hydrogen, etc., be free of contaminants such as hydrocarbons or moisture. Therefore, all carrier air is scrubbed with a thermal catalytic device to oxidize any stray hydrocarbons to an acceptable level. In addition the air (compressor supplied) and hydrogen are dried by passing through silica gel to prevent column contamination and interferences (see Figure 7).

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The support equipment required is an air compressor with a reservoir, a drier assembly, a hydrogen (H_2) generator (see Figure 8) or cylinder hydrogen, a drier for H_2 including molecular sieves to insure hydrocarbon free supply, sample pump and related plumbing to provide a secure system. It is very important to clean all fittings and sample flow system parts to remove residual oils and greases. A component installed by hand with normal skin oils will elevate the background signal 5 or 10 times above normal for as long as a week (the time for the air sample to absorb it off the walls or valve stems, etc.)

It has been found that cleaning all sample related parts with methanol, rinsing with distilled H_2O and drying with dry nitrogen minimizes the problem. After cleaning and installing new "O" rings on G.C. valve stems, it is recommended that a light coating of silicone stopcock grease be applied for long life of the O-rings and freedom from valve jamming. This non-hydrocarbon grease does not interfere with the analysis yet protects the seals.

The F.I.D. vent expels combustion generated condensate but must be free to the atmosphere to prevent errors due to flow changes. Therefore a collection jar or container must be provided to collect condensate from this vent but with free venting.

All hydrogen plumbing should consist of refrigeration grade copper tubing to prevent hydrocarbon contamination and provide a semi-rigid conductor which is less subject to rupture than plastic tubing.

Oxides of Nitrogen

A chemiluminescence type analyzer is used for the detection of Nitric Oxide (NO) in ambient air. The chemiluminescent method of nitric oxide analysis is based upon the principle that nitric

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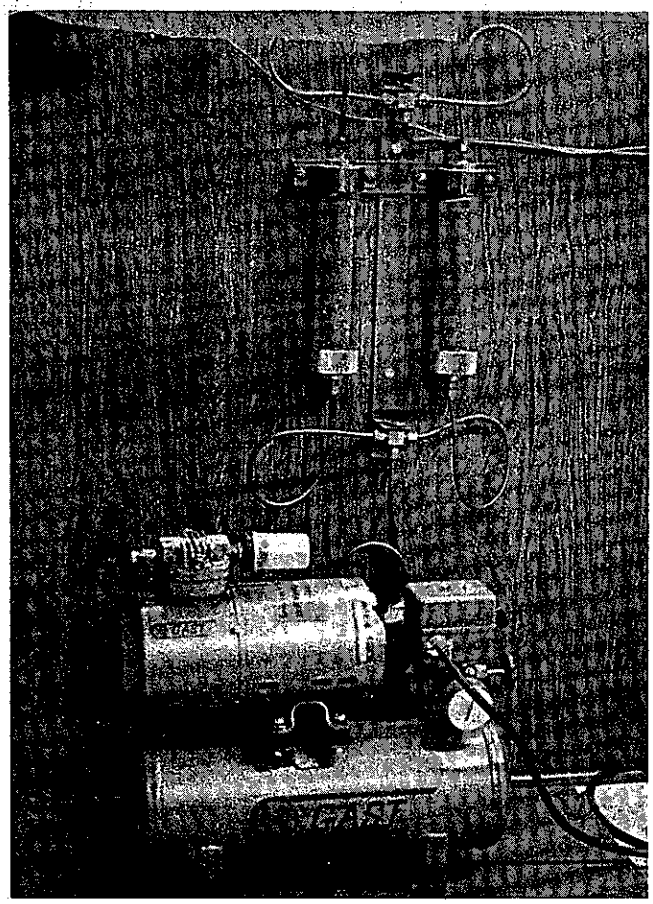

Fig. 7 Air Compressor and Drier System

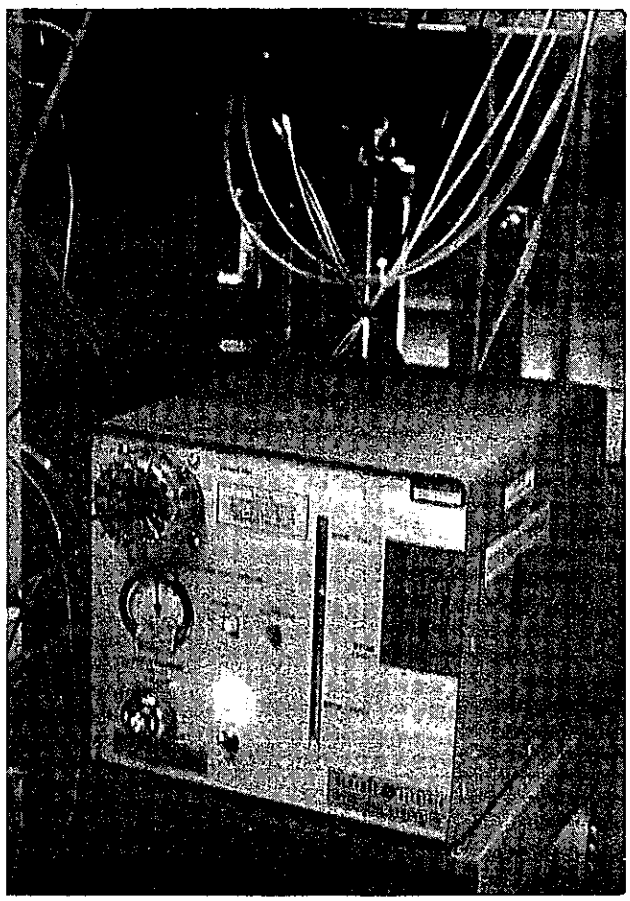

Fig. 8 Hydrogen Generator and Drier System

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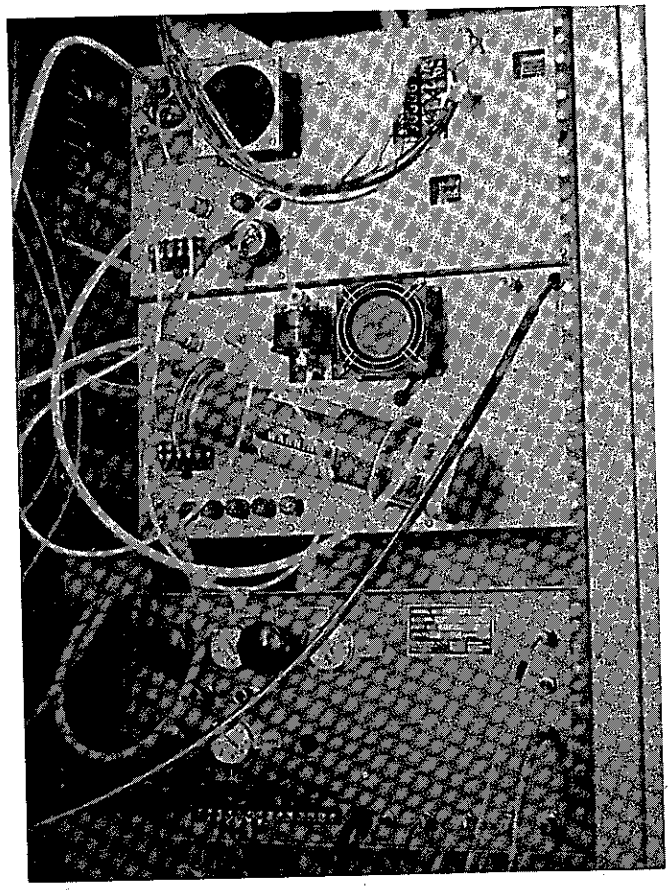

Fig. 9 Rear Support System for NO_x Analyzer (Top Two) and THC Analyzer (Bottom)

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oxide (NO) reacts with ozone (O_3) to give nitrogen dioxide (NO_2), oxygen (O_2), and about 10 percent electronically excited NO_2*. The transition of electronically excited NO_2* to its normal state gives a light emission (hv) between 590-2750 nm, i.e.:

$$NO + O_3 = NO_2 + NO_2^* + O_2$$
$$NO_2^* = NO_2 + hv$$

In the presence of an excess amount of ozone, the intensity of this emission is proportional to the mass flow rate of nitric oxide into the reaction chamber. Ozone for the reaction is generated by passing air over an ultraviolet light source. As ozone and nitric oxide mix, the chemiluminescent reaction produces a light emission which is proportional to NO concentration and is measured by the photomultiplier tube.

This method also lends itself to toal oxides of nitrogen analysis (NO and NO_2) by disassociating the nitrogen dioxide to nitric oxide by passing it over a heated catalyst, then proceeding with the reaction,

$$NO_2 = NO + O$$
$$NO + O_3 = NO_2 + NO_2^* + O_2$$
$$NO_2^* = NO_2 + hv$$

The analyzer selected, Monitor Labs Model 8440, operates somewhat differently than other chemiluminescent NO_x analyzers as it has a dual detection system. This replaces cycling the sample through one detector. The operational schematic diagrams are given in Figures 14, 15 and 16 in the Appendix. In addition, it has a signal chopper system to reduce interferences by scanning for the signal only on the frequency generated by the rotating photochoppers. The 8440 works at a vacuum of 18" (45.7 cm) Hg in the reaction cell and controls flows by the critical orifice flow method. It has

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two system checks built in, one an electronic test, the other a light emitting diode in the reaction cell to simulate the signal for testing the photomultiplier tube.

This analyzer is calibrated by injecting a sample containing NO (about 3-4 ppm) in dry nitrogen from an aluminum cylinder. Zero level is set by one of two methods, either by shutting off the ozone supply to the reaction cell, thereby eliminating the reaction or by using a $NO-NO_2$ scrubber to strip these components from the sample input.

The NO_2 converter is tested for efficiency every three months by the Department of Health, Air and Industrial Laboratory (AIHL) during primary calibration.

Data Recording

There are two methods of recording data in these trailers. One is the basic strip chart recorder using one per signal channel (total 8 per trailer). The other is a cassette magnetic tape data acquisition system that samples the signals and records them on magnetic tape for computer reduction.*

The magnetic tape system is the primary data source and the strip charts are used as a back up.

The recorders used were made by Esterline Angus Co., model "Mini-Servo" MS401 with Z-fold paper. These units were modified for our use by changing the location of zero and span adjustments from the housing side to the front upper corners. The right top corner inside for span; the upper left inside corner for zero. This allows easy adjustment when the recorder is panel mounted as in trailer usage.

*See report AUTOMATED METHODS OF ACQUIRING AND REDUCING AEROMETRIC DATA - CA-DOT-TL-7157-1-76-08 March 1976

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Operation

The strip chart paper is of Z-fold type 100 cm (39.4 inch) active width and feeds at 15 cm (5.9 inch) per hour. One strip chart lasts about 5 days. This requires changing the paper and the magnetic tapes once a week.

The instruments are checked for zero and proper operation 3 times a week, usually on a Monday, Wednesday, Friday schedule. Driers, H_2 generator, magnetic tape drive, compressors, flow rates, pressures, and recorders are also checked then. On the average, the NO_x and THC analyzers are calibrated with span gases every two weeks. The CO analyzer is zeroed and spanned every visit to the trailer to compensate for drift in this particular model of instrument.

On a three month basis, the equipment is calibrated by AIHL and a cross check is performed on the gases used for routine span tests. AIHL uses U.S. Environmental Protection Agency (EPA) recommended methods and National Bureau of Standard Reference Materials where available.

Strip chart recorders are checked with a DC voltage standard for span and linearity when new and on a 6 month basis thereafter. The magnetic tape data recording system had bench testing performed before application using known DC voltages for various input channels. Then the magnetic tape reader output was checked for accuracy.

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Field Usage Experience

Three trailers of this design have been in field usage for two years. There have been minimal problems with the setup as designed. There has been only one case of vandalism and that was limited to pulling a sample line down and out of the sample mast. This allowed dirt to be pulled into the THC sample pump and required disassembly and cleaning of the pump valve body to correct a malfunction.

The air conditioning has been adequate to maintain 80°F (27°C) or below on hot summer days when the ambient temperature reaches 100°-110°F (38°-43°C).

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APPENDIX

ANALYZERS AND SUPPORT

SYSTEM DIAGRAMS

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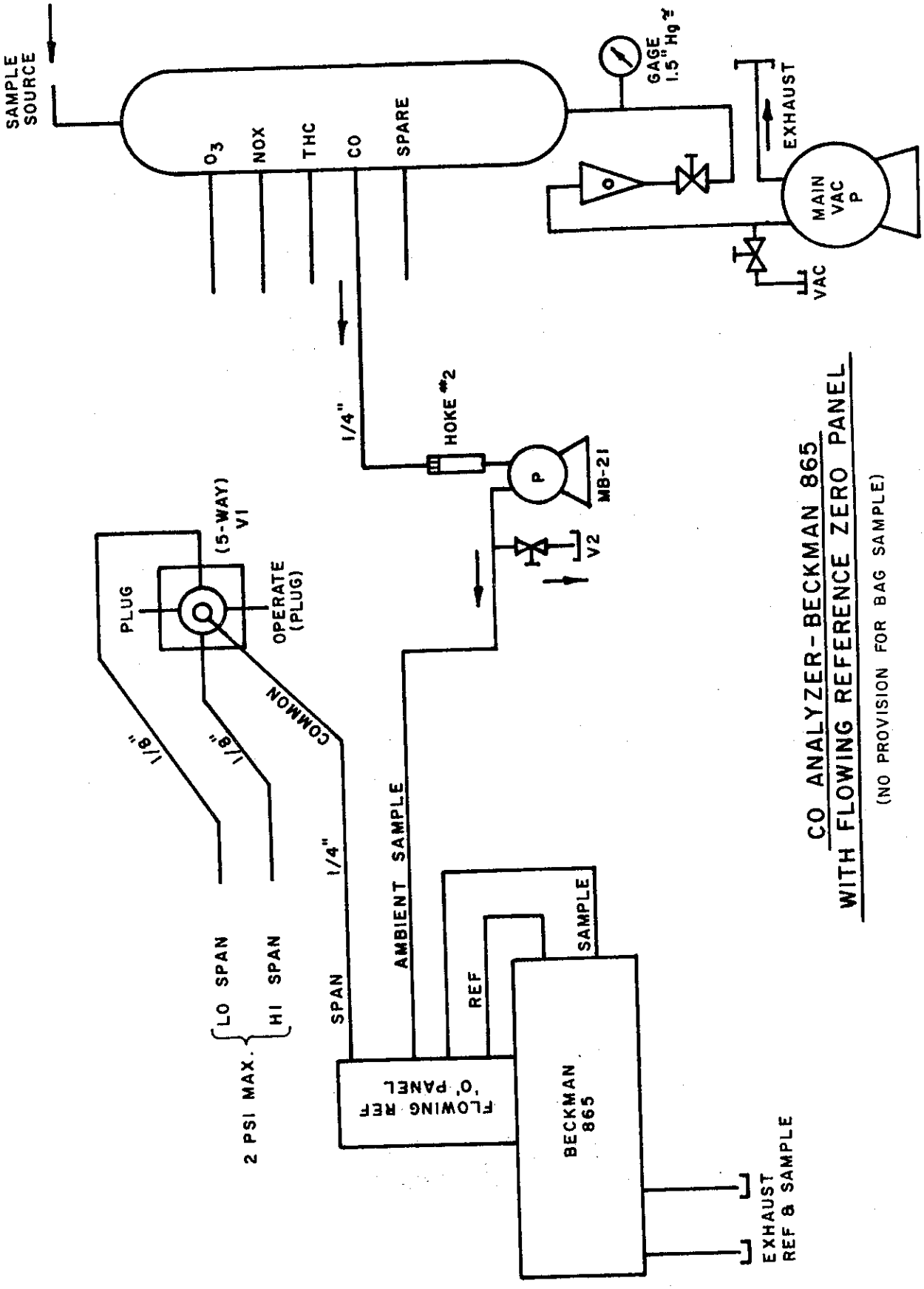

Figure 10

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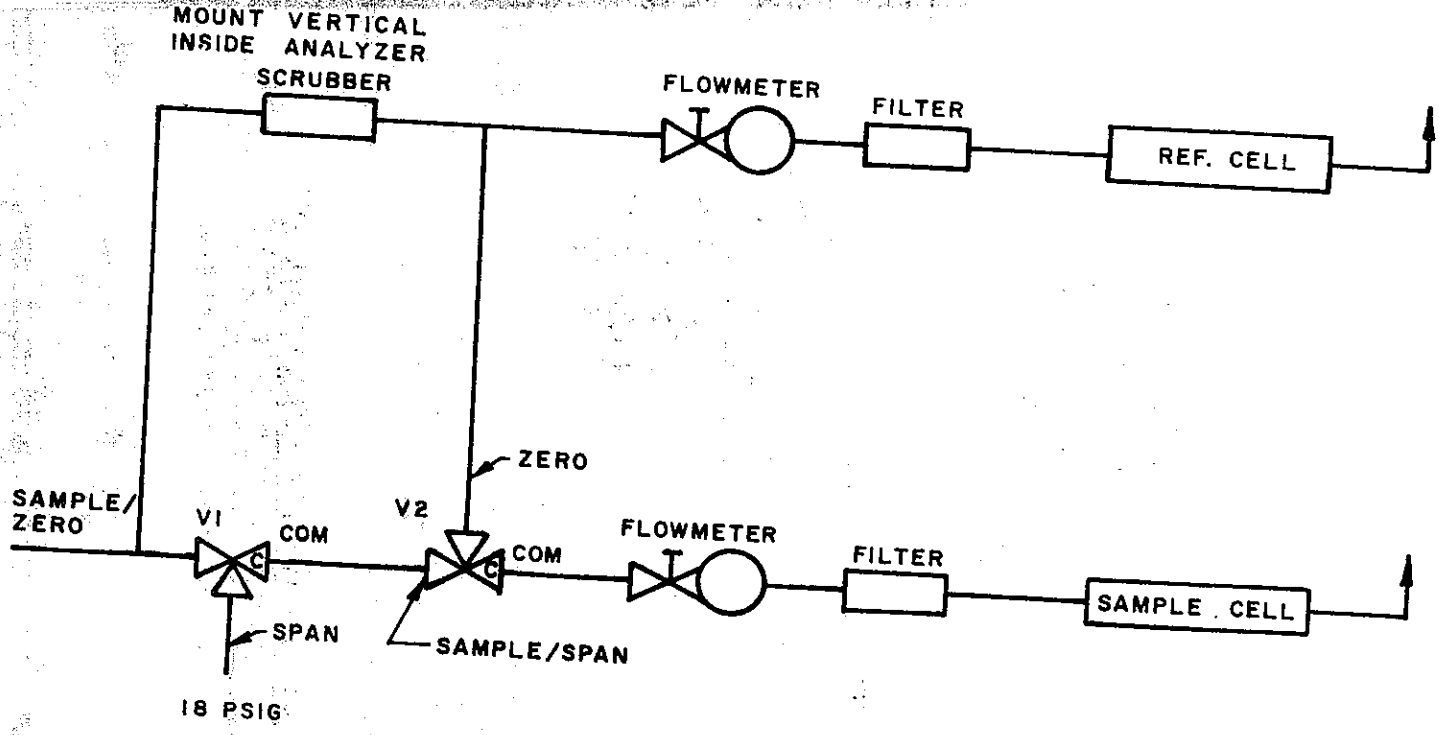

SAMPLE SELECTOR PANEL FOR
MODEL 865 CO-AIR MONITORING
(FLOWING REFERENCE 'O' PANEL)
MFG BY BECKMAN INSTRUMENTS INC.

