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PROCEEDINGS

SEMINAR ON THE USE OF COMPOSITE THIRD RAIL IN ELECTRIFIED TRANSIT AND COMMUTER RAIL SYSTEM

Presented at the

U.S. DEPARTMENT OF TRANSPORTATION
RESEARCH AND SPECIAL PROGRAMS ADMINISTRATION
TRANSPORTATION SYSTEMS CENTER
CAMBRIDGE, MA 02142

SEPTEMBER 14-15, 1977

November 1978

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16. Abstract

The seminar on "The Use of Composite Third Rail in Electrified Transit and Commuter Rail Systems", held at the Transportation Systems Center (TSC) in Cambridge, MA, on September 14 and 15, 1977, was organized to disseminate accurate information on, and experience with, composite (aluminum and steel) third, or contact rail, in wayside power distribution systems of electrified urban rail properties. The seminar provided the opportunity for the exchange of pertinent information among the suppliers, using properties, consultants and designers, potential users, and government agencies.

This document contains the transcripts of the presentations made to the seminar participants, as well as the question-and-answer sessions which followed each presentation and the round table discussion of Thursday, September 15, 1977. Information pertinent to the seminar, but not available in detail at the time of the conference, is presented in a series of four appendices. The document also contains a list of the participants in the seminar and their addresses as of September, 1977.

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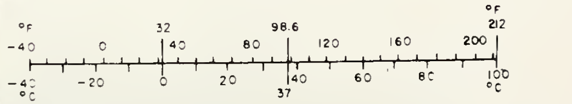
METRIC CONVERSION FACTORS

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

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	35	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



METRIC CONVERSION FACTORS

PREFACE

One of the goals of the Urban Mass Transportation Administration (UMTA) is the improvement of urban transit and commuter rail systems through the evolutionary development and application of new technologies to such systems. A major portion of this effort has been assigned to the Transportation Systems Center (TSC) in Cambridge, Massachusetts under the Urban Rail Supporting Technology Program. Included in this assignment is the dissemination of pertinent technological information to all persons concerned with the design, operation and maintenance of these rail facilities.

The seminar on "The Use of Composite Third Rail in Electrified Transit and Commuter Rail Systems", held at TSC on September 14 and 15, 1977, was organized at the request of UMTA to disseminate to those associated with the transit industry accurate and current information concerning the advantages and disadvantages of composite (aluminum and steel) third, or contact, rails for electrified systems. Composite rail, properly used, offers a potential for reducing significantly overall construction costs of the electrification system, improved system performance, and some reduction in operating energy costs. Disadvantages include, among other things, possible increases in stray voltages and stray currents, or electrolysis effects. It was also known that much information circulating within the transit industry was based on erroneous or misleading information and hearsay. It is hoped that the seminar dispelled the misconceptions surrounding the use of composite rail.

The seminar comprised a day of presentations by representatives of industry suppliers, a consultant, and using transit properties. On the following morning an inspection was made of the Haymarket North Extension of the Massachusetts Bay Transportation Authority, a system extension which uses a composite third rail and has been in revenue service and trouble free for approximately two years. In the afternoon there followed a round table discussion during which all the seminar participants were encouraged to ask questions concerning the use of composite third rail. Answers were furnished by representatives of industry suppliers and the three transit systems that have both had significant operating experience with composite rail.

The seminar was attended by approximately 70 persons who represented actual and potential industry suppliers, consultants and designers, properties using or thinking of using composite rail, and government agencies. Although the subject is of interest to a relatively small technical community, that interest was intense, as demonstrated by the level of discussion and the comments received subsequent to the seminar.

Written papers were not submitted for the meeting, primarily because of the short time allotted for preparation and the heavy demands on the time of those who made the presentations. However, the proceedings of the entire seminar were recorded on tape, and the transcript of the tapes form the basis of this document. Inevitably, a few short portions of the tapes were undecipherable; these are denoted by (unclear) or (inaudible). In several other instances, explanatory words have been added in parentheses to facilitate comprehension by the reader. In the discussion periods, names of participants who spoke have been identified to the extent practicable. The transcripts have been edited only to the extent necessary to remove extraneous material, eliminate unnecessary repetition, and ensure clarity of the material presented. Though necessarily imperfect, the transcripts are believed to reflect quite accurately the tenor of the seminar.

At a few points in the meeting, questions were raised which could not be answered completely, primarily because of the unavailability at the seminar of the specific information requested. Since some of this information was considered to be of interest to many participants, that data was subsequently collected and appears in a series of four appendices. A list of all participants in the seminar, together with titles, organizational affiliations, and addresses as of September 14, 1977 is also provided. It is hoped that this listing will permit the subsequent interchange of information among the seminar participants.