Figure 11

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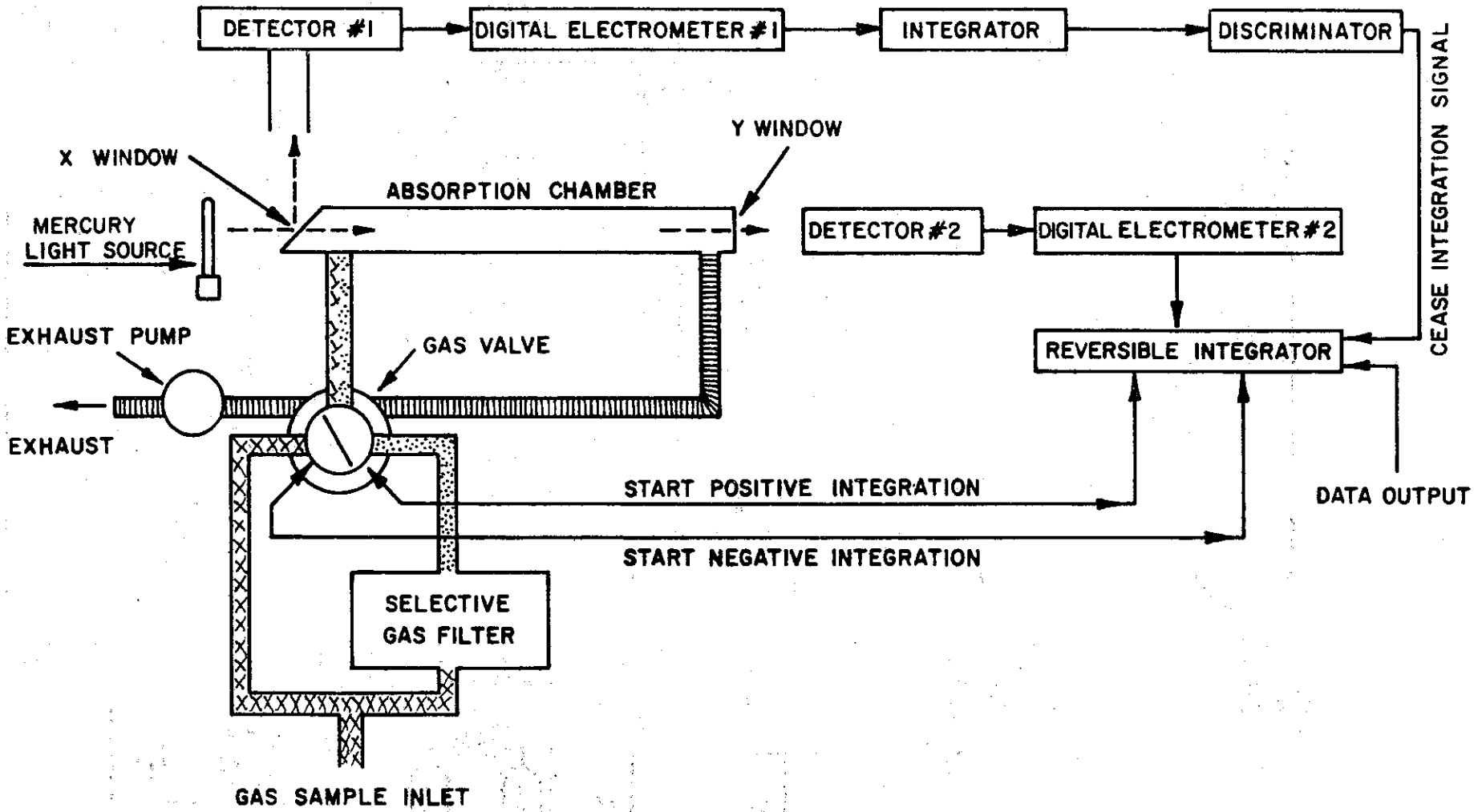

Figure 12

BLOCK DIAGRAM - DASIBI OZONE MONITOR

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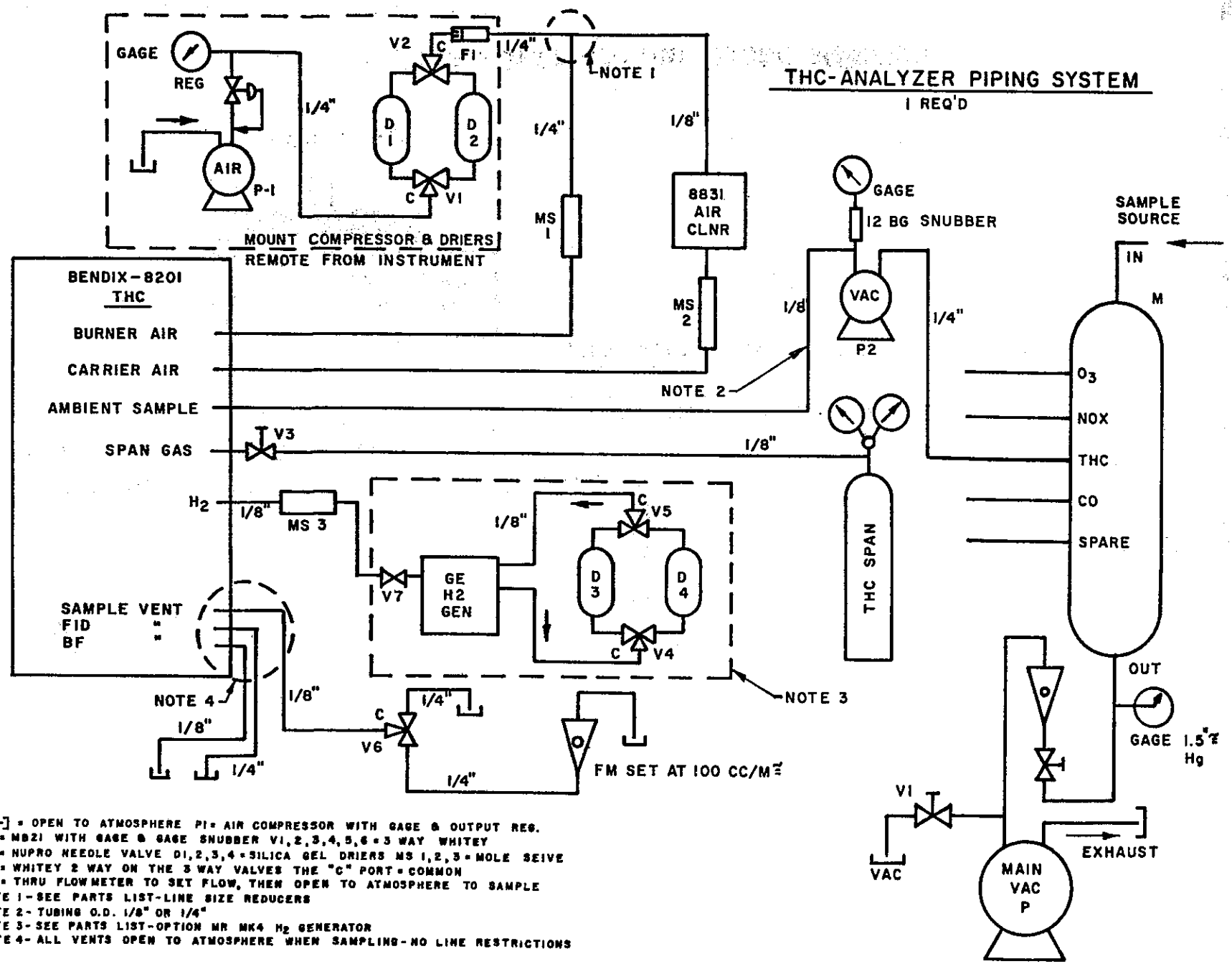

Figure 13
20

—] = OPEN TO ATMOSPHERE P1 = AIR COMPRESSOR WITH GAGE & OUTPUT REG.
P2 = M821 WITH GAGE & GAGE SNUBBER V1,2,3,4,5,6 = 3 WAY WHITEY
V3 = NUPRO NEEDLE VALVE D1,2,3,4 = SILICA GEL DRIERS MS 1,2,3 = MOLE SEIVE
V7 = WHITEY 2 WAY ON THE 3 WAY VALVES THE "C" PORT = COMMON
V8 = THRU FLOWMETER TO SET FLOW, THEN OPEN TO ATMOSPHERE TO SAMPLE
NOTE 1 - SEE PARTS LIST - LINE SIZE REDUCERS
NOTE 2 - TUBING O.D. 1/8" OR 1/4"
NOTE 3 - SEE PARTS LIST - OPTION MR MK4 H_2 GENERATOR
NOTE 4 - ALL VENTS OPEN TO ATMOSPHERE WHEN SAMPLING - NO LINE RESTRICTIONS

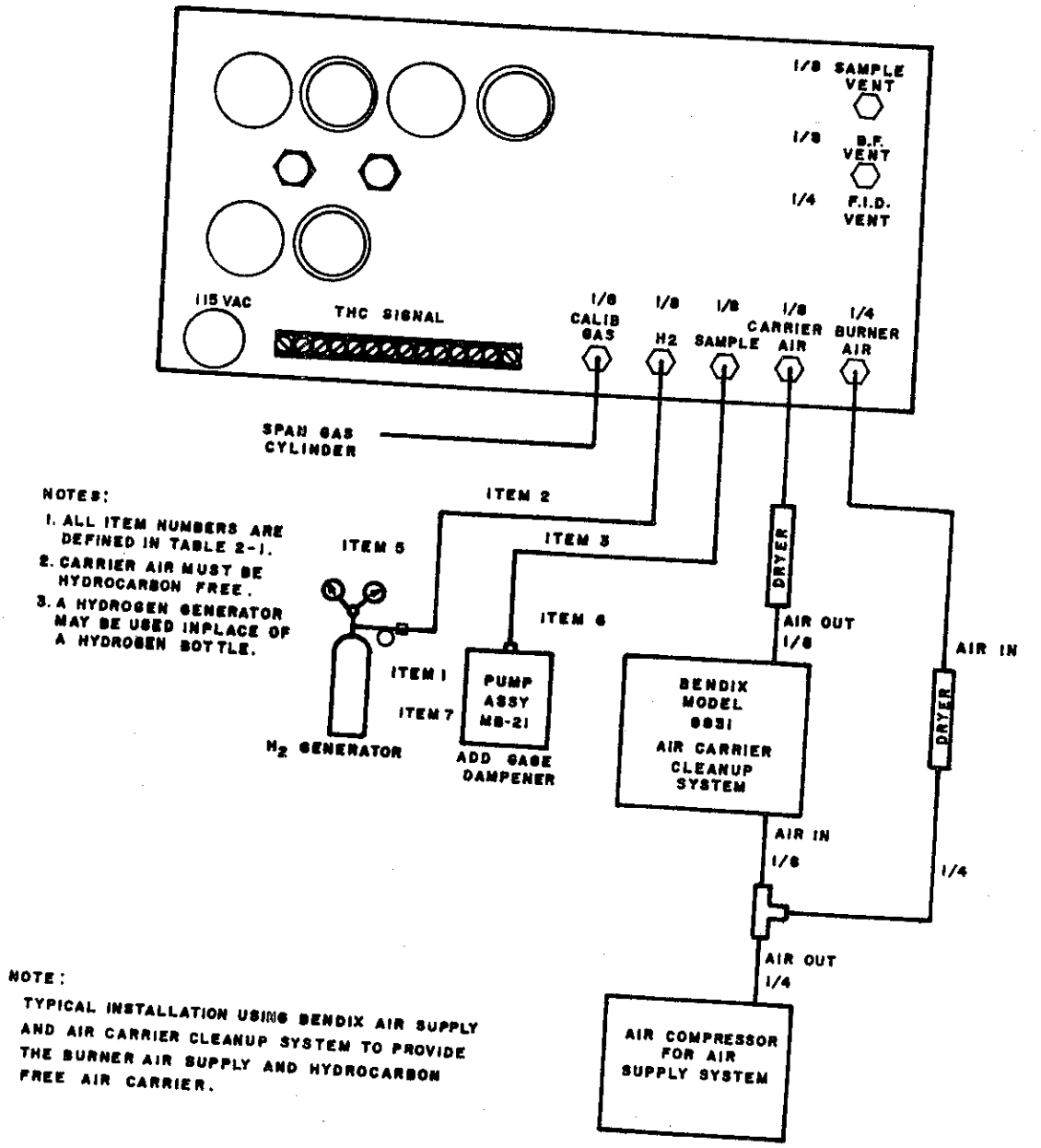

DIAGRAM FOR BENDIX CO MANUAL

REFERENCE ONLY

Figure 14

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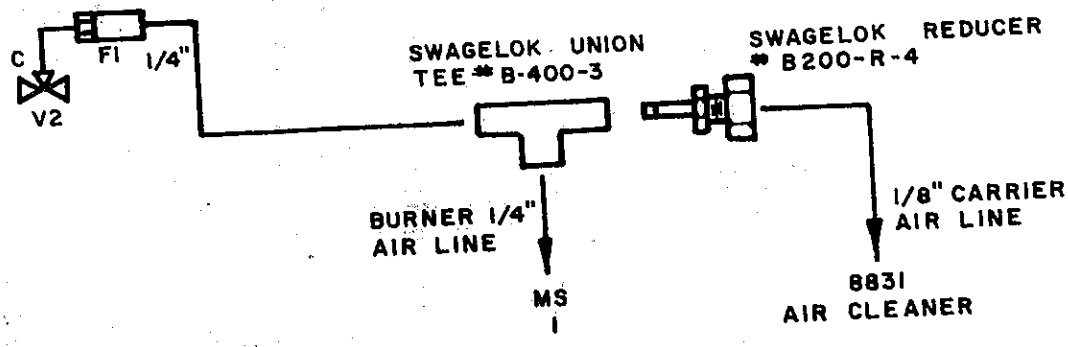
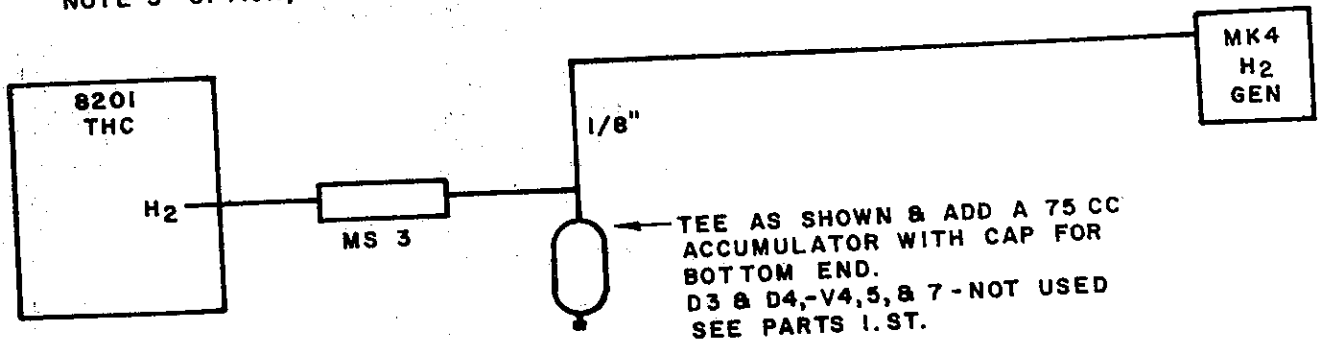
NOTE 1 – REDUCE LINE SIZE AFTER AIR DRIERS.



NOTE 3 – OPTION, MILTON ROY MK4 H_2 GENERATOR.



BENDIX 8201 THC-ANALYZER AIR SYSTEM

Figure 15

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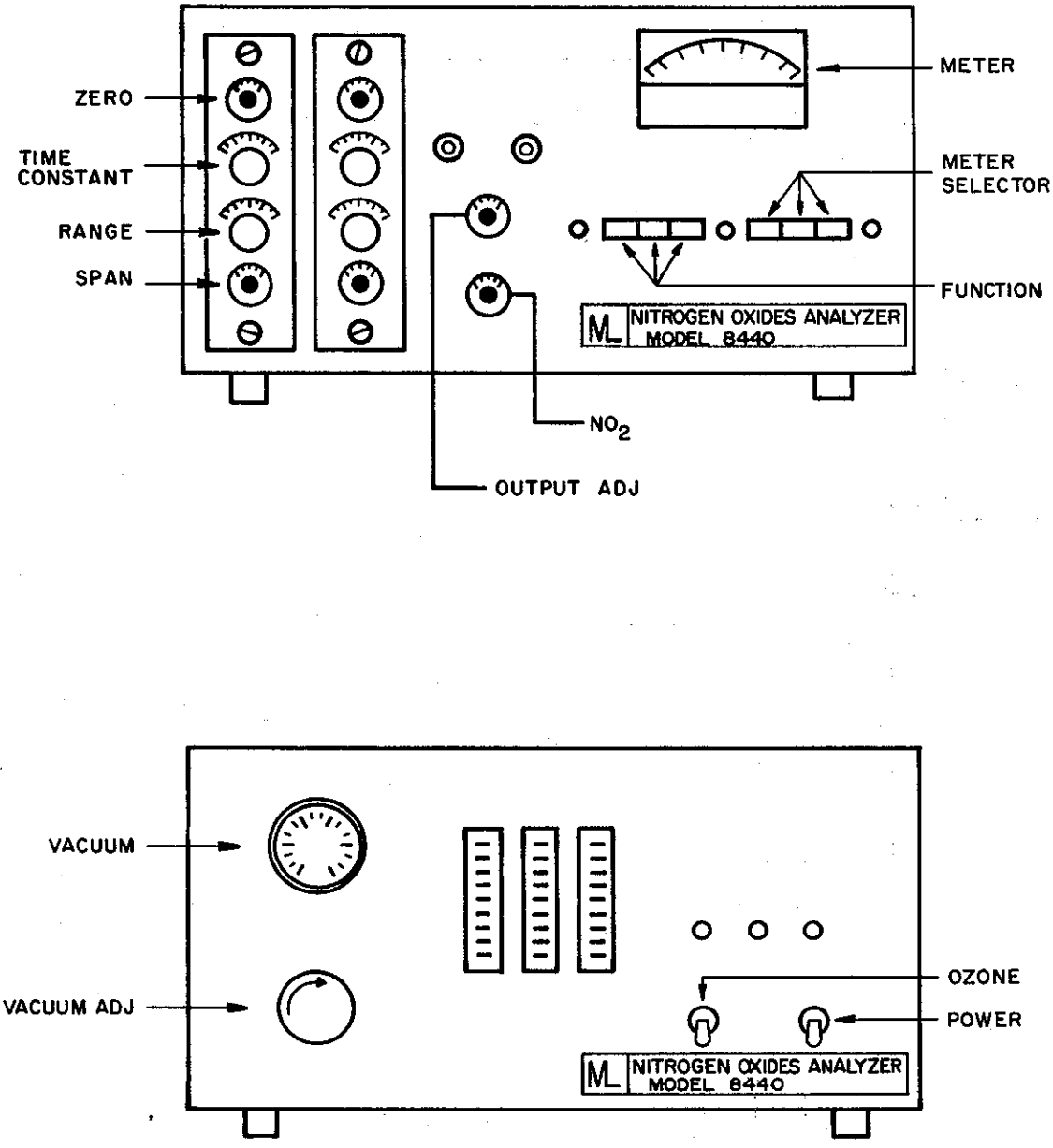

OPERATING CONTROLS

MONITOR LABS MODEL 8440 NO_X ANALYZER

Figure 16

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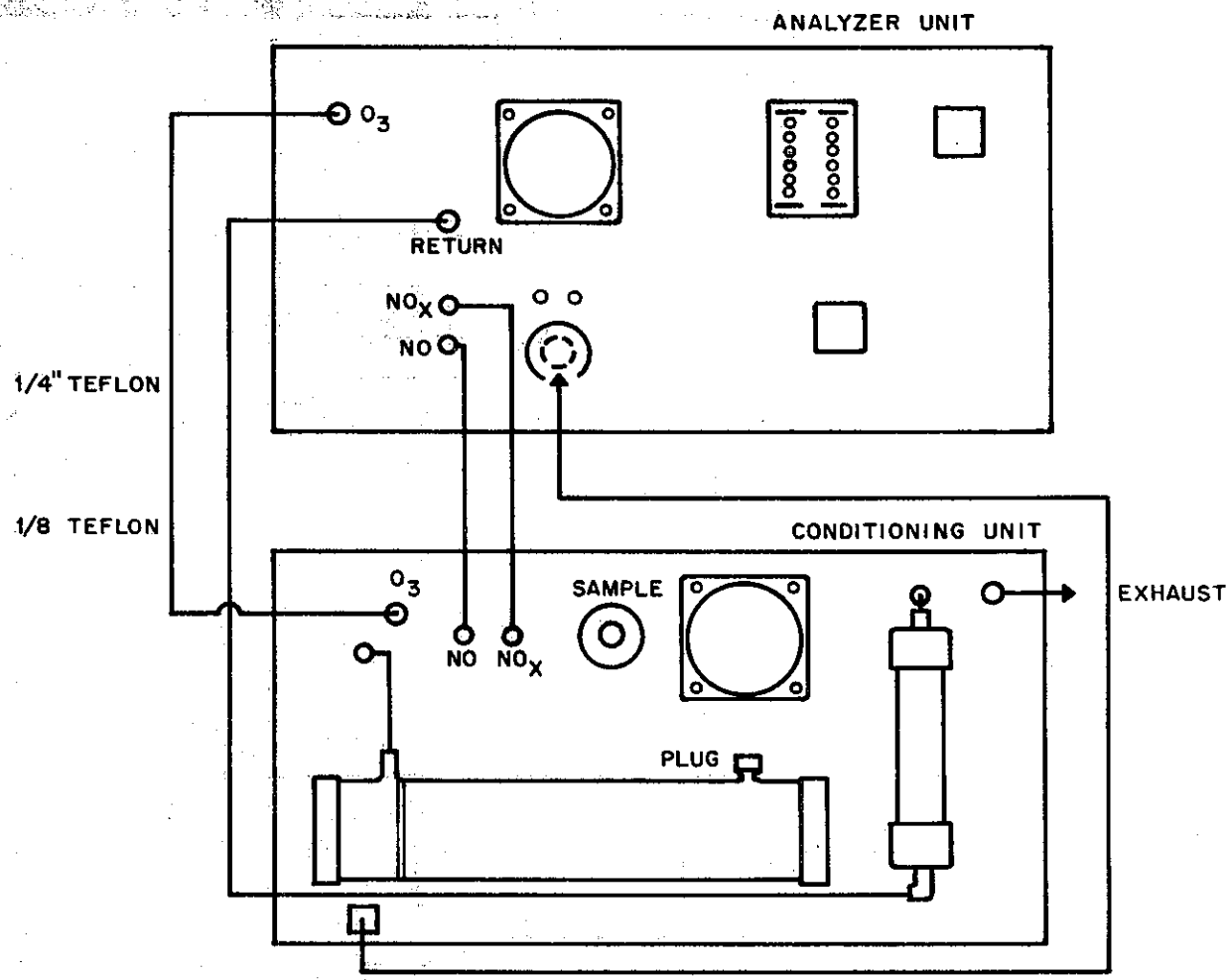

ANALYZER - SAMPLE CONDITIONING INTERFACE
MONITOR LABS MODEL 8440 NO_X ANALYZER

Figure 17

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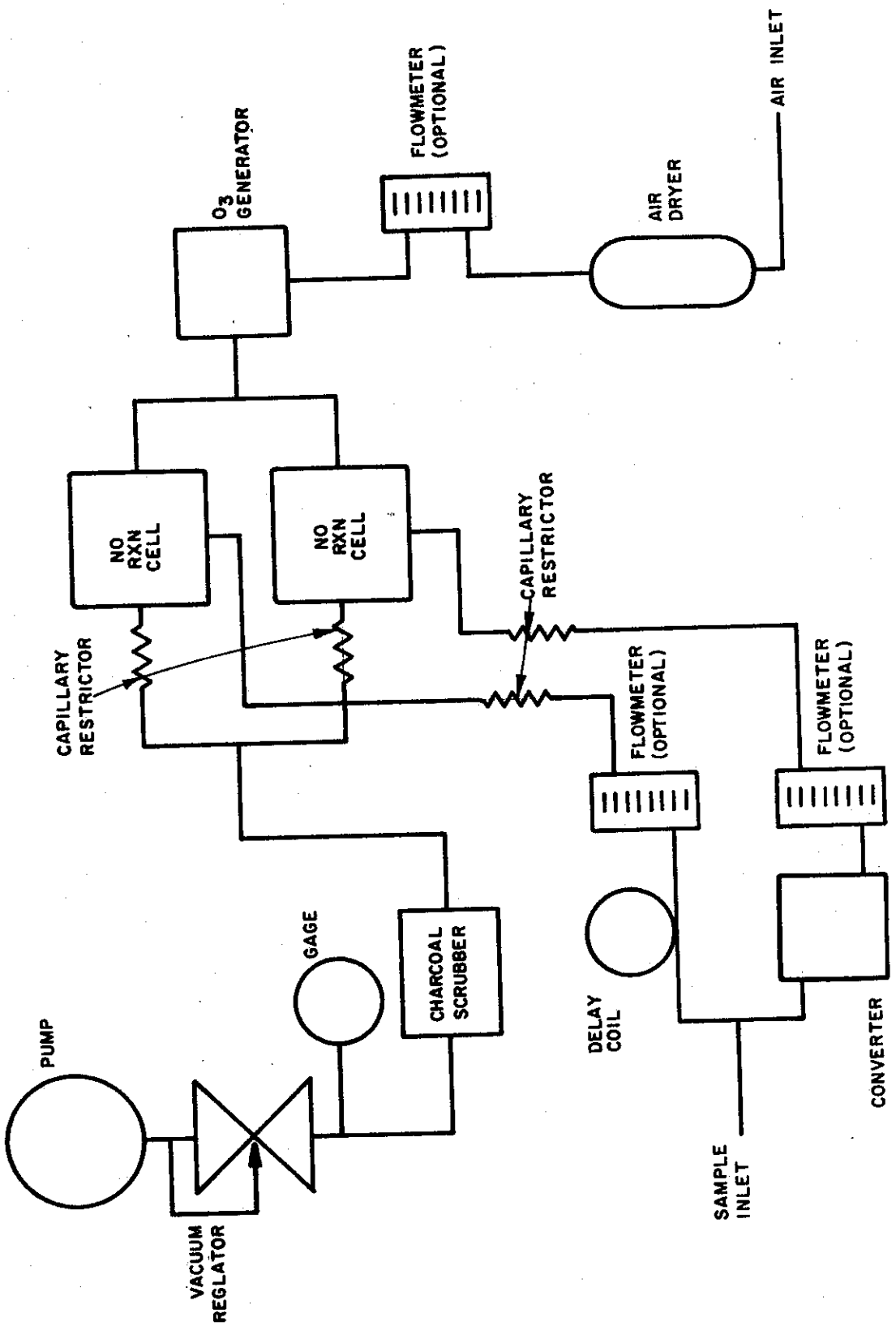

SCHEMATIC FLOW DIAGRAM

MONITOR LABS MODEL 8440 NO_X ANALYZER

Figure 18

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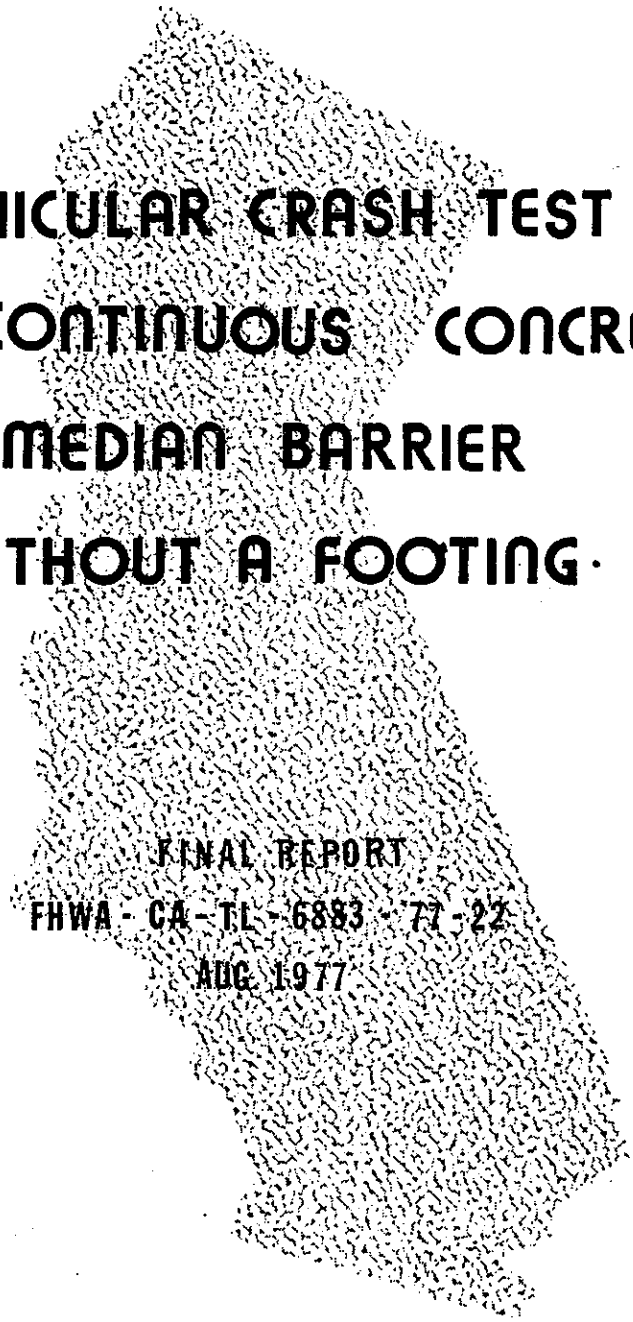
DIVISION OF STRUCTURES AND ENGINEERING SERVICES
TRANSPORTATION LABORATORY
RESEARCH REPORT

VEHICULAR CRASH TEST OF A CONTINUOUS CONCRETE MEDIAN BARRIER WITHOUT A FOOTING



FINAL REPORT
FHWA-CA-TL-6883-77-22
AUG. 1977

Prepared in Cooperation with the U.S. Department of Transportation,
Federal Highway Administration

Caltrans
CALIFORNIA DEPARTMENT OF TRANSPORTATION

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	6 PERFORMING ORGANIZATION CODE

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15 SUPPLEMENTARY NOTES

This study was conducted in cooperation with the U. S. Department of Transportation, Federal Highway Administration.

16 ABSTRACT

A vehicular impact test, 4700 lb (2130 kg) vehicle/61 mph (27 m/s)/ 26 degrees (0.46 rad), was conducted on a continuous New Jersey concrete median barrier (CMB) without a footing cast on an asphalt concrete surface. The test barrier contained two continuous longitudinal No. 4 (12.7 mm) steel reinforcing bars one at 6 inches (152 mm) and the other at 12 inches (305 mm) down from the top of the barrier. There were no contraction or construction joints in the barrier. The barrier was allowed to crack randomly.

The barrier suffered no structural damage and did not move laterally or rotate about its longitudinal axis during the impact. After being redirected by the barrier, the vehicle rolled over.

Based on this test, the CMB designs used in California have been changed. The 10 inch (254 mm) deep concrete footing has been eliminated from both the Type 50 standard 32 inch (813 mm) high New Jersey barrier design and the Type 50C New Jersey CMB design. The Type 50C design is used for superelevated transitions and at other locations where the offset in elevation between opposing roadways varies up to 3 feet (914 mm). Three longitudinal No. 4 (12.7 mm) steel reinforcing bars have been added to the Type 50 and 50C CMB designs.

17 KEY WORDS	18 DISTRIBUTION STATEMENT
Impact tests, median barriers, reinforced concrete, shrinkage cracks vehicle dynamics	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161

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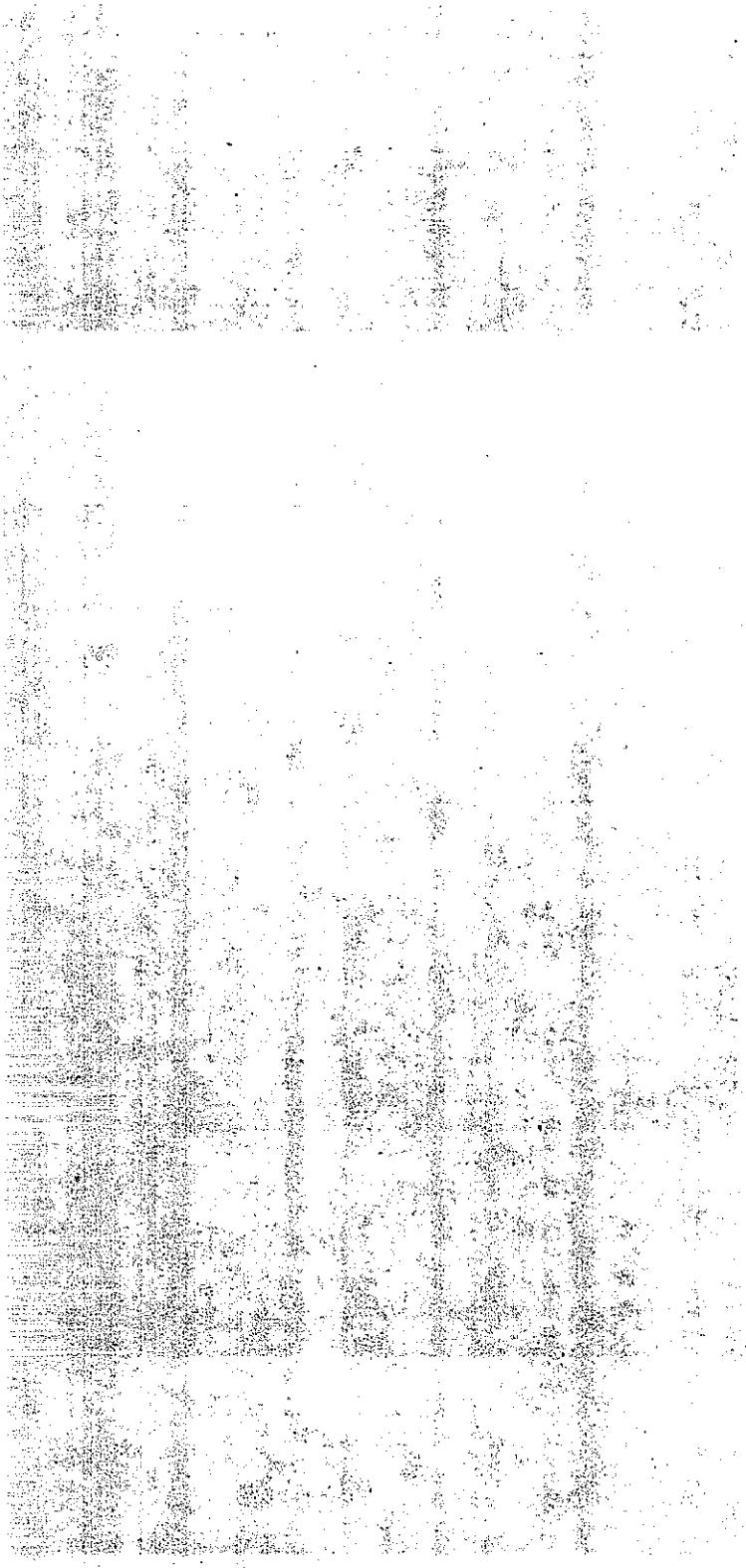

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STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF STRUCTURES & ENGINEERING SERVICES
OFFICE OF TRANSPORTATION LABORATORY

August 1977

TL No. 636883
Item No. D-4-151

Mr. C. E. Forbes
Chief Engineer

Dear Sir:

I have approved and now submit for your information this final research project report titled:

VEHICULAR CRASH TEST OF A CONTINUOUS
CONCRETE MEDIAN BARRIER WITHOUT A FOOTING

Study made by ..... Structural Materials Branch

Under the Supervision of ..... E. F. Nordlin, P. E.

Principal Investigator ..... J. R. Stoker, P. E.

Co-Principal Investigator ..... R. L. Stoughton, P. E.

Co-Investigator ..... D. M. Parks, P. E.

Report Prepared by ..... D. M. Parks, P. E.

Very truly yours,

George A. Hill

GEORGE A. HILL
Chief, Office of Transportation Laboratory

DMP:bjs
Attachment

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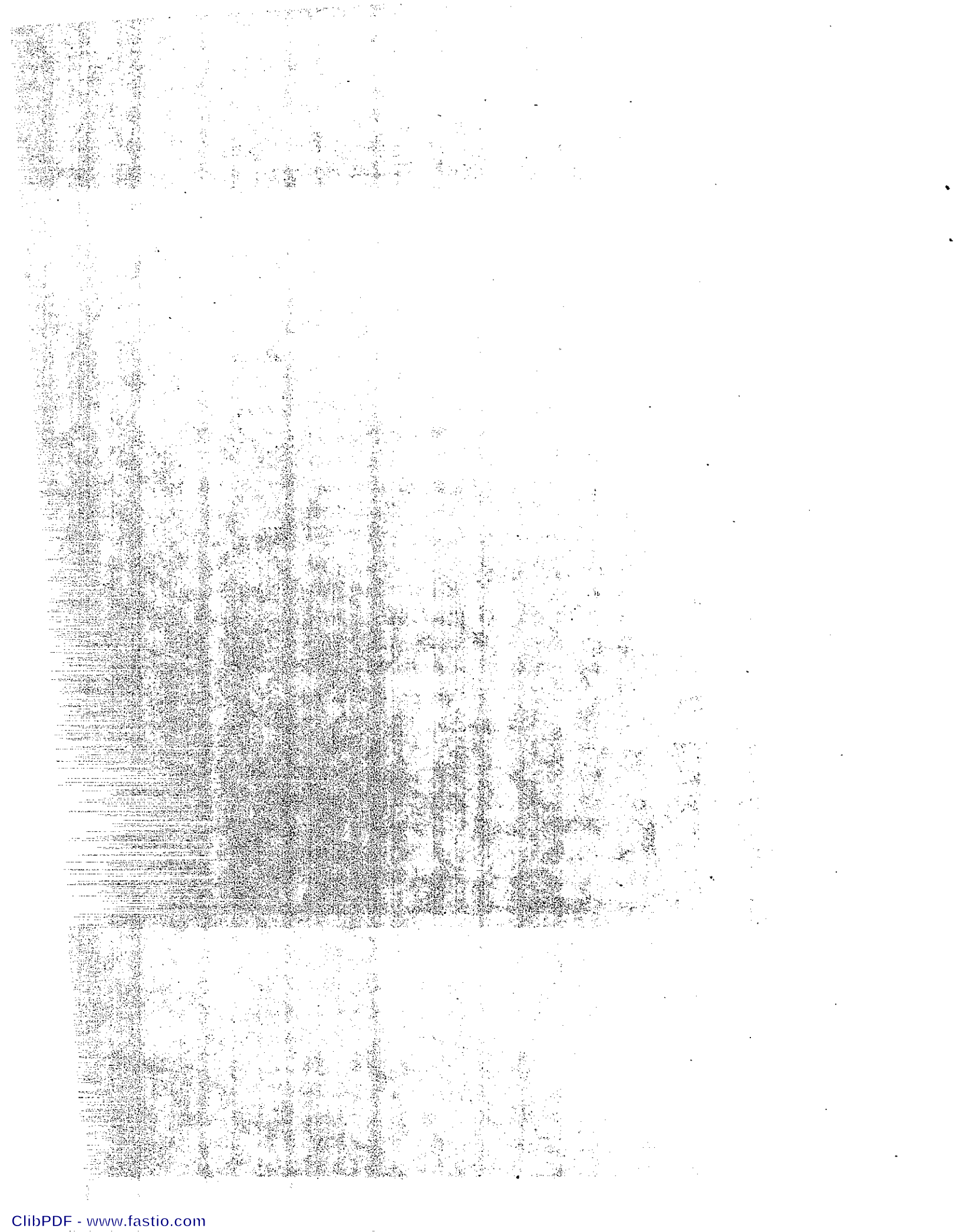

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ACKNOWLEDGEMENTS

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The contents of this report reflect the views of the Transportation Laboratory which is responsible for the facts and the accuracy of the data presented herein. The contents of this report do not necessarily reflect the official views or policies of the State of California or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation. It should also be recognized that the opinions, findings, and conclusions expressed in this publication are not necessarily those of the Federal Highway Administration.