The seminar was funded by UMTA through TSC under the Urban Rail Supporting Technology Program. These proceedings have been compiled by Ahmed Associates (now Pacific Consultants) under contract to TSC.

The Urban Mass Transportation Administration and the Transportation Systems Center wish to acknowledge the contributions of the several people who made the seminar an interesting and highly informative meeting. Particular thanks is due the Massachusetts Bay Transportation Authority for making possible the field inspection trip to their Haymarket North Extension to see at first hand an application of composite third rail in revenue service.

CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Continued)

LIST OF ILLUSTRATIONS (Continued)

LIST OF ILLUSTRATIONS (CONTINUED)

LIST OF TABLES

OPENING REMARKS

Dr. Robert K. Whitford

OPENING REMARKS

Dr. Robert K. Whitford, Deputy Director
Transportation System Center

I want to welcome you to Cambridge, and say just a few words to those who are not familiar with what we do here at TSC.

First of all, I would like to speak a bit about the Conference on Composite Third Rail. I'm particularly excited about this conference. Since 1972, and even more so since the oil embargo, we've been looking at ways to save energy. I gather that the efforts in which you are involved--represented here by your respective technologies--will provide improvements for your properties, and a savings of money as well. I understand that if you could improve the rails considerably, you could raise the voltage at the cars because of decreased voltage drops, which also has advantages. From the standpoint of conserving energy that is used in transit, we see an excellent opportunity to make headway; and from an economic point of view, such energy saving has lots of other potential advantages.

We, in particular, are very glad that you took the time to come, and we hope that your efforts in this interchange of technical knowledge will be fruitful, will result in some savings for you and for the taxpayers, and maybe decrease the drain on our resources. Every little bit helps. Everybody says, "Well gee, if I don't drive that, and if I don't do this, you know it's not much, it's only a drop in the bucket; but every little bit helps."

Let me say a few words about TSC. We are on about 15 acres here at Kendall Square, and nearby there are a couple of locations that you might want to visit. There is an area in the front of this building which contains our transportation information center. This will be open, and you may conduct yourself through it in a very short time and get a pretty good overview of the kinds of projects and things that are going on at the Transportation System Center. At TSC we have about 950 Federal employees and support contractor personnel. About 600 are full time Federal employees. Our laboratory capabilities include motor vehicle testing, and environmental measurements, including things like measuring the noise from the Concorde SST. We have taken our instrumentation into the subways. We are also engaged in evaluation of transit materials and are looking at flammability and toxicity of materials, automation, track research, and non-destructive testing. This includes looking at couplers, journals, and bearings.

We feel that there are many techniques to be used to accomplish maintenance routines in addition to first-time inspection. For example the retreaders have picked up a device that we've developed, that can be used for checking tire carcasses before they are retreaded to determine that there are no hidden flaws in either the sidewall or the main part of the tire. Radars and lasers are sensors mostly used for aircraft, but we have been using them for other purposes such as air traffic control. Data processing and electric propulsion are also supported by the urban rail effort, and we are deeply involved in Pueblo with the transit test track there.

There is one other building--to the rear of this one--that I should have pointed out, where we have converted a shipping/receiving building into a dynamometer facility in which we are beginning to do some hands on testing of new engines, and also on full scale automobiles with slightly different propulsion systems. DOT, as you may be aware, has the responsibility for regulating and setting the standards for fuel economy for automobiles. As the R&D arm of DOT we have the capability to test and assess motor vehicles, and in essence provide data to the Secretary of Transportation for decisions related to fuel economy. It's not a large facility. We do not do testing on an operational basis; we simply do one of a kind testing. That facility is now available if you choose to walk back and look at it.

One last word about our mission. TSC is the multi-modal systems research, analysis, and development organization in the Department of Transportation. Some of the modal agencies like FAA and Federal Highway Administration have their own research laboratories. TSC's job in general is to support all the modes and to work on technology and the front end work which we frequently call "socioeconomic," and that operates across modes--things like forecasting, for example. Obviously rail technology is of concern both to the Federal Railroad Administration and to UMTA. Air Traffic control, vessel traffic control, automobile traffic control, the whole concept of traffic control and how one implements it are some of the multi-modal things that we're concerned with. Additional multi-modal things of concern to us are electric propulsion, buses, automobiles, and transit cars.

Thus, our role is really to do research and development, of both the hard and the soft kind, and to support the mission of the Department of Transportation.

In your packet is a book, and I urge and ask you to look through it so you'll learn more about TSC. With that, I want to introduce your host for today: Harold Decker.