Special appreciation is due the following staff members of the Transportation Laboratory who were instrumental in the successful completion of the test, construction of the test barrier, and in the preparation of this report:

Lee Staus	In charge of preparation and operation of the test vehicle and other test equipment; helped conduct the test and assisted with barrier construction.
Jim Keesling	In charge of photo and electronic instrumentation data reduction; prepared the movie report; helped conduct the test; and assisted with barrier construction.
John P. Dusel Jr. Duane H. Anderson Enrico Maggenti	Assisted with barrier construction
Robert Mortensen	Data and documentary photography.

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Richard Johnson Delmar Gans	Electronic instrumentation of the test vehicle and barrier.
Elmer Wigginton	Drafting of tables, figures, and instrumentation data traces.
Larry Stevens	Reproduction.

Appreciation is also due the following personnel from the California Department of Transportation who were available for technical consultation and advice during the project:

Edward J. Tye	Office of Traffic
Ralph W. Bishop	Office of Structures Planning
John Evans	Value Engineering Branch

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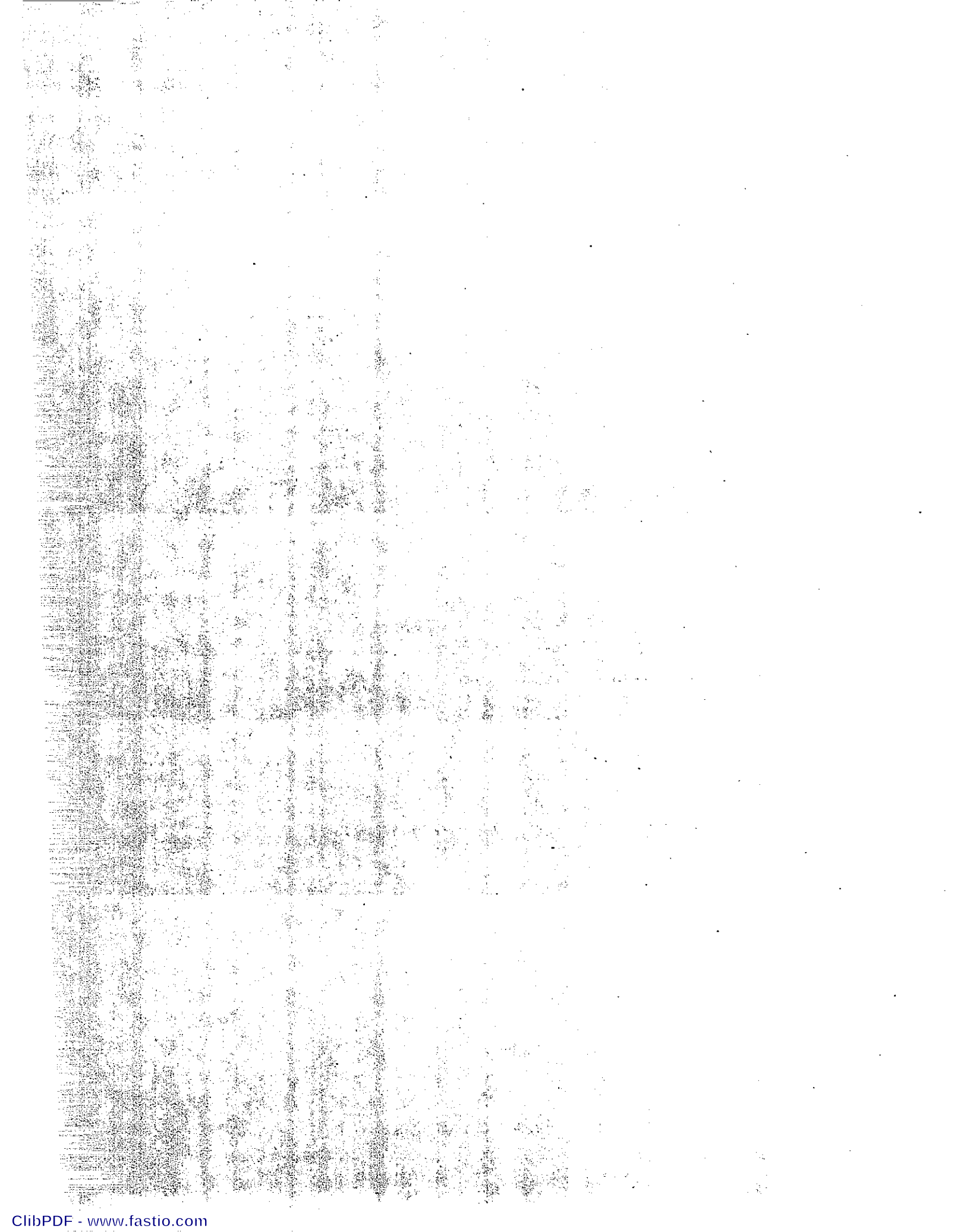

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INTRODUCTION

Between 1971 and 1976 about 300 miles (483 km) of New Jersey shape concrete median barrier (CMB) was built on California highways. Virtually none of this type of barrier existed before that time in California. The New Jersey shape CMB design has been enthusiastically promoted during this short time because of its good impact performance, its low maintenance costs, its low first cost and its relatively pleasing appearance.

This project was initiated in January 1976 after a report(1)* by the Value Engineering Branch of the California Department of Transportation (Caltrans) indicated that the CMB (California Type 50 and Type 50C) might still be functional without its continuous concrete footing.

A cost savings of $3.80 per lineal foot was estimated for the standard 32 inch (813 mm) high CMB (Type 50) without a footing. This barrier is commonly used in flat narrow medians.

A cost savings of $4.35 per lineal foot was anticipated for the Type 50C CMB design without a footing This design is used exclusively where offsets in elevation occur between opposing roadways. The cost estimate was based on an average differential height of 10 inches (254 mm) which makes the overall height of the barrier 42 inches (1.1 m). The maximum offset allowed in California for Type 50C CMB is 36 inches (914 mm).

*Numbers underlined in parentheses refer to a reference list at the end of this report.

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In the 1976-77 fiscal year about 112 miles (180 km) of CMB (all types) were scheduled for construction in California. In recent years, the ratio of Type 50 and Type 50C CMB (both cast-in-place and slipformed) to all other types of CMB were 58% and 35% respectively. Using these ratios and the cost savings per lineal foot for these designs, a total possible cost savings of about $2,200,000 could have resulted by eliminating the concrete footings. In addition, construction time could be reduced if the footings were eliminated. It is expected that similar levels of new CMB construction will continue in the next few years.

The cost savings above are based on the elimination of the footings with no other conditions changed. Provisions for an adequate bearing surface (pavement or compacted base) needed for the barrier in some locations could reduce the projected cost savings.

The purpose of this project was to test the structural strength and stability of continuous CMB without a footing. Since 1967 Caltrans has previously evaluated three New Jersey shape CMB designs with different foundation anchorage systems for structural adequacy by conducting crash tests, Figure 1. Other agencies (2,3,4,5) have qualified similar CMB designs.

In addition Caltrans has conducted full scale impact tests(6) on freestanding precast segments of New Jersey shape CMB, 12.5 ft and 20 ft (3.8 and 6.1 m) long, with pinned end connections. These barrier segments when impacted at impact speeds/angles of about 65 mph (29 m/s)/25 degree (0.44 rad) moved laterally and rotated excessively causing vehicle vaulting and other undesirable vehicle behavior.

It was concluded that CMB cast-in-place or slipformed continuously without a footing might fall somewhere between

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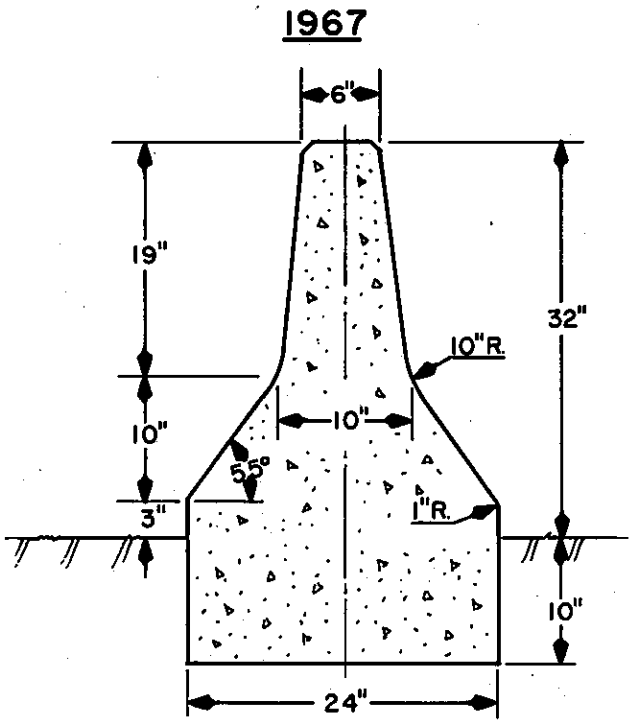
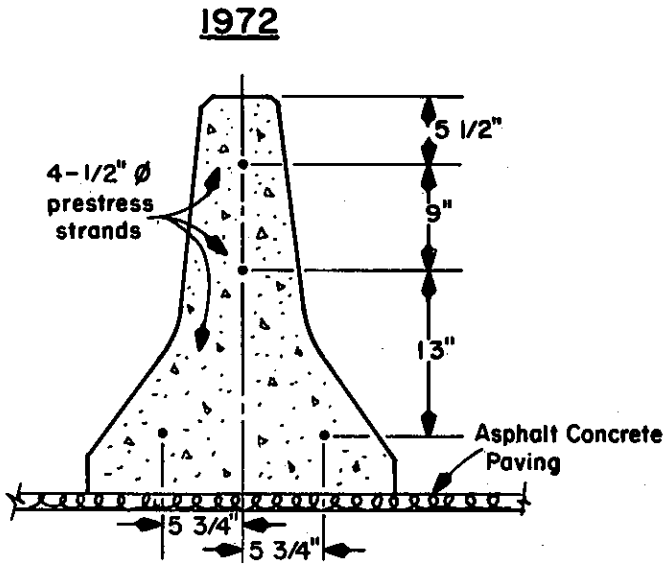
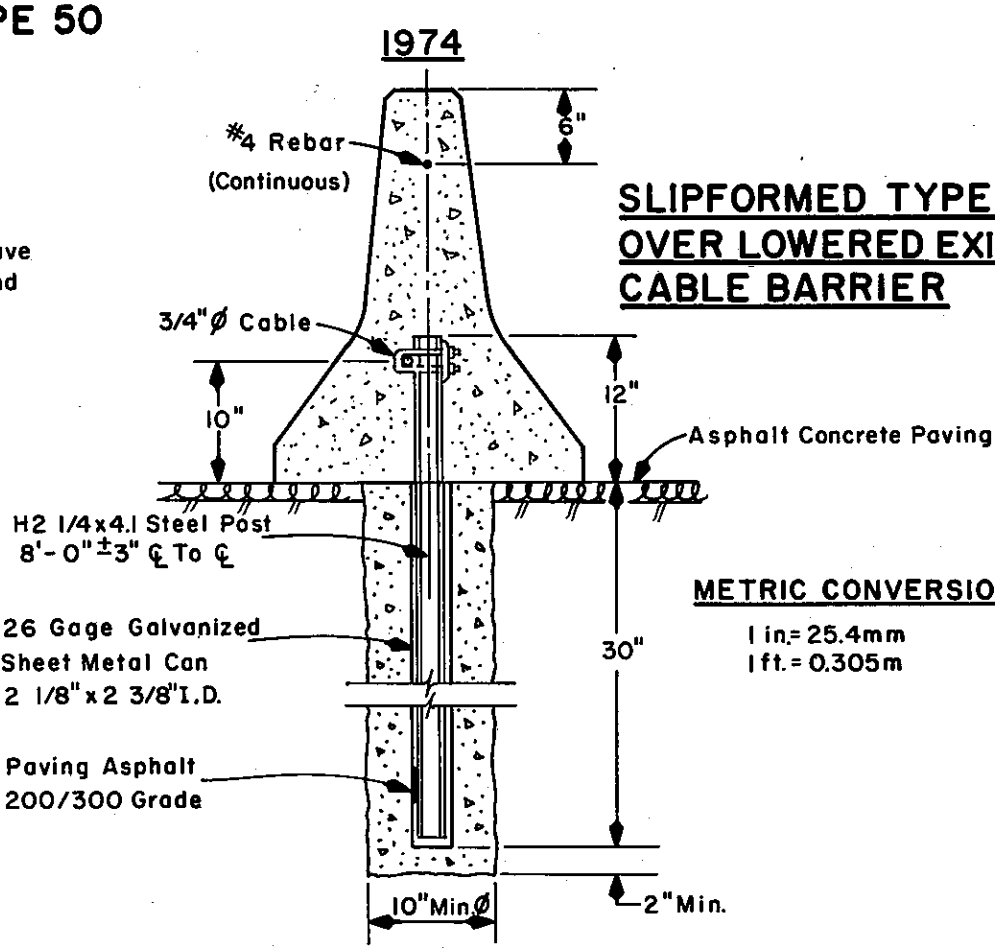


CONCRETE BARRIER
TYPE 50



PRESTRESSED CONCRETE
BARRIER
TYPE 50

NOTE:
All three designs have the same above ground concrete dimensions.



SLIPFORMED TYPE 50
OVER LOWERED EXISTING
CABLE BARRIER

METRIC CONVERSIONS
1 in.= 25.4mm
1 ft.= 0.305m

Figure 1, TYPICAL SECTIONS OF NEW JERSEY SHAPE CMB TESTED BY CALTRANS

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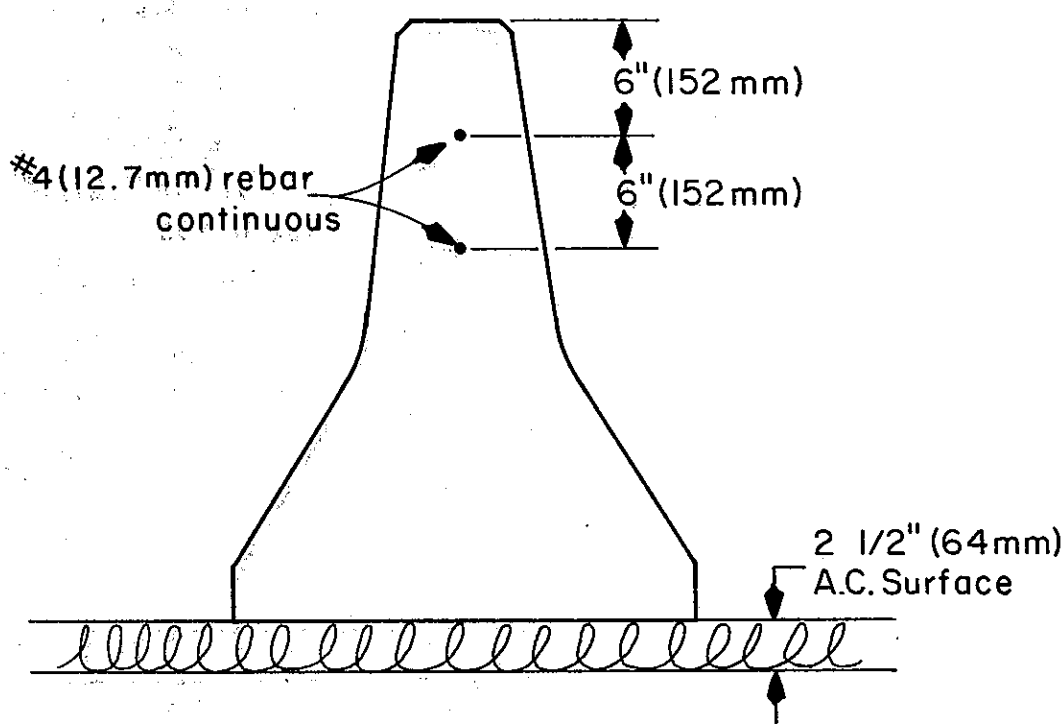
the strength and stability range of barriers with footings and the freestanding precast CMB designs which were unacceptable for severe impact conditions. Therefore, a crash test of a New Jersey shape CMB without a footing was warranted.

This report describes the results of a vehicular impact, 4700 lb (2130 kg) vehicle/61 mph (27 m/s)/26 degrees (0.46 rad), into the CMB without a footing as shown below:



A second impact test of a CMB design (Type 50C) used in saw-tooth medians without a footing was also scheduled for this project. However, this test was not conducted due to the favorable strength and stability results from the first test.

This report also summarizes and discusses other large angle passenger vehicle tests and all heavy vehicle impact tests conducted on other permanent CMB designs.

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CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The following conclusions were based on the results of a 4700 lb (2130 kg) vehicle/61 mph (27 m/s)/26 degree (0.46 rad) impact test, Test 321, of a lightly reinforced continuous New Jersey shape concrete median barrier (CMB) cast without a concrete footing on an asphalt concrete surface:

- The structural strength and stability of the barrier were not affected by eliminating the 10 inch (254 mm) deep concrete footing specified for use with cast-in-place or slipformed New Jersey shape CMB (Type 50) in the 1975 California Standard Plans. The test barrier did not move laterally or rotate about its longitudinal axis during impact.

- The test barrier suffered no structural damage even though the point of impact occurred at one of five shrinkage cracks which were allowed to form randomly during construction. There were no construction or contraction joints in the test barrier.

- During this severe impact test, the test vehicle rolled over after it was redirected by the CMB. The rollover was caused primarily by excessive rolling and yawing motions of the vehicle and was not related to the fact the barrier had no footing.

- The uncontrolled postcrash rollover trajectory of the test vehicle, if occurring on a highway, would be hazardous to adjacent traffic and might cause a secondary accident.

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- Based on the favorable strength and stability results of Test 321 the second impact test planned for this project on a similar design, the California Type 50C CMB for "sawtooth" medians, was not conducted. It was concluded that lateral barrier movement and rotation were unlikely to occur with this sawtooth CMB design due to its mass per lineal foot which would have been up to three times greater than the mass of the barrier used in Test 321.

Recommendations

The following recommendations are based on the results of Test 321 described in this report, and on a review of other large angle passenger vehicle and heavy vehicle tests summarized in Table 1 of the Discussion of Results section of the report:

- The 24 inch (610 mm) wide by 10 inch (254 mm) deep continuous concrete footing shown in the California 1975 Standard Plans should be eliminated from all types of CMB except at the ends of the barrier. The last 10 ft (3.1 m) of the CMB should retain that footing and the barrier should be reinforced at these locations.

- The California Type 50 and 50C CMB should include four continuous longitudinal No. 4 (12.7 mm) steel reinforcing bars (Grade 60) as shown below to prevent any loss in reserve lateral strength resulting from removal of the concrete footing. The reinforcing bars at the top of the barrier are needed to help contain chunks of concrete from falling into opposing traffic lanes during a punchout failure when the barrier is hit at a large angle. The bars at the bottom of the barrier should help minimize lateral barrier movement.

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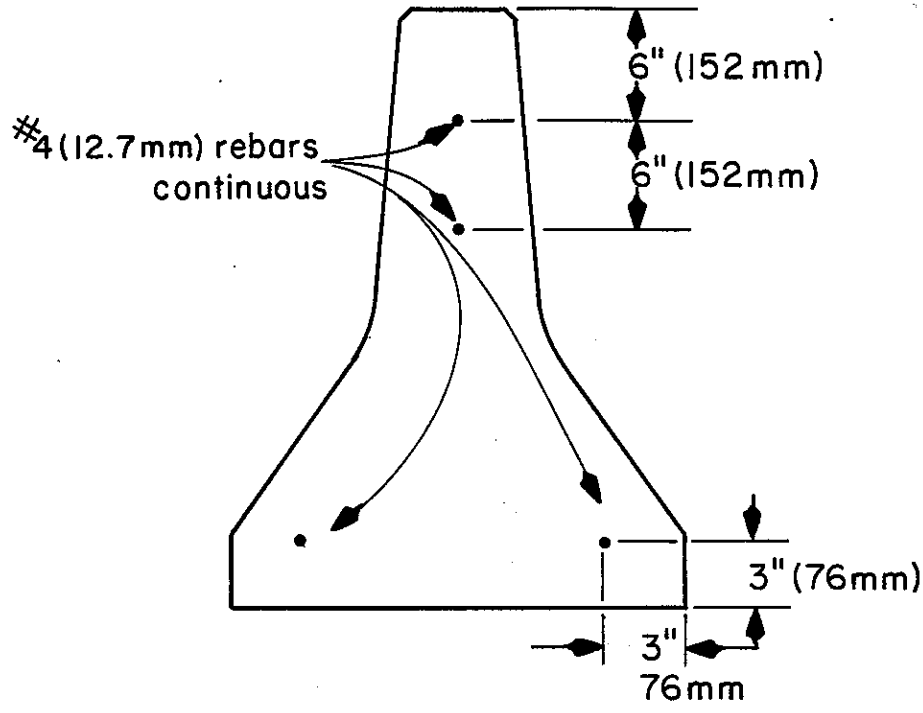

- The New Jersey CMB without a footing should be cast directly on top of asphalt concrete, portland cement concrete, or a well compacted aggregate base.

- There may be situations or site conditions where additional restraint against lateral translation may be required or warranted. For such non-standard conditions the use of a footing, an abutting asphalt concrete overlay, dowels, or other alternate designs may be required. Caltrans Headquarters should be consulted for the use of special details which deviate from the "Standard" design.

- The use of a 10 inch (254 mm) by 24 inch (610 mm) footing could be considered as a viable Contractor alternative to the placement of a prepared base as required in the third recommendation above. For such an alternate the lower two No. 4 (12.7 mm) steel reinforcing bars would not be

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required. This design may be necessary for unique roadway conditions.

- The placement of the Type 50 CMB over an existing lowered cable barrier in accordance with Caltrans special details could also be considered as a viable Contractor alternative in which case the lower two No. 4 (12.7 mm) steel reinforcing bars would not be required.

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IMPLEMENTATION

Special details A75-A.5 and A75-B.4 of the 1977 California Standard Plans, Figures 2 and 3, show the implementation of the recommendations of this research report. The 10 inch (254 mm) deep concrete footings have been removed from Concrete Barrier Type 50 and Type 50C and the extra longitudinal reinforcing bars have been added to these designs. Also, details have been added to anchor the last 10 ft (3.1 m) of the CMB with a concrete footing.

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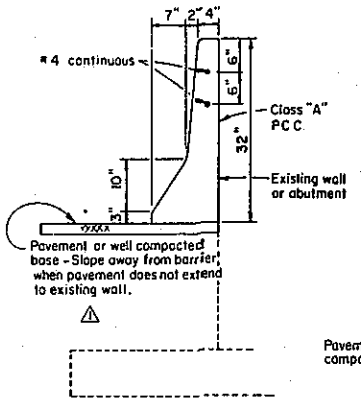
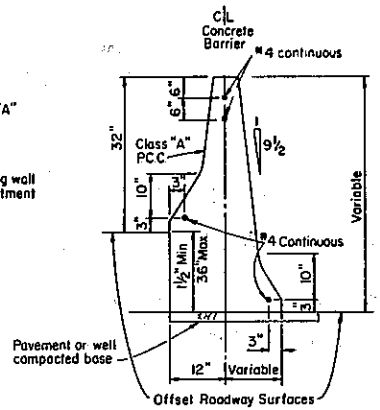


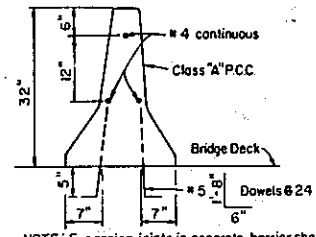
CONCRETE BARRIER
(TYPE 50D)

Placed on Face of Existing Structure.
(Details similar to Type 50 except as noted.)



CONCRETE BARRIER
(TYPE 50C)

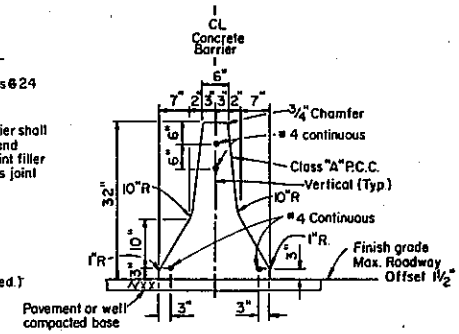
For Offset or Superelevated Roadways
(Details similar to Type 50 except as noted. Barrier End Anchor when necessary.)



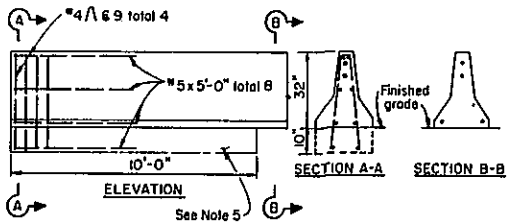
NOTE: Expansion joints in concrete barrier shall be located at all deck, pavement and principal wall joints. Expansion joint filler material shall be the same size as joint or ½" minimum.

CONCRETE BARRIER
(TYPE 50A)

Placed on New Structures
(Details similar to Type 50 except as noted.)

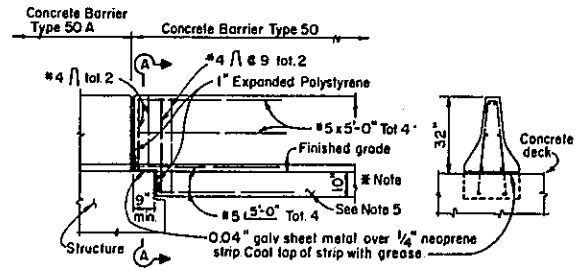


CONCRETE BARRIER
(TYPE 50)



BARRIER END ANCHOR

For Transition to other barriers
See Standard Plan A81



CONNECTION TO STRUCTURE

* Note- 10" Barrier footing extends 10' back from structure.

GENERAL NOTES

1. See Standard Plans A75-B for Transition at Bridge Column or Sign Pedestal, Type 50E Barrier, Glare Screen Attachment Details and A77-B for additional Headlight Glare Screen Details.
2. Openings into existing drainage inlets shall not extend above the 3-inch vertical face at bottom of the barrier.
3. Where the barrier is added to the face of an existing concrete structure match existing weep holes.
4. Contractor may submit alternative details for Engineer's approval.
5. Footing Monolithic or doweled with 2- #8 x 0'-8" @ 24

CHIEF, TRAFFIC BRANCH
REGISTERED CIVIL ENGINEER NO 11210
APPROVED December 10, 1976

STATE OF CALIFORNIA
BUSINESS AND TRANSPORTATION AGENCY
DEPARTMENT OF TRANSPORTATION

CONCRETE BARRIER TYPE 50 | A75-A.5

6/12/74 - REDRAWN | ⚠ 2/11/76 - REMOV FACING, REV NOTE

Figure 2
10

A75-A.5

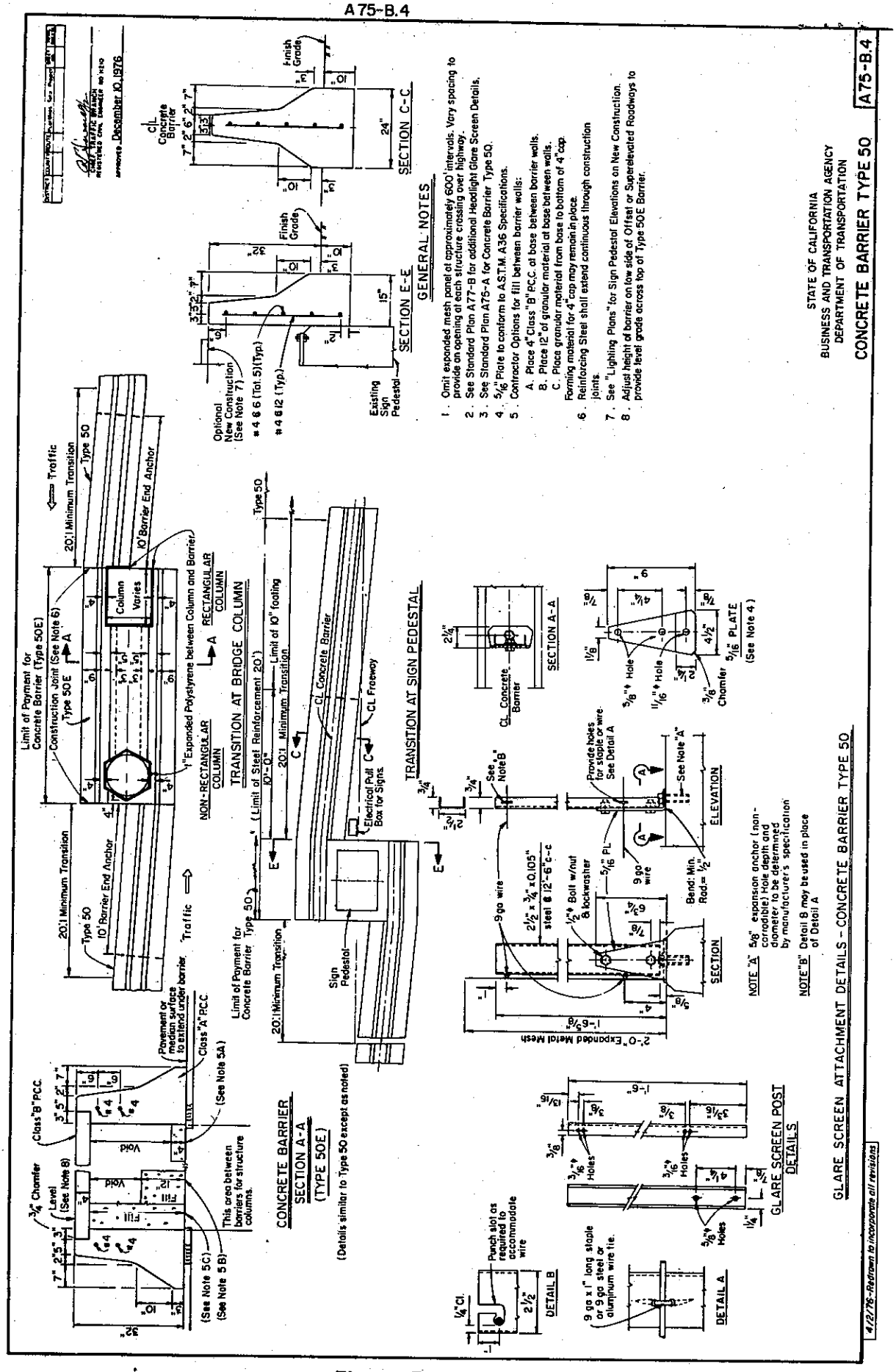


Figure 3

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TECHNICAL DISCUSSION

Test Facility and Equipment

The vehicular impact test was conducted at the Caltrans Dynamic Test Facility in Bryte, California. The test vehicle complied with NCHRP Report 153(12). A description of test equipment mounted on the test vehicle is included in the Appendix. Also included is a detailed description of the photographic and electronic data collection equipment used for the test.

Barrier Design and Construction

The 120 ft (36.6 m) long test barrier was cast-in-place without a footing on top of a 2 1/2 inch (64 mm) thick asphalt concrete surface, Figure 4.

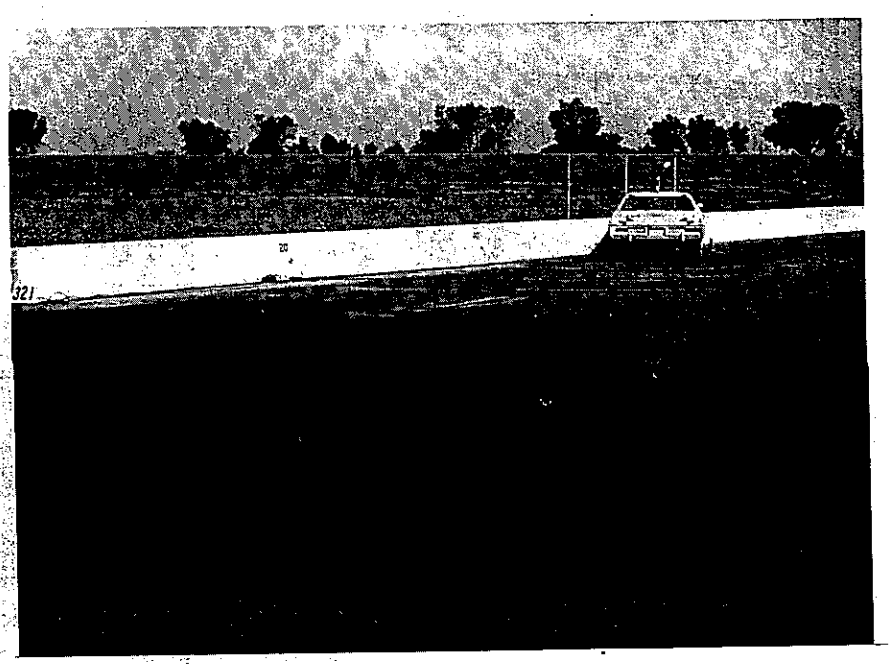

Figure 4, Test Barrier

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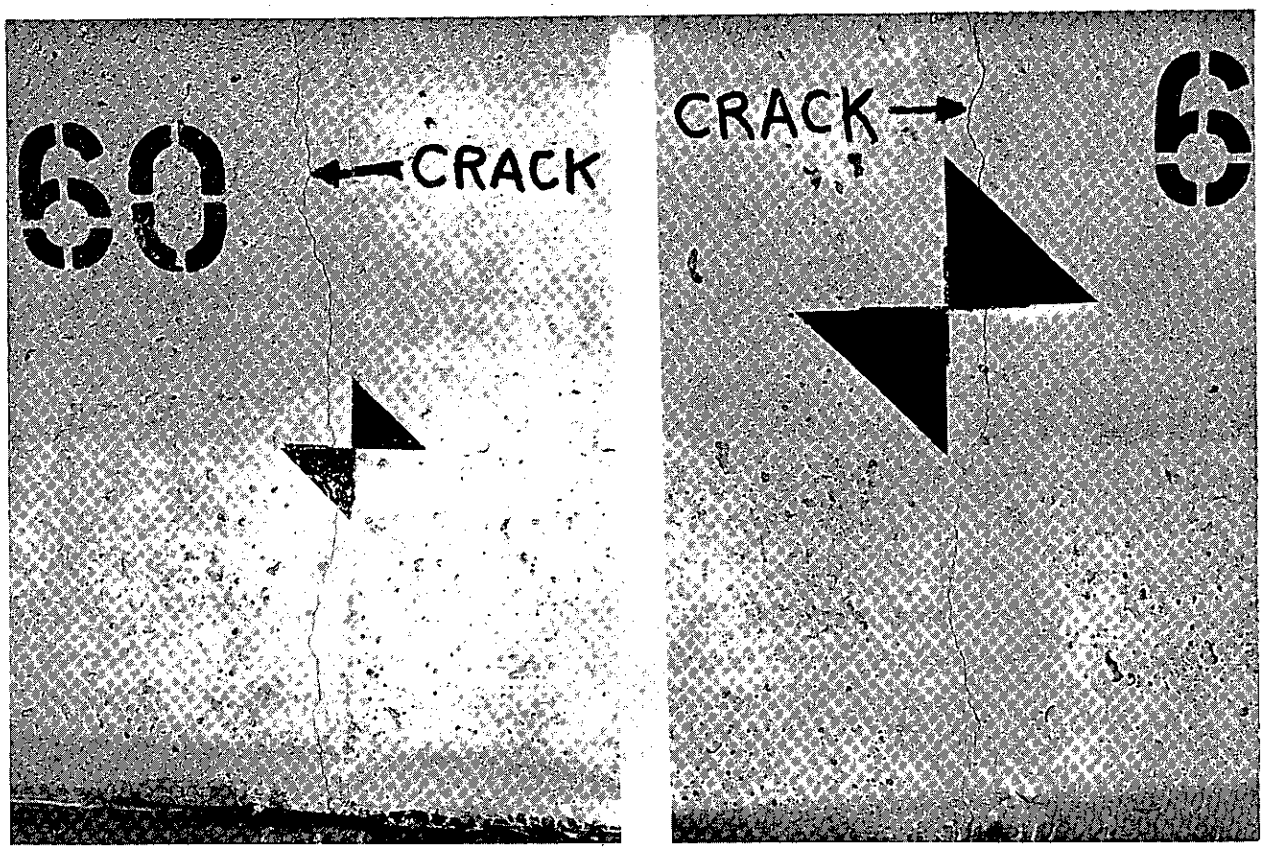
The barrier contained two continuous longitudinal No. 4 (12.7 mm) steel reinforcing bars (Grade 40) placed at 6 and 12 inches (152 and 305 mm) down from the top of the barrier.

There were no construction or contraction joints in the test barrier section, however, random shrinkage cracks appeared at 26.3, 37, 60, 75.4, and 90 feet (8.0, 11.3, 18.3, 23.0, and 27.4 m) from the upstream end on both sides of the barrier. A typical shrinkage crack is shown in Figure 5.



Impact Side Back Face

Figure 5, Shrinkage Crack at Middle of Test Barrier, Sta. 60+00

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A concrete mix design with 6 sacks of portland cement per cubic yard (0.77 m^3) and 1 inch (25 mm) maximum size aggregate was used. This mix design was similar to that used for constructing New Jersey CMB with a slipforming machine. The 28 day compressive strength of the concrete was 4504 psi (31.1 MPa). The strength of the concrete at the time of the crash test, the 36th day, was 4738 psi (32.7 MPa).

Small cracks in the asphalt concrete paving at each end of the test barrier were evidence of a developed bond strength between the bottom of the barrier and the paving which did not fail during longitudinal shrinkage of the concrete barrier.

Test Results

Test 321: 4700 lb (2130 kg) vehicle/61 mph (27 m/s)/26 degrees (0.46 rad).