Harold Decker has been with TSC since its inception in 1970 and his efforts during that time have included a lot of work on urban rail technology. He was the project engineer largely responsible for the development of the urban transit test track at Pueblo. When I first came here in '72 he was on the airplane more than any place else. He has been the project engineer for a number of our important efforts in the urban supporting technology program, which has been TSC's biggest program since its inception. We have spent close to $35 million now for the urban rail technology program. Bringing projects like the composite rail into some kind of focus is one of the things we think is a very important part of our job. So with that, I'd like to turn it over to Harold Decker. I welcome you all to Cambridge. I hope the weather improves tomorrow and hope you have a good day here.

INTRODUCTION TO SEMINAR

Harold D. Decker

INTRODUCTION
TO

SEMINAR ON THE USE OF COMPOSITE THIRD RAILS IN ELECTRICIFIED TRANSIT AND COMMUTER RAIL SYSTEMS

Harold D. Decker, Project Engineer
Transportation Systems Center

BACKGROUND

Recent developments by industry suppliers have made available to the transit industry composite third rail materials, which have a steel wearing surface backed by aluminum current carrying members. Experience on three transit systems--BART (San Francisco), MBTA (Boston), and CTA (Chicago)--have shown that the proper use of composite rail can reduce overall electrification system installation and operating costs while improving system performance. In view of these experiences, UMTA has requested TSC to present this seminar on the use of composite third rail in electrified urban and commuter rail systems. The seminar is bringing together representatives of industry suppliers, transit and commuter rail systems, designers and consultants, and government agencies to present technical and economic considerations on and experience with composite third rail. It will also give users, potential users, designers and consultants, the opportunity of asking questions pertinent to the use of composite contact rail.

PURPOSE

The seminar is being presented with three major objectives in mind:

. To outline the relative advantages of composite (aluminum - steel) third rail and all steel third rails in electrified transit and commuter rail systems.

. To delineate an integrated or systems approach to the design of electrification systems.

. To point up the desirability of using life cycle costing techniques in trade-off studies.

Before examining in detail the relative advantages of composite third rail and economic factors involved, as the following presentations will do, it seems desirable to consider an overall view of a transit electrification system so that some appreciation of the relationships that exist among the several elements of the system may be gained.

TRANSIT SYSTEM COMPONENTS

The major components of an electrified transit or commuter rail system include:

Right of way
Track and roadbed
Vehicles
Electrification (traction power)
Signals and communications
Stations
Repair and maintenance facilities.

The basic requirements or demands placed on the electrification system are established by the vehicle characteristics and operational considerations--such as train length, frequency of service, grades and operating speeds. Some restraints on the electrification system may be imposed by the track, since the running rails are used as the negative power return and their resistance may become significant. The interfaces between the electrification system and other component systems are not of major significance for the purpose of this review.

ELECTRIFICATION SYSTEM

The electrification system may be considered as being comprised of two major parts:

. Multiple substations distributed along the route which convert high voltage AC power to DC power for use on the track.

. A wayside distribution system which comprises a third rail, the running rail return, and supplementary cables (which may parallel either, or both, the third rail and the running rail.)

Each substation comprises the following major equipment, housed in a suitable structure adjacent to the track:

Incoming high voltage AC feeders
AC switch gear and bus
Rectifier transformer
Rectifier
DC switch gear and bus
Positive and negative get-away cables
Control, protective, and metering systems

A simplified schematic diagram of one substation and section of track is shown in Figure 1. It should be noted that the major items of equipment in the substation are in series with the contact rail, vehicle(s), and running rails. Each of these elements has an electrical resistance. The combined resistance of the contact rail and the running rail return--the loop resistance--is dependent on the distance between the vehicle(s) and the substation.

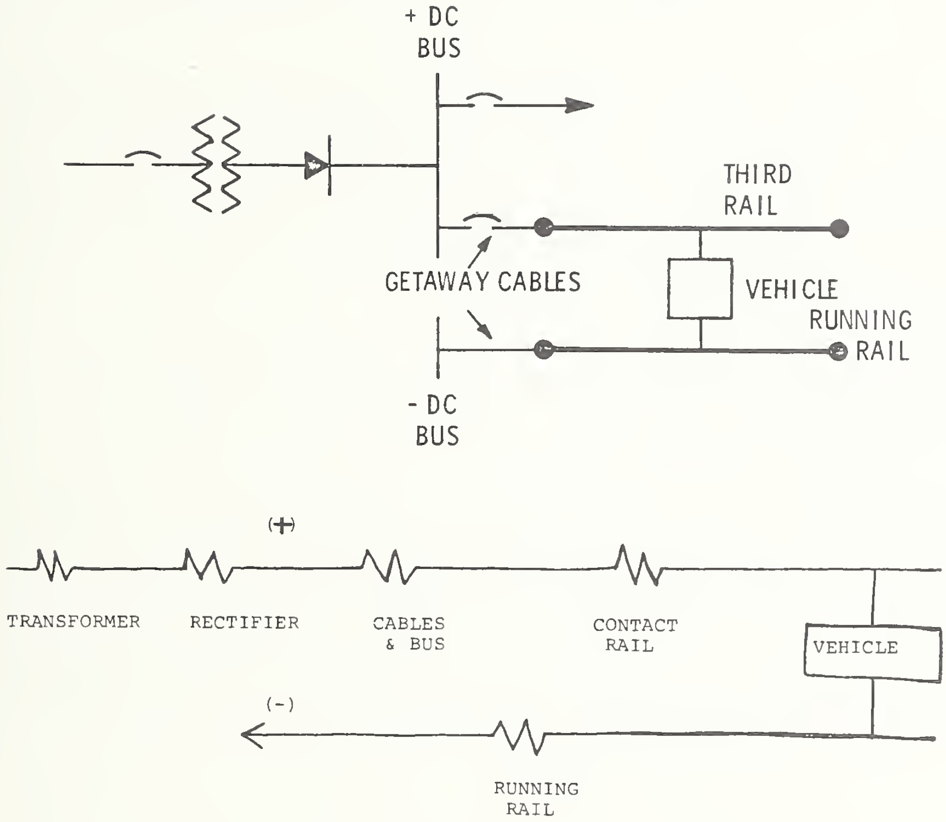


FIGURE 1 SIMPLIFIED SCHEMATIC OF ELECTRIFICATION SYSTEM

Although the individual resistances of each element are quite low, the currents drawn from the substation are of the order of several kilo-amperes, and voltage drops become significant. Under adverse conditions, the voltage at the vehicle may be only 75 percent of the no load voltage at the rectifier. The other 25 percent appears as voltage drops throughout the system. Under such conditions, power losses in the system may reach 25 percent of the power drawn by the substation. These losses, although paid for by the transit authority, do not help move the vehicles, but appear as I^2R or heat losses.

Obviously, if a substantial reduction in any of these resistances can be achieved, the pattern of voltage drops in the system will be changed and a higher voltage will be available at the vehicle.

Composite rail offers such a possibility. The resistance of composite third rail is approximately half the resistance of the all-steel, 150 pound contact rail that has been the best material available and an unofficial standard of the transit industry for many years. The use of composite third rail will, for the same current drawn by a vehicle, increase the voltage available at that vehicle (voltage between third and running rails.)

Considering these factors, and the requirement that the voltage at the vehicle be kept above a specified minimum for satisfactory operation, the use of composite third rail will, in new construction, permit one or more of the following:

. Increase distance between substation and vehicle while maintaining the specified minimum voltage at the vehicle (i.e., spacing between substations can be increased.)

. Number of substations required on a route may be reduced.

. Possibly reduce the required rectifier rating, particularly if the rectifier has been sized for reasons of voltage drop.

. Reduce contact rail losses, per-unit of length.

In the modernization or upgrading of existing systems, replacement of steel contact rail with composite rail will permit:

. Increasing the maximum current which can be drawn by a train, without decreasing the voltage at the train below the allowable minimum. This, in turn, would permit the use of a longer train, or higher performance chopper controlled (and air conditioned) cars.

. Obtaining this increase in capacity with only minor revisions to the substations, particularly in instances where the substations have been designed to meet minimum voltage requirements of the vehicles at the extremity of a track section.

. Reduce contact rail losses.

The technical factors mentioned above, together with pertinent economic considerations and trade-offs, will be presented in detail in the papers and presentations that follow.

ELECTRIFICATION SYSTEM DESIGN

In the past, 150 pound steel contact rail has been chosen as the most economical and effective material for heavy traction systems, despite its relatively high resistance compared to other elements of the system. Substation spacing and design were generally determined by the maximum current to be drawn by the trains, the allowable minimum voltage at the train, the availability of real estate, and reasonable contingency conditions. Subsequently, components of the electrification system were individually specified and procured competitively. Under this approach, the system so designed is not necessarily, by today's standards, the system with lowest life cycle costs. In addition, the losses in the contact rail, although recognized as significant, were accepted as part of the cost of operating the transit system since energy costs were low. The costs of such losses are now significant, and economical means of reducing them are attractive.

The availability of relatively new materials, such as composite contact rail, together with the rapidly rising costs of all materials, labor, and energy and the difficulty in obtaining adequate capital and operating funds, make it necessary to design a system that, in addition to being operationally acceptable and safe, must also be of lowest cost for the long run i.e., lowest life cycle cost. It is therefore suggested that life cycle costing techniques be employed in the design of electrification systems (as well as others.)

Such an approach, perhaps oversimplified, would include the following steps:

1. Develop reasonable alternative system configurations that satisfy technical and operational requirements. (For example, all steel vs. composite third rail, or substations located at passenger stations rather than between them.)