Impact Description - The left front of the 1973 Dodge Polara sedan impacted the middle of the concrete median barrier 59 feet (18 m) from its upstream end. During the initial impact, the right front wheel was forced under the vehicle towards the barrier. As the vehicle climbed and began to roll away from the barrier, the vehicle momentarily pivoted about its lowered right front wheel allowing the right side of the vehicle to approach the ground. During the pivoting motion, the left back side of the vehicle swung around to impact the barrier. At this instant the vehicle, having rolled 24 degrees (0.42 rad) away from the barrier, grazed only the top edge of the barrier. The vehicle remained in contact with the barrier for 16 feet (4.9 m). It continued to roll and yaw clockwise while traveling adjacent to the barrier, becoming airborne for about 5 feet (1.5 m) and attaining a maximum height of 5.5 feet (1.7 m) above ground (measured at the left rear bumper). The vehicle reached the

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end of the barrier at an attitude nearly perpendicular to the barrier. During this time it reached a maximum roll angle of 48 degrees (0.84 rad). Returning to the ground, the vehicle rolled counterclockwise, rolling over once, and came to rest approximately 103 feet (31.4 m) from the end of the barrier. In this position, the vehicle was 23 feet (7.0 m) away from the impact side of the barrier and faced back towards the impact area almost parallel to the centerline of the barrier. Figure 8, at the end of the Test Results section of this report, summarizes the data for Test 321 and includes sequential impact photographs and a vehicle trajectory diagram.

Barrier Performance and Damage - The test barrier redirected the impacting vehicle. The vehicle did not penetrate or vault the barrier.

There was no permanent lateral barrier movement during the test. A maximum dynamic lateral barrier deflection of 1/4 inch (6 mm) was recorded at a point 5 feet (1.5 m) downstream from initial barrier contact 0.093 seconds after impact. Figure 6A in the Appendix shows the barrier deflection versus time plots of four deflection potentiometers located 6 inches (152 mm) down from the top of the barrier and placed along the barrier at 10 foot (3.1 m) intervals.

The barrier did not crack or sustain any structural damage during the test. Beginning at the point of impact, the barrier was scuffed and scraped for about 16 feet (4.9 m), as shown in Figure 6.

Impact occurred at a shrinkage crack located in the middle of the barrier at 60 feet (18 m). There was no apparent change in the width of this crack after the test. There was also no change in the size of the other shrinkage cracks as a result of impact.

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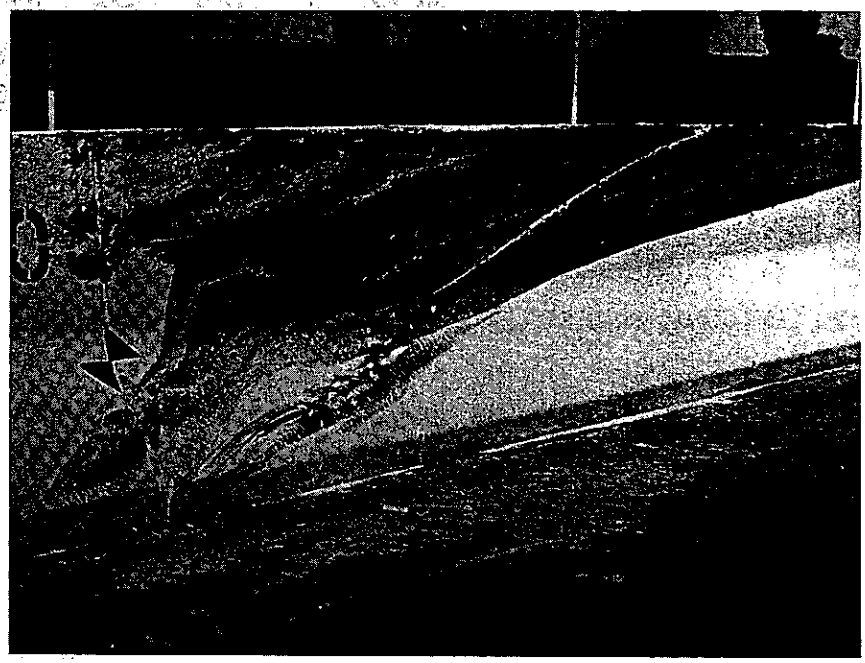

Figure 6, Scuff Marks and Scrapes on Barrier

Vehicle Damage - The test vehicle was severely damaged from the barrier impact and the resulting vehicle rollover, Figure 7. The left front quarter panel was crushed back under the vehicle. The floor of the vehicle in the vicinity of the brake pedal was slightly pushed up into the passenger compartment; however, there was no intrusion of vehicle or barrier components. Damage resulting from the vehicle rollover included crushing in of the top of the vehicle about 6 inches (152 mm), broken front and back windshield glass, dents along both sides and on top of the trunk area of the vehicle, and ejection of the vehicle's battery. The battery was found about 60 feet (18 m) away from the end of the barrier and about 11 feet (3.4 m) in front of it. Assessment of vehicle damage according to the Traffic Accident Scale (TAD)(7) and Vehicle Damage Index (VDI)(8) was as follows:

TAD: LFQ-5, LD-3, L&T-5
VDI: 11LFEW5, 00TYG03

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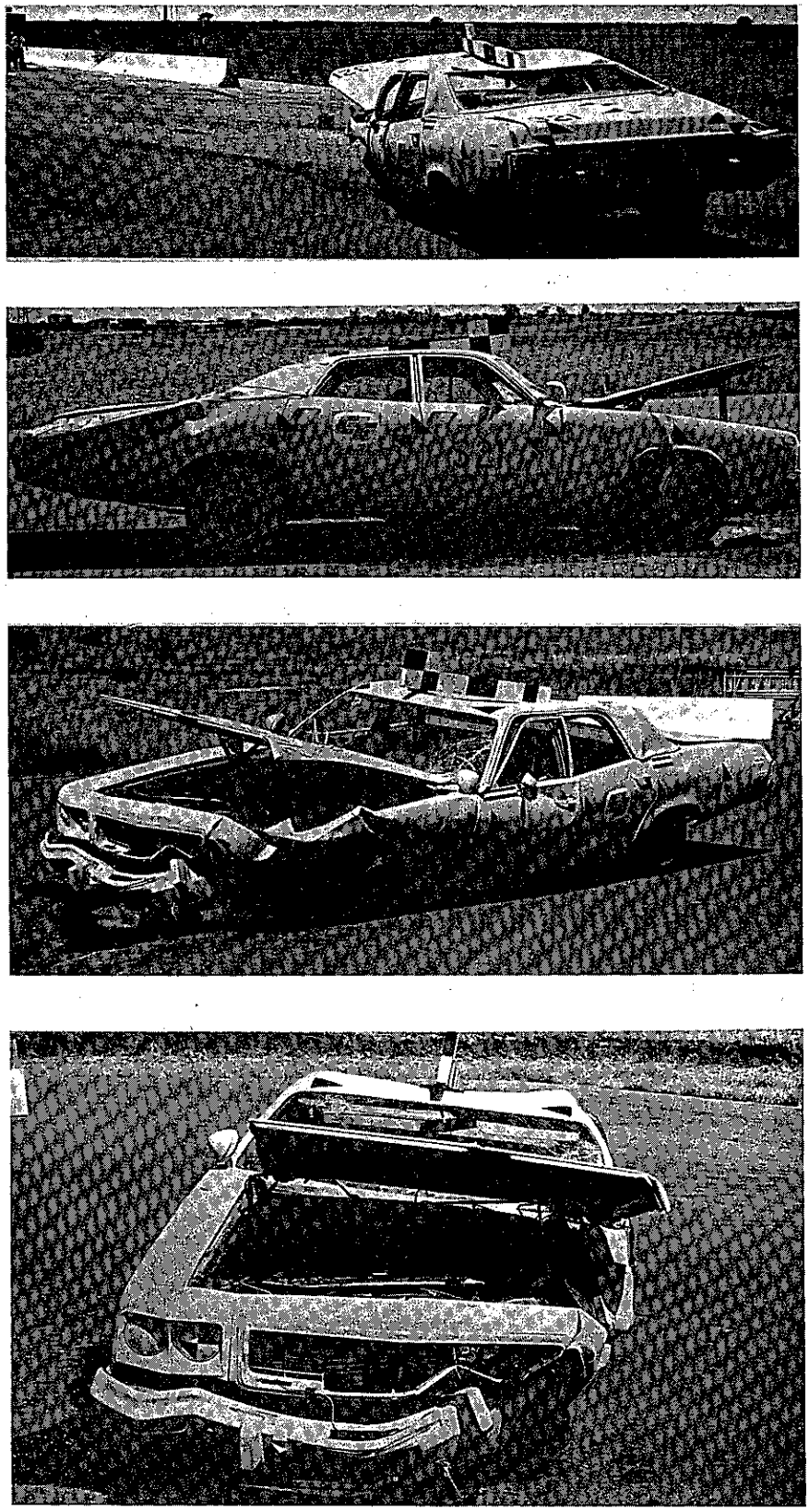

Figure 7, Vehicle Damage

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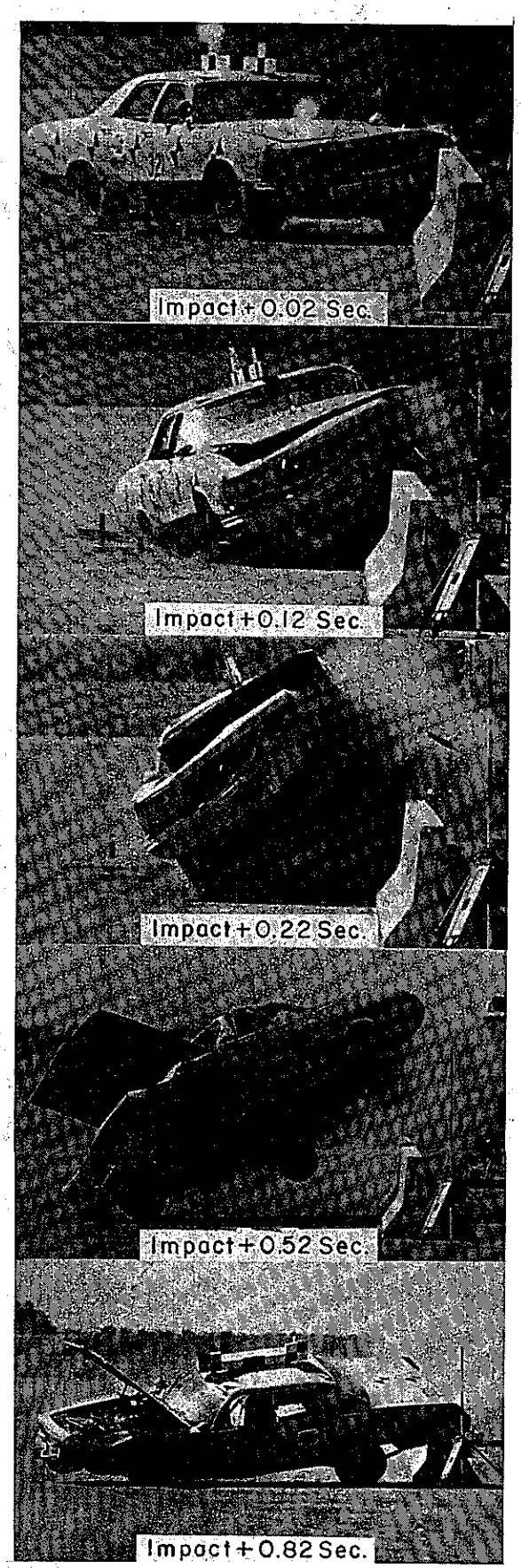
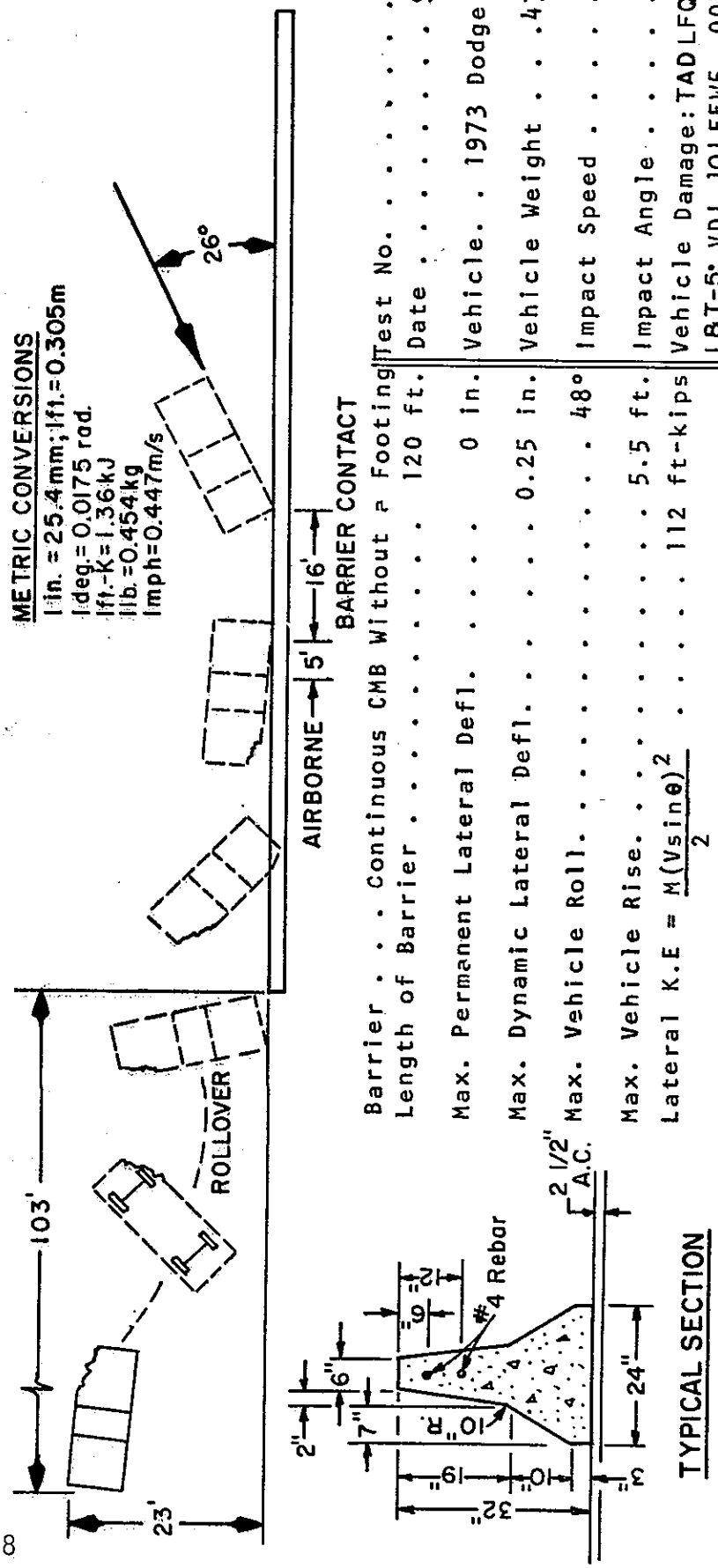
FIGURE 8, DATA SUMMARY SHEET





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Discussion of Results

Safety performance of the CMB used in Test 321 can be judged by comparison with the three appraisal factors, defined in NCHRP Report 153 "Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances"(12). These factors are structural adequacy, impact severity, and vehicle trajectory and are discussed in the following three sections of the report.

Table 1 summarizes data from other tests on CMB and can also be used on a relative basis for judging the results of Test 321. Included in the table in chronological order are data from tests on four CMB designs tested at 25 degrees (0.44 rad) by Caltrans since 1967(9,10,11) along with other large angle tests of similar designs conducted by the Texas Transportation Institute (TTI)(2) and the National Institute for Road Safety (NIRS) of France(4). Also included for comparison are three 48,800 lb (22,100 kg) tractor/trailer truck tests conducted by TTI(3), a 21,650 lb (9,830 kg) tank truck test by NIRS(4), and three 40,000 lb (18,200 kg) scenicruiser bus tests conducted by Southwest Research Institute (SWRI)(5) on CMB.

Structural Adequacy - The test barrier redirected the test vehicle without moving laterally, rotating, or sustaining any structural damage. The barrier did not crack during the test. The point of impact was located at a shrinkage crack. This crack, however, did not widen from the impact. Other than removing the scuff marks on the face of the barrier, little maintenance would be required. The gouges in the face of the barrier probably could be neglected.

The test vehicle did not penetrate or vault the barrier. However, during impact it went through a series of strong yawing and rolling motions. The roll was 24 degrees (0.42 rad)

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TABLE* I, DATA SUMMARY OF LARGE ANGLE PASSENGER VEHICLE AND HEAVY VEHICLE CMB CRASH TESTS

TEST NO.	REF.	BARRIER(8)	LENGTH ft.	FOOTING, ANCHORAGE	VEHICLE TEST PARAMETERS						VEHICLE(9) DECELERATION Gs		VEHICLE TRAJECTORY							MAX. PERM. LATERAL DEFLECTION IN	REMARKS
					YEAR & MAKE	WEIGHT lbs.	SPEED mph	IMPACT ANGLE°	KINETIC ENERGY 1000 ft-lb	LATERAL (23) KINETIC ENERGY 1000 ft-lb	LONG.	LAT.	EXIT(13) ANGLE°	RISE(14) ft.	ROLL(16) degrees	EXIT(19) Speed mph	BARRIER CONTACT ft.	AIRBORNE DISTANCE ft.	MAX.(22) REBOUND ft.		
162	(1) (2) CALIF.	Unreinforced Concrete	160	24"x 10" Deep Concrete Footing	1965 Dodge Polara	4540	63	25	602	108	NA	NA	16	NA	25	51	12.5	20	47	ø	Vehicle redirected
262		Prestressed Type 50 4-1/2" ϕ Strands @ 28 kips each	150	NONE	1970 Mercury Monterey	4960	59	25	577	103	7.0	11.6	NA	2.8	28	57	13	50	43	ø	Vehicle redirected, but rolled
263		Prestressed Type 50 4-1/2" ϕ Strands @ 28 kips each	150	NONE	1970 Mercury Monterey	4960	66	25	722	129	NA	NA	8	2.7	35	55	14	55	51	ø	Vehicle redirected, but rolled; torsional fracture in barrier.
264		Prestressed Type 50 3 of 4-1/2" ϕ Strands @28 kips each; 1 @ 0 kips	150	NONE	1969 Dodge Polara	4860	64	25	665	119	5.2	13.0	5	3.0	43	54	15	20	52	ø	Vehicle redirected
265		Prestressed Type 50 4-1/2" ϕ Strands @ 10 kips each	150	NONE	1968 Dodge Polara	4780	62	24	614	102	NA	NA	4	3.7	40	52	13	30	42	ø	Vehicle redirected; hairline fracture
CMB-1	(3) (4) T. T. I.	Reinforced Concrete 8-#5 rebars	50	3-18" diameter CIDH Concrete Shafts	1963 Plymouth	4000	62.4	25	521	93	(10) 8.7/3.2	(10) 16.1/4.4	7.3	NA	NA	NA	NA	NA	NA	ø	Vehicle redirected
CMB-2			150	1" layer of asphalt concrete at front & back face of barrier	1964 Chevrolet	4230	55.7	25	439	78	(10) 10.3/1.8	(10) 13.3/2.8	6	NA	NA	NA	NA	NA	NA	ø	Vehicle redirected
CMB-5					Tractor-trailer Truck	48,800 includes 22,800 ballast	34.9	19.1	1986	213	NA	NA	NA	0.7/1.3 (15)	7 (17)	NA	150 (20)	ø	NA	ø	Vehicle redirected
CMB-6							33.8	15.5	1863	133	NA	NA	NA	0.7/1.6 (15)	6 (17)	NA	150 (20)	ø	NA	ø	Vehicle redirected
CMB-7							44.7	15	3258	218	NA	NA	NA	1/1.6 (15)	17 (17)	NA	150 (20)	ø	NA	ø	Vehicle redirected
301	(5) CALIF.	Reinforced Concrete 1-#4 rebar Slipformed Type 50 Over Lowered Cable Barrier	97	H2 1/4 x4.1 Steel Posts@8'-0" spacing 1'-0" above grade; 3/4" cable attached to posts; turnbuckle W/anchor rod embedded in conc. end anchors	1969 Dodge Polara	4860	68	27	751	155	11.7	13.8	7	3.2	27	50	13.1	30	31	0.08	Vehicle redirected
MT-ISC 01/319	(6) FRANCE	Reinforced Concrete 2-#4 rebars (Same location as Calif. Test 321)	> 160	NONE	404 Peugeot	2745	52	31	248	66	>10 (11)	16 (11)	Small	NA	NA	NA	8.5	Slightly	NA	ø	Vehicle redirected
TS-ISC 02/320					Truck Bernard Type 19 DA150	21,650	44.7	21	1446	186	7.5 (11)	11.5 (11)	Small	NA	NA	NA	59	Some	NA	ø	Vehicle redirected 8"x 9' section of barrier top broke out
CMB-21	(7) SWRI	Reinforced Concrete 1-#4 rebar	200 With const. joints 50ft. from each end	1" layer of asphalt concrete placed at base of barrier on the side opposite impact	1955 GMC Scenicruiser Bus Model PD-4501	40,000 With 10,200 ballast	41.7	11.5	2324	92	0.9 (12)	0.7 (12)	Small	NA	8 (18)	NA	25.9	ø	NA	ø	Vehicle redirected
CMB-22							51.6	6.6	3559	47	0.9 (12)	0.8 (12)	Small	NA	9 (18)	NA	28	ø (21)	NA	ø	Vehicle redirected
CMB-23							52.9	16	3741	284	0.8 (12)	1.0 (12)	Small	NA	24 (18)	NA	65	ø	NA	31	Vehicle redirected; extensive barrier damage
321	CALIF.	Reinforced Concrete 2-#4 rebars	120	NONE	1973 Dodge Polara	4700	61	26	584	112	—	—	7	5.5 (24)	48	45	16	5	23	ø	Vehicle redirected but rolled

*Footnotes on following page

TABLE 1, continued

DATA SUMMARY OF LARGE ANGLE PASSENGER VEHICLE
AND HEAVY VEHICLE CMB CRASH TESTS

Footnotes for Table 1

(1) California Division of Highways, report reference 9.

(2) California Division of Highways, report reference 10.

(3) Texas Transportation Institute, report reference 2.

(4) Texas Transportation Institute, report reference 3.

(5) California Department of Transportation, report reference 11.

(6) National Institute for Road Safety, report reference 4.

(7) Southwest Research Institute, report reference 5.

(8) All have the New Jersey median barrier cross section except CMB-1, CMB-2, CMB-5, CMB-6 and CMB-7 which are 2" wider at the top and 3" wider at the bottom.

(9) Maximum 50 millisecond accelerometer averages except for CMB-1, CMB-2, CMB-21, CMB-22, CMB-23, MI-ISC 01/319 and TS-ISC 02/320.

(10) Maximum/average deceleration values

(11) Peak deceleration values.

(12) Maximum 50 millisecond averages obtained from high speed film analysis

(13) Direction of travel of vehicle c.g. immediately following final contact with barrier.

(14) Maximum height above ground of the left front wheel unless noted.

(15) Rise of center of front bumper/rise of center of mass of truck cab.

(16) Maximum rotation about the longitudinal axis of the vehicle away from the face of the barrier unless noted.

(17) Trailer roll only.

(18) Roll toward barrier.

(19) Velocity of vehicle c.g. immediately following final contact with barrier.

(20) Front wheels locked in straight ahead steering position prior to impact.

(21) Right front tire airborne for 0.3 seconds.

(22) Maximum lateral distance of vehicle travel (includes width of vehicle) from face of barrier after impact.

(23) $\frac{m(V \sin \theta)^2}{2}$

(24) Maximum rise above ground of left rear quarter panel of vehicle.

Metric Conversions

1 in. = 25.4mm	1 deg. = 0.0175 rad.
1 ft. = 0.305 m	1ft.-lb= 1.36 J
1 lb. = 0.454kg	1 mph = 0.447 m/s

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when the vehicle was parallel with the barrier and incurred a light secondary impact (backslap). This roll angle increased to 48 degrees (0.84 rad) before the vehicle rolled the other way. Eventually it rolled over after it was redirected.

In comparison, large roll angles between 28 and 43 degrees (0.49 and 0.75 rad) were also reported for some of the earlier 25 degree (0.44 rad) impact tests of a prestressed CMB without a footing conducted by Caltrans in 1972, Table 1. Further analysis of these tests (Tests 262 to 265) indicated vehicle roll angles of 21 degrees (0.37 rad) at the time of their secondary impacts. Two of the four vehicles in these tests (Tests 262 and 263) rolled over after being redirected. Yaw angles approaching 90 degrees (1.58 rad) also contributed to the vehicle rollovers for these tests.

In contrast, the vehicle for Caltrans Test 301, Table 1, did not yaw excessively and the roll angle of the vehicle at the time of its secondary impact was only 11 degrees (0.19 rad). It did not roll over.

Hence, it appears that in severe impact tests with 4500 lb (2040 kg) vehicles having impact speeds/angles of 60-65 mph (27-29 m/s)/25 degrees (0.44 rad) there is a likely possibility of vehicle rollovers. Slight differences in vehicle suspensions and crushability or other variables are critical.

The lack of a footing, however, did not influence vehicle roll in Caltrans Test 321.

The results of heavy vehicle tests of CMB were included in Table 1 to point out the ability of New Jersey CMB without footings to contain heavy vehicles. The three TTI tractor/trailer truck tests, CMB-5, CMB-6, and CMB-7 cannot be compared directly with the other heavy vehicle tests in Table 1. The

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continuous CMB used for the TTI tests was heavily reinforced with 8 longitudinal No. 5 (15.9 mm) steel reinforcing bars and had an 8 inch (203 mm) top width and a 27 inch (686 mm) base width as opposed to the standard New Jersey shape used for the other heavy vehicle tests in Table 1. The New Jersey shape has a top and bottom width of 6 and 24 inches (152 and 610 mm) respectively. Regardless of these differences, however, the vehicles in the TTI tests were redirected and the test barrier for these tests did not move laterally or suffer any structural damage.

The two French tests also summarized in Table 1, MI-ISC 01/319 and TS-ISC 02/320, were conducted on the same barrier design used for the project of this report. It also contained two longitudinal steel reinforcing bars, equivalent to the U. S. standard No. 4 (12.7 mm) rebar, placed in the same locations as those used for this project. In addition, the French barrier was slipformed without a concrete footing on an asphalt concrete surface. No lateral barrier movement was reported for either the 2745 lb (1250 kg) Peugeot passenger vehicle test or the 21,650 lb (9830 kg) tank truck test. In both tests, the vehicles were redirected by the barrier. There was no barrier damage in the light weight passenger vehicle test; however, in the truck test an 8 inch by 9 foot (203 mm x 2.7 m) section of the barrier stem was broken out during the impact. The lateral impact kinetic energy was about 66% greater for the truck test than that for Test 321.

The three tests conducted by SWRI also verify that New Jersey shape CMB without a continuous concrete footing can adequately redirect heavy vehicles. There were three differences in the barrier for these tests compared to the barrier used for Test 321. First, only one continuous longitudinal No. 4 (12.7 mm) steel reinforcing bar was placed in the stem. Second, a 1 inch (25 mm) layer of asphalt concrete was placed at the base of

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the barrier on the side opposite of impact to restrain lateral barrier movement. Lastly, there were two construction joints in the barrier, one at 50 feet (15 m) from each end of the 200 foot (61.0 m) barrier section. The longitudinal reinforcing bar was continuous across these construction joints.

There was no structural barrier damage or lateral barrier movement in either Tests CMB-21 or CMB-22 conducted by SWRI. The 40,000 lb (18,141 kg) scenicruser bus, impacting at 11.5 and 5.5 degrees (0.20 and 0.11 rad), was smoothly redirected during these tests. The lateral kinetic energy for Tests CMB-21 and CMB-22 was 82% and 42% greater than that for Caltrans Test 321.

The lateral kinetic energy for SWRI Test CMB-23, which was conducted with the same scenicruser bus impacting at 52.9 mph (23.6 m/s) and 16 degrees (0.28 rad), was over 2 1/2 times larger than that for Caltrans Test 321. There was, however, extensive barrier damage in Test CMB-23. The maximum lateral movement of the barrier was 31 inches (787 mm). Even though the barrier was damaged, the heavy bus was redirected. The New Jersey shape CMB without a footing used for this test (except for the layer of asphalt concrete restraining lateral movement) functioned as a longitudinal beam, failing in a flexural mode. This mode of failure probably would have been quite different if a concrete footing were present. With a footing the barrier probably would have acted more like a cantilever and rotated back away from its vertical axis. If this happened, the bus might have rolled more toward the barrier. During the test, the bus rolled 24 degrees (0.41 rad) toward the barrier. Barrier rotation encourages vehicle ramping. Lateral barrier translation thus is a preferable mode of barrier failure. With this mode of failure barrier ramping is discouraged. Ramping adversely affects the post crash controllability of the vehicle and could possibly increase the chance of occupant injury.

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Recognizing the differences in possible failure modes between New Jersey shape CMB with and without continuous concrete footings, the addition of two more steel longitudinal reinforcing bars to the bars used in Test 321 is recommended for CMB when no concrete footing is used. These extra bars will increase the lateral strength of the barrier and should minimize the excessive lateral barrier movement similar to that reported by SWRI in their heavy vehicle bus test, Test CMB-23.

Impact Severity - NCHRP Report 153(12) recommends that impact severity for new longitudinal barrier designs be evaluated with an impact test using a 2250 lb (1021 kg) vehicle having an impact angle of 15 degrees (0.26 rad). Since the New Jersey profile has already been validated for these conditions and the objective of this project was to test the structural strength and stability of a continuous New Jersey CMB without a concrete footing, no accelerometers were mounted in the test vehicle. Representative values of vehicle decelerations for similar large angle passenger vehicle impacts into CMB are shown in Table 1. Based on a comparison of previous Caltrans test results, expected 50 millisecond average lateral and longitudinal vehicle decelerations would probably be in the range of 11 to 14 g's (108 to 137 m/s^2) and 5 to 12 g's (49 to 118 m/s^2), respectively, for this type of impact.

Although maximum vehicle decelerations probably would not have been significantly affected, the severity of possible occupant injuries probably would have increased when the vehicle rolled over. The extent of occupant injuries would depend to a large extent on the geometry of the vehicle passenger compartment and the restraint system used by the passengers. An anthropometric dummy was not used in this test.

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Vehicle Trajectory Hazard - The final resting position of the test vehicle after impact is shown on the Data Summary sheet, Figure 8, in the Test Results section of the report and in Figure 9 below.

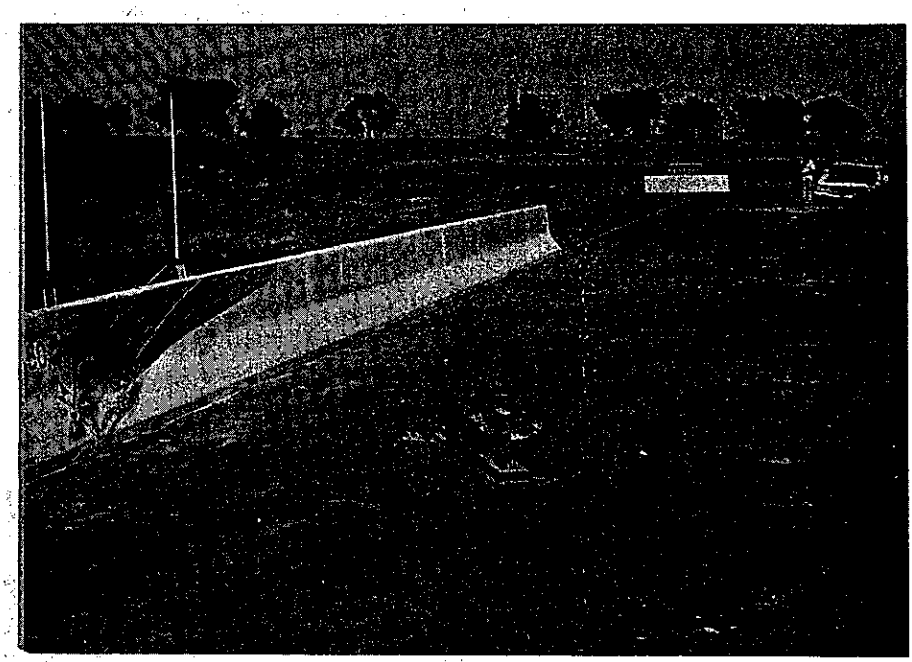

Figure 9, Vehicle Position After Impact

The postcrash trajectory of the vehicle probably would have interfered with the flow of adjacent traffic. The maximum rebound distance for the vehicle was 23 feet (7.0 m) from the impact side of the barrier. Assuming an 8 foot (2.4 m) shoulder width next to the CMB and 12 foot (3.7 m) traffic lanes, the test vehicle would have obstructed about 1 1/3 lanes of traffic. The vehicle exited the barrier at about 7 degrees (0.12 rad) at a speed of about 45 mph (20 m/s) in an uncontrolled manner. During the subsequent vehicle rollover, the vehicle's

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12-volt battery was ejected and was found about 60 feet (18.3 m) downstream from the end of the barrier and about 11 feet (3.4 m) from the impact side of the barrier.

The postcrash trajectory of the vehicle probably would have been somewhat different if the test barrier had been longer than 120 feet (36.6 m). The back 2 feet (610 mm) of the vehicle would have landed on top of the barrier when the vehicle reached its maximum yaw attitude nearly perpendicular to the barrier.

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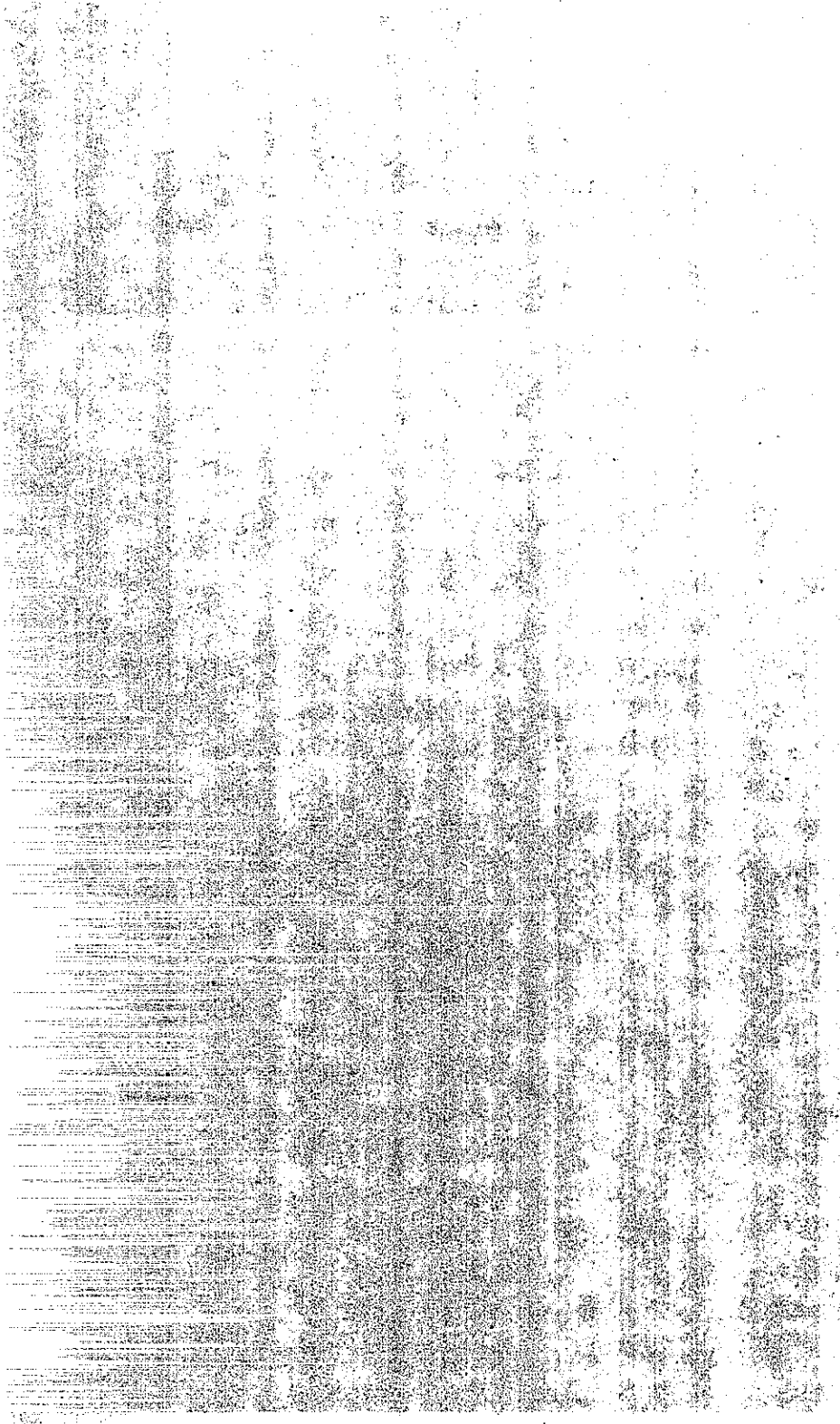

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APPENDIX

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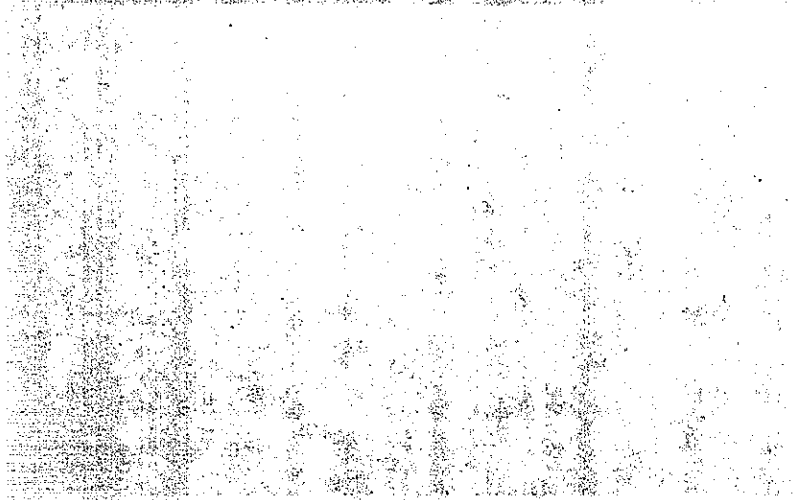
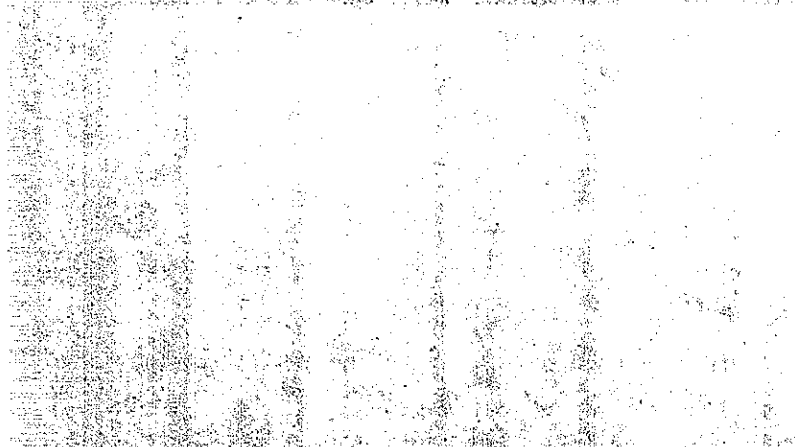
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APPENDIX

Test Vehicle Equipment and Guidance System

Vehicle modifications and the guidance system used for this test are itemized as follows:

1. The test vehicle gas tank was disconnected from the fuel supply line, drained and refilled with water. A one gallon (3.79 l) safety gas tank was installed in the trunk compartment and connected to the fuel supply line.