2. Evaluate the interactions between elements of each alternative system (such as rectifier rating vs substation location.)

3. Estimate, for each alternative configuration considered, for the anticipated life of the system, the following:

    a. Initial capital cost (equipment, land, construction, installation, etc.)

b. Interest costs (for bond issues)
c. Operating and maintenance costs
d. Energy costs
e. Determine the present value of future costs of (b), (c) and (d) above. In this respect, it should be noted that OMB circular A-94 recommends using a 10 percent discount rate. This figure is generally used in federal procurements. Other values could be used, if warranted.
f. Determine the life cycle cost of each alternate.

With all other factors being equal, the system having the lowest life cycle cost is preferred. Admittedly, the prediction of future costs is somewhat of a guessing game.

DISADVANTAGES OF COMPOSITE CONTACT RAIL

One of the disadvantages of composite third rail stems directly from its lower resistance (or greater conductivity). The increased conductivity of the third rail permits the train to be operated at a greater distance from the substations. Since the conductivity of the running rail return per unit of length is the same, the voltage drop in the running rails is increased, and the voltage difference between the running rail and ground is increased. This increase in voltage increases the amount of stray currents produced by the system and increases effects of electrolysis, both of which are undesirable. Good system design can alleviate some of these problems. For example, the system can be designed so that under normal operating conditions, trains are accelerating (and drawing most power) near the substations, and running at speed or braking when the train is remote from the substation and drawing minimum power. Alternatively, in those instances in which severe effects from stray currents and electrolysis may be experienced, the running rails can be paralleled with a supplementary return cable or return path.

Although no composite rail has seen 50 years of service, experience to date on composite rail in service for five years or more has shown no degradation in performance or tendency of the aluminum to separate from the steel. In fact, resistivity tests on composite rail made after several years of service have indicated that the resistance decreases slightly with time in service. This is attributed to the fact that under vibration and thermal cycling, the aluminum tends to improve its seating against the steel wearing surface.

TECHNICAL AND ECONOMIC CONSIDERATIONS ON THE USE OF COMPOSITE THIRD RAIL

Dr. Alexander Kusko

TECHNICAL AND ECONOMIC CONSIDERATIONS ON THE USE OF COMPOSITE THIRD RAIL

Dr. Alexander Kusko, President
Alexander Kusko, Inc.

The subject of my talk concerns technical and economic factors in the use of composite third rail. Actually, my function in this program is to act as a bridge between Mr. Decker's introductory talk and the later talks by both the manufacturers and the transit property operators who use composite third rail and who have available all of the specific data on its rationale and cost.

In order to get into the subject I have prepared a very simple example in electrical terms. As an electrical engineer, I look on the composite third rail as another resistance element where other people probably look on it as a physical body. I chose the simplest possible example I could, recognizing that the kinds of calculations that Harold Decker was talking about are very, very expensive, very complicated, and are probably the kinds of calculations that have to be carried out in the initial design of an electrification system. They further have the difficulty of requiring very good propulsion system modeling, if one really wanted to compare losses of system A vs. system B.

Let me just briefly list again what composite rail can do:

1. Obviously the first thing it can do is reduce voltage drop, as we well know.

2. It can also reduce currents--currents both in the contact rail system, in the vehicles themselves, and in the substation.

3. It can reduce energy losses in the contact rail system.

4. The use of composite third rail permits the reduction in rectifier rating or the increase in the spacing of substations.

5. Depending on the propulsion system considered, the use of composite third rail can raise average train speed of system A over system B.

6. It can also extend the regeneration zone by reducing the overvoltage that occurs at the train when it goes into regeneration.

7. Finally, another trade off is that composite third rail permits the use of an increased number of cars in a train, all other conditions being equal.

There are many, many other pros and cons and the later speakers will go into them in greater detail, and I'm sure we will get into them in the discussion.

The principal advantage of composite third rail obviously is the reduction in voltage drop. Engineers like to get specific so I've collected typical values of resistance to give you a comparison of where the third rail fits in and what some of the other resistances in the electrification system amount to. These appear in Table I.

I've shown return rail resistance of two running rails in parallel as .0127 ohms per mile or 12.7 milliohms per mile. A better feel for resistances of this magnitude is to either multiply them by 1,000 amperes or 10,000 amperes depending on how rich your taste is. But at 1,000 amperes, which is less than the accelerating current of a typical transit car, the return rail voltage drop is 12.7 volts per mile. The voltage drop with steel contact rail (150 lb) is 21.6 volts per mile. Keep in mind that the maximun allowable voltage drop of 25% on a 650 volt system is only 160 volts, so you have at most 160 volts to dissipate with these components. Composite third rail resistance is 10.8 milliohms per mile which is exactly half that of the steel contact rail.