2. Two 12 volt wet-cell storage batteries were mounted on the floor of the rear seat compartment to supply power for the remote control equipment.

3. A solenoid-valve actuated CO_2 system was connected to the brake line for remote braking. With 700 psi (4.83 MPa) in the accumulator tank, the brakes could be locked in less than 100 milliseconds after activation. Brakes are activated by remote control.

4. The ignition system was connected to the brake relay in a failsafe interlock system. When the brake system was activated, the vehicle ignition was switched off.

5. A micro switch was mounted below the front bumper and connected to the ignition system. A trip line installed near impact triggered the switch, thus opening the ignition circuit and cutting the vehicle motor prior to impact.

6. The accelerator pedal was linked to a small electric motor which, when activated, opened the throttle. The motor was activated by a manually thrown switch mounted on the top of the rear fender of the test vehicle.

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7. A cable guidance system was used to direct the vehicle into the barrier. The guidance cable, anchored at each end of the vehicle path, passed through a slipbase guide bracket, Figure 1A, bolted to the spindle of the right front wheel of the vehicle. A steel angle bracket, Figure 2A, anchoring the end of the cable closest to the barrier to a concrete footing, projected high enough to knock off the guide bracket thereby releasing the vehicle from the guidance cable prior to impact.

Figure 1A, Slipbase Guide Bracket

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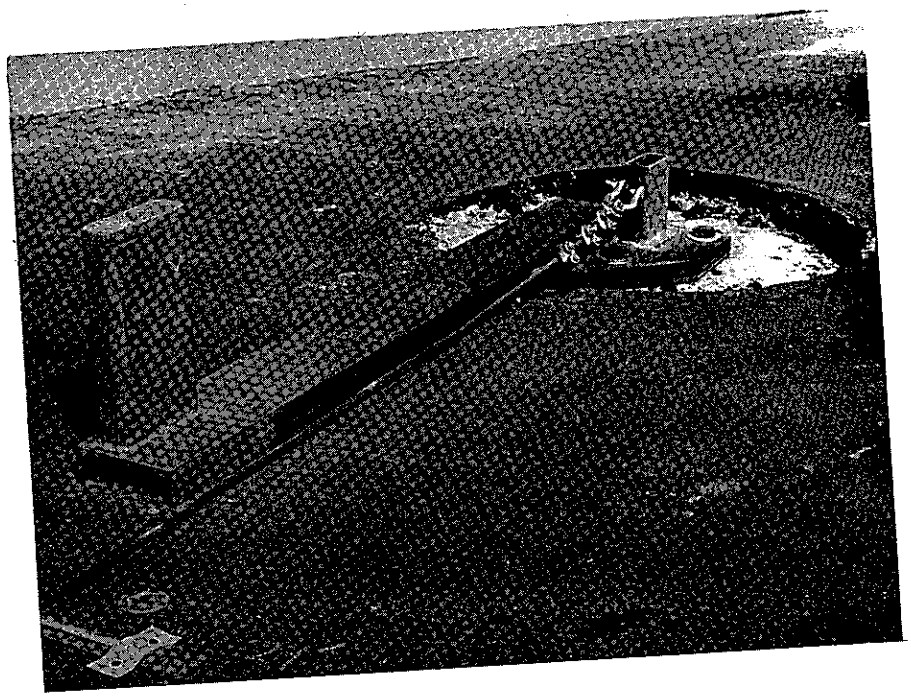

Figure 2A, Steel Knockoff Bracket

8. The remote brakes were controlled at the console trailer, Figure 3A, by using an instrumentation cable connected between the vehicle and the electronic instrumentation trailer, and a cable from that trailer to the console trailer. Any loss of continuity in these cables caused an automatic activation of the brakes.

9. A speed control device connected between the negative side of the coil and the battery of the vehicle regulated the speed of the test vehicle based on engine revolutions per minute. This device was calibrated prior to the test by conducting a series of trial runs through a speed trap composed of two tapeswitches set a known distance apart connected to a digital timer.

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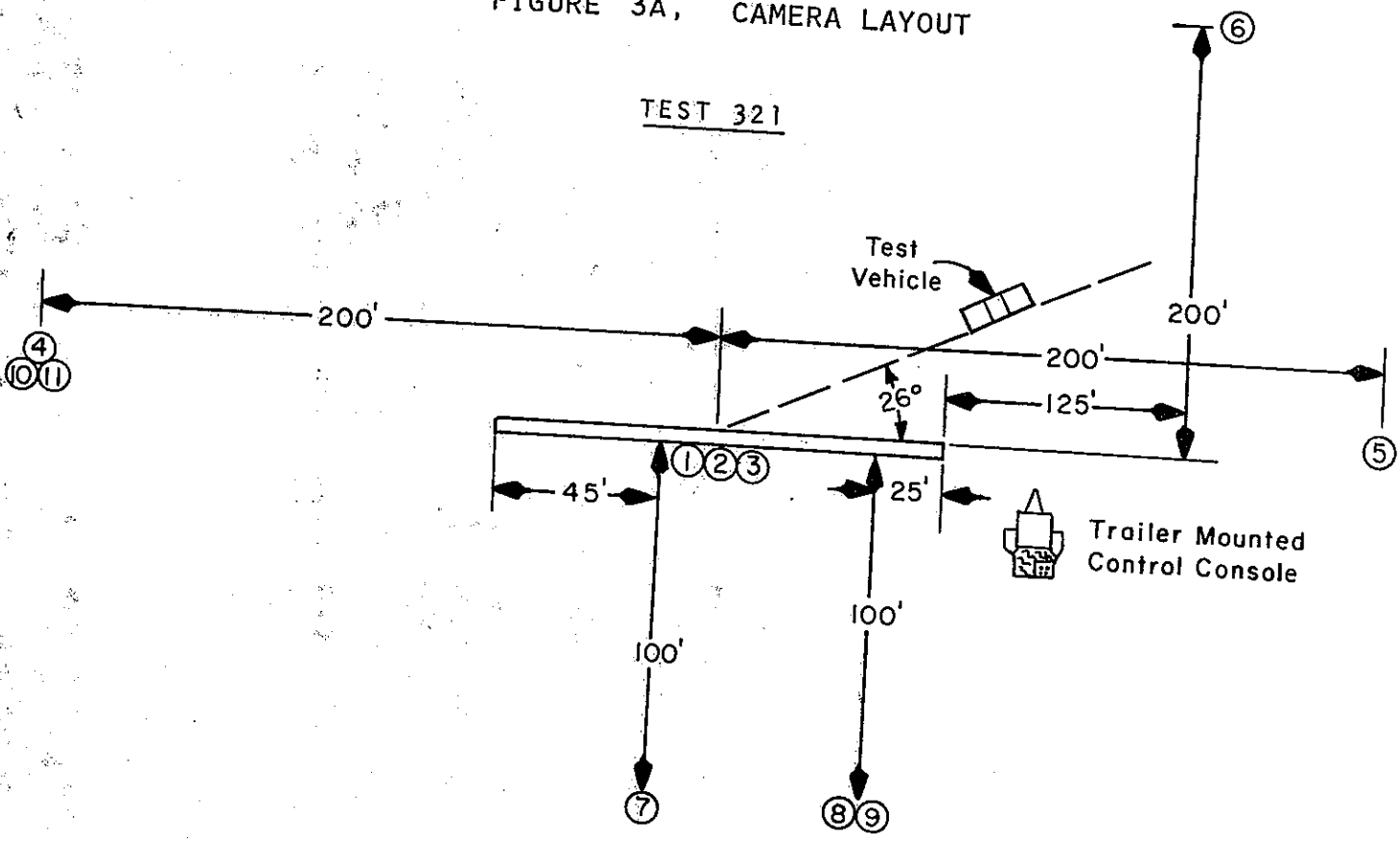
FIGURE 3A, CAMERA LAYOUT

TEST 321



CAMERA DATA[1]

①②③ Photo-Sonics Model 16mm-1B, 13mm lens, (275-350) fps[2]; mounted on 31 ft. tower.

④⑤⑥ Photo-Sonics Model 16mm-1B, 4" lens, (300-350) fps.

⑦ Redlake Locam 16mm, 12/120mm lens, 500 fps

⑧ Photo-Sonics Model 16mm-1B, 2" lens, 350 fps, pan camera

⑨ Bolex, 1" lens, 24 fps, pan camera

⑩ 70mm Hulcher, 12" lens, 20 fps, sequence camera

⑪ 35mm Hulcher, 50mm lens, 20 fps, sequence camera

1. All cameras mounted on tripods unless otherwise noted.

2. Frames per second.

METRIC CONVERSIONS

1 in. = 25.4 mm; 1 ft. = 0.305 m
1 deg. = 0.0175 rad.

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Photo-Instrumentation

Data film was obtained by using eight high speed Photo-Sonics Model 16mm-1B cameras, 200-400 frames per second (fps) and a high speed Redlake Locam camera, 500 fps. These cameras were located around the barriers as shown in Figure 3A, Camera Layout. All cameras were electrically actuated from a central control console, Figure 3A.

All cameras were equipped with timing light generators which exposed reddish timing pips on the film at a rate of 1000 per second. The pips were used to determine camera frame rates and to establish time-sequence relationships. Additional coverage of the impacts was obtained by a 70mm Hulcher sequence camera and a 35mm Hulcher sequence camera (both operating at 20 frames per second). Documentary coverage of the tests consisted of normal speed movies and still photographs taken before, during, and after each impact. Data from the high speed movies was reduced on a Vanguard Motion Analyzer, Figure 4A.

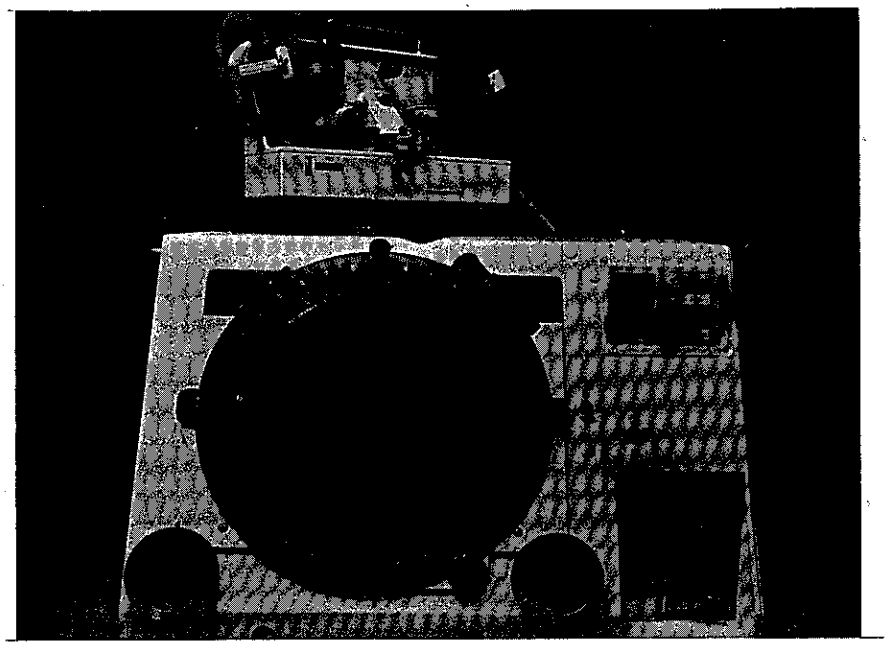

Figure 4A, Vanguard Motion Analyzer

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Some procedures used to facilitate data reduction for the test are listed as follows:

1. Targets were attached to the vehicle body and to the barrier.

2. Flashbulbs, mounted on the test vehicle, were electronically flashed to establish (a) initial vehicle/barrier contact and (b) the application of the vehicle's brakes.

3. Five tape switches, placed at 10 foot (3.0 m) intervals, were attached to the ground perpendicular to the path of the impacting vehicle beginning 6 feet (1.8 m) from impact. Flashbulbs were activated sequentially when the tires of the test vehicle rolled over the tape switches. The flashbulb stand was placed in view of all the data cameras and was used to correlate the cameras with the impact events.

Electronic Instrumentation and Data

Three pressure activated tape switches were also attached to the ground beginning at 5 feet (1.5 m) from impact and spaced at 12 foot (3.7 m) intervals in the vehicle approach path. When activated by the test vehicle tires, these switches produced sequential impulses which were recorded on a fourteen channel Hewlett Packard 3924C magnetic tape recorder. A time cycle was also recorded on tape concurrently with the tape switch impulses. The impact velocity of the vehicle was determined from these tape switch impulses and timing cycles.

Dynamic barrier deflection was monitored during the test by four Houston deflection potentiometers placed behind the barrier, Figure 5A.

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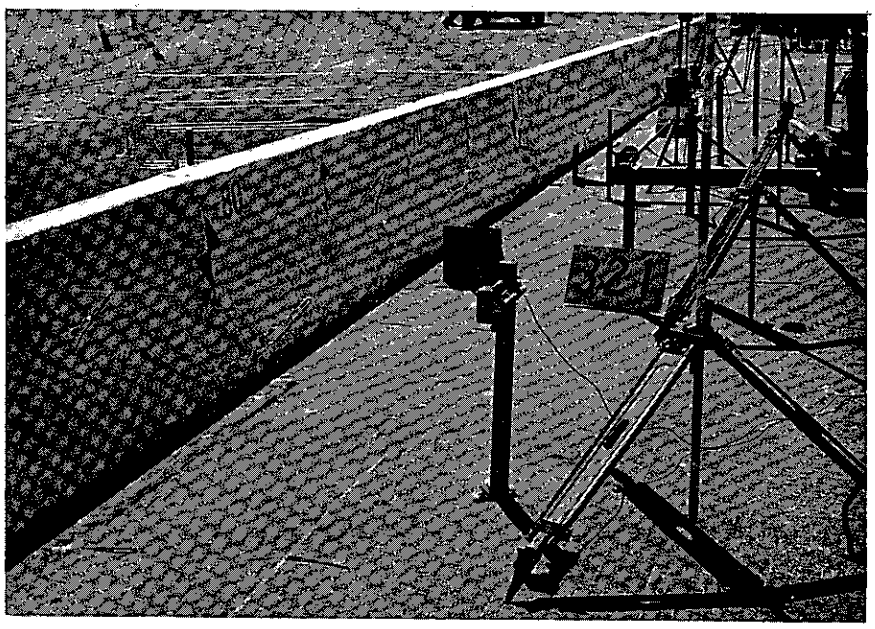

Figure 5A, Deflection Potentiometers Mounted 4 Feet (1.2 m) Behind Base of Barrier

After each test, the tape recorder data was played back through a Visicorder which produced an oscillographic trace (line) on paper for each channel of the tape recorder. Each paper record contained a curve of data representing one potentiometer, signals from the three tape switches, and the time cycle markings.

The barrier deflection versus time plots and the locations of the four potentiometers are shown in Figure 6A.

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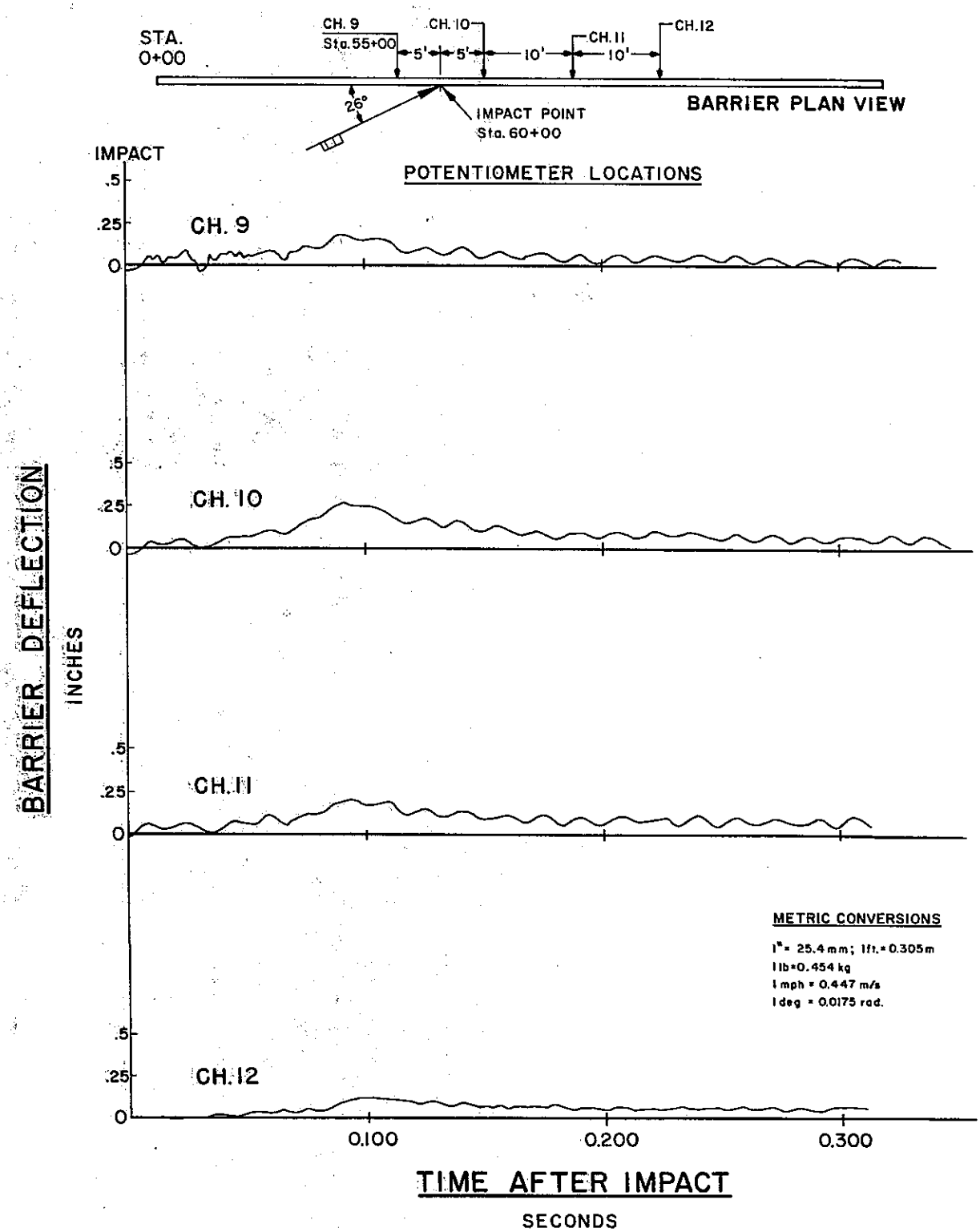
Figure 6A, BARRIER DEFLECTION VS. TIME*

TEST 321, 4700 lb. VEHICLE, 61 mph, 26°
CONTINUOUS CMB WITHOUT A FOOTING



* Middle ordinate plots of unfiltered data from Houston Deflection Potentiometers located 6 inches down from top of barrier.

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