TABLE I
ELEMENTS CAUSING REDUCTIONS IN VOLTAGE DROP

. Running return rail (two - 115 lb)	- 0.0127Ω/mi
. Steel contact rail (150 lb)	- 0.0216Ω/mi
. Composite rail (H.K. Porter)	- 0.0108Ω/mi
. Traction rectifiers (650 V)	
2 MW	- 0.0126Ω
4 MW	- 0.0063Ω
6 MW	- 0.0042Ω
. DC Feeders (6 x 750 kcmil)	- 0.0003Ω/100 ft

An important element in the calculation of the voltages in an electrification system is the traction rectifier. I have used some equivalent resistances here for traction rectifiers of 2 megawatts, 4 megawatts and 6 megawatts capacity based on 6% regulation. If you take the loop of return running rail and steel contact rail which is about 34 milliohms per mile and compare that with the equivalent resistance of a 4 megawatt rectifier, you see that it is about five times the resistance of the 4 megawatt substation.

Now, we have to be careful in talking about the equivalent resistances of traction rectifiers. Those of you in the rectifier business know that the term equivalent resistance means the commutation effect of the rectifier in reducing DC voltage. That is essentially the effect of the rectifier transformer inductance and the AC feeder inductance on the overlap period in the rectifier which makes the DC voltage decline as the rectifier is loaded. That decline in voltage which is shown here as caused by the equivalent resistance does not cause any energy loss. It is a voltage drop that has its genesis back in the inductive part of the system. In making comparisons of energy losses in systems, even though we know we get severe voltage drops in the traction rectifiers because of these inductances, we cannot assign energy losses to this drop, but we can assign voltage losses to the inductances. This is a familiar concept to electrical engineers and it may be hard for a civil engineer or a mechanical engineer to accept. Finally, I included a typical DC feeder resistance of 6 - 750,000 circular mil cables of 0.3 millihoms per hundred feet to give you some idea of their effect on voltage drop.

Being an electrical engineer, my approach is to work up a simple model or equivalent circuit. I arrived at what I considered was the simplest possible model to compare composite third rail with steel rail. This is shown in Figure 1. I took 2 miles of contact rail and two 4-megawatt rectifiers with some source impedance and took a 9-car train accelerating from the left hand rectifier at 3 miles per hour per second and reaching 45 mph in approximately 495 feet, or about a tenth of a mile. This point represents a kind of a knee in a propulsion characteristic, and is the maximum power point as the train accelerates. At this point it would go into a constant power mode or it would go into a field weakening mode. This point represents the worst case as far as power drain is concerned.

If you are an electrical engineer, the elements in the traction system appear as resistances in the equivalent circuit diagram, as shown in Figure 2. There are two 4 megawatt traction rectifiers, shown as R_r, and we've included some source resistance, just to get the resistance high enough. There are two sections of steel contract rail R_A and R_B. This is a base case corresponding to the train at 45 mph, having accelerated at 3 mph per second, and drawing 1900 amperes per car in a 650 volt system. We purposely picked the number of cars to be nine so the voltage at this point would be down to 490 volts, which would be 75% of 650 and represents the maximum permissible limit of 25% voltage drop.

Now, as many of you know who have done these calculations, the maximum current comes off the left hand rectifier and is 14,504 amperes. 2621 amperes are drawn off the right hand rectifier and the train is drawing over 17,000 amperes. This is about 8 1/2 megawatts at this particular point. The equivalent internal voltage looking back in the system is 689 volts for the no load case. The total power losses in the rails at this particular instant of time with the train drawing about 8 1/2 megawatts is 1.17 megawatts of loss in R_A and R_B, R_A and R_B being the loop resistances (that is the steel contact rail going and the two running rails returning). Those of you that have worked these problems know that, even in this simple example, to find the

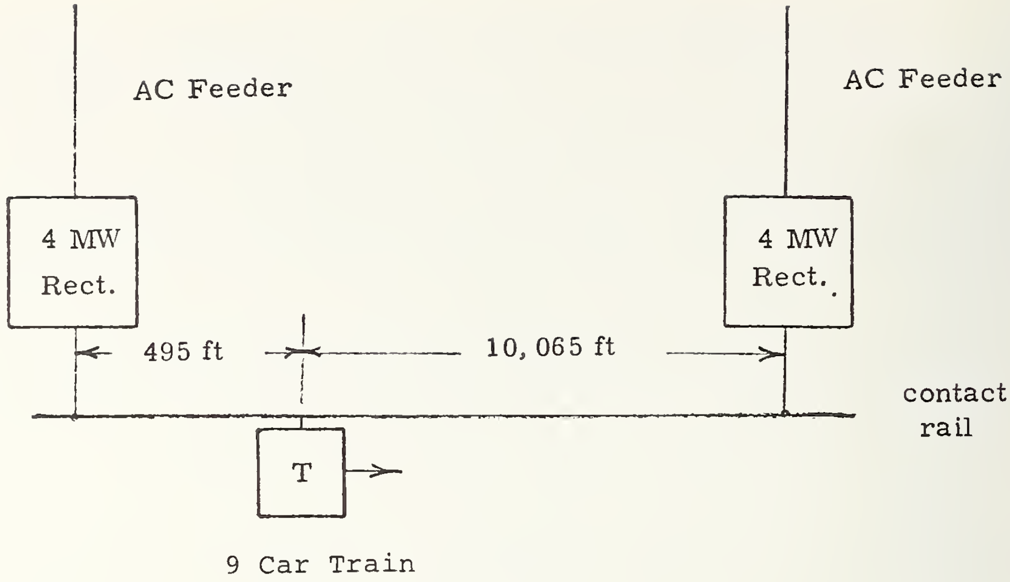


FIGURE 1
SIMPLIFIED MODEL OF ELECTRIFICATION SYSTEM

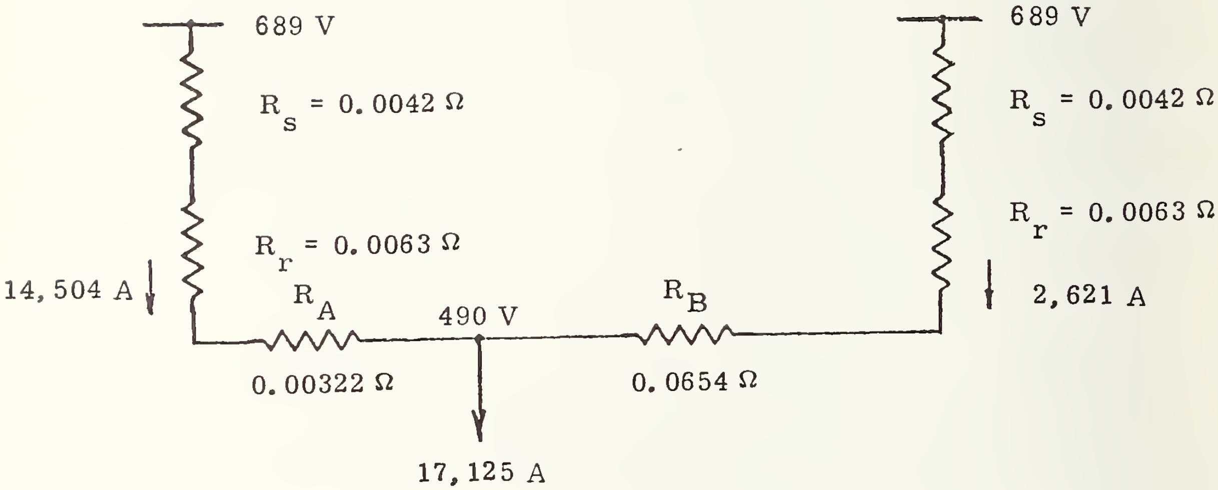


FIGURE 2
EQUIVALENT CIRCUIT FOR SIMPLIFIED MODEL
WITH STEEL CONTACT RAIL

energy loss for a trip from point A to point B means either doing a lot of hand calculations or writing a computer program to simulate the acceleration of the train, the level running or balancing speed, the braking, and adding up all the kilowatt hours to get the figure of kilowatt hours to the train and the kilowatt hours loss. I've really taken the simplest possible example, and have just taken one point as the train goes from left to right.

Figure 3 shows the same example worked with composite contact rail. Now you see the impact of the composite contact rail, which reduces R_A and R_B to about 2/3 of their previous values. We still have to include the resistance of the running rail return. Even though the contact rail resistance goes down by a factor of two, we still have the same resistance for the running rail return. If we make the running return rail a composite rail then we can get the resistances, R_A and R_B down still further. Now, if we look at the left hand substation we see that the rectifier is really the big offender insofar as voltage drop is concerned. The loop resistance of the rail is now small compared to the source resistance of the rectifier and feeders. Hence, there is a limit as to how much good you can do with contact rail when you consider that the rectifier contributes a major portion of the voltage drop.

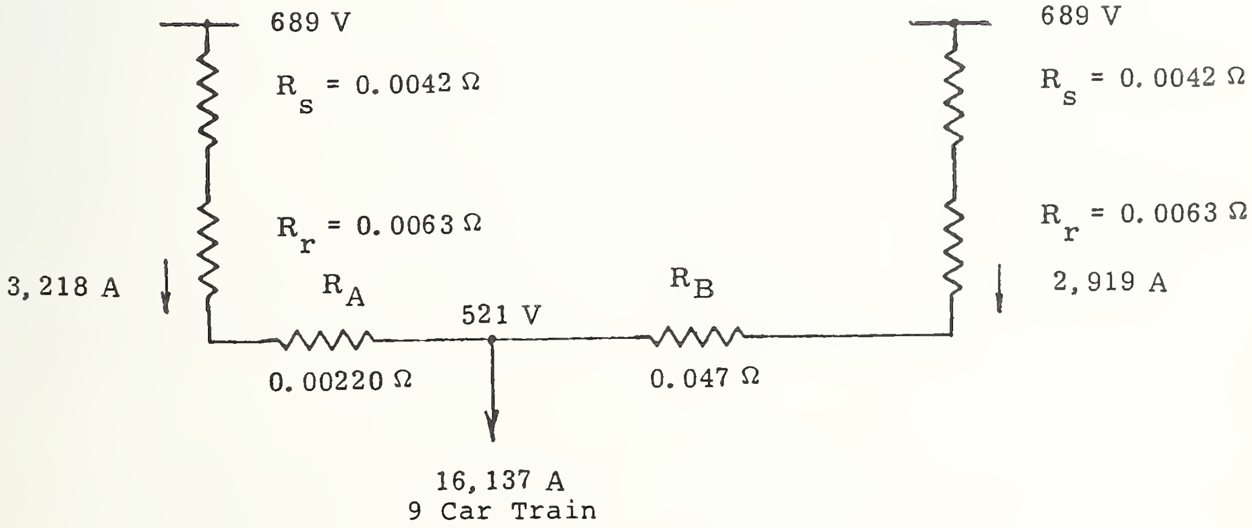


FIGURE 3
EQUIVALENT CIRCUIT FOR SIMPLIFIED
MODEL WITH COMPOSITE CONTACT RAIL

The comparison shows that with the same nine car train and the composite contact rail, other things being equal and the train drawing constant power such as it would do if it had chopper controlled propulsion systems, the voltage has gone from 490 volts up to 521 volts, which is a pretty significant rise. The train current has gone down to 16,000 amps, the rectifier loadings have gone down, and the losses have gone down from 1,177 kilowatts to 785 kilowatts. That's a reduction of about 30%. That doesn't mean that if you make the trip from A to B that the kilowatt hour losses will go down by 30 percent, but at this particular point in the run it shows the effect of the composite contact rail in reducing the losses.

In presenting these basic examples it was not our intention to offend your intelligence, or simply try to get something quantitative that could serve as a basis for discussion and argument for the rest of the seminar, but rather to establish a basis for comparison. Thus, we took some variations of that very simple example of the two substations and did some calculations and tabulated the results in Table 2. Case 1 shows for the same example, two substations of 4 megawatts each, a 9 car train, steel contact rail, 490 volts at the train, 17,100 amperes at the train, and 1177 kilowatts in rail losses. Case 2 shows the same 9 cars, 2 substations of 4 megawatts, 521 volts at the train with composite rail. Current is down to 16,100 amperes and the loop rail loss is down to 785 kilowatts. Those losses are just in elements R_A and R_B. We are not doing anything about the rectifiers. One simplification we made, which really you have no right to make if you go into very detailed calculations, is to ignore the losses in the propulsion system. Now obviously, if you have a cam controller system, and if the contact rail source working back from the train into the electrical system has higher resistance at each point in the acceleration, depending on how the propulsion system is regulated, the cam controllers can be operating with less series resistance to compensate for the greater resistance in the steel contact rail system. In effect you get no net saving in energy. You're not dissipating power in the propulsion system, you're dissipating it in the contact rail. To really do the calculations correctly you have to model the propulsion system and keep track of the losses both in the propulsion system and in the contact rail system. In a chopper controlled propulsion system, since the chopper losses are relatively low, you can just look at the loss in the contact rail system and have a pretty good idea of what's going on.

In case 3, we assumed the composite contact rail, and increased the number of cars from 9 to 10. The voltage drops down to 490 volts. The cars are now drawing 19,100 amps. and the loss is 1,103 kilowatts. This shows one simple advantage for the composite contact rail. You can increase the number of cars, and still operate at the allowable minimum voltage. You operate with slightly less loss than you had with the steel contact rail and one less car.

TABLE 2
SOME VARIATIONS POSSIBLE WITH COMPOSITE CONTACT RAIL

Case	Cars	Rect. Rating	Train Voltage	Current I_t	I_A	I_B	Loop Rail Loss
	No.	MW	V	kA	kA	kA	kW
1. Steel contact rail	9	4	490	17.1	14.5	2.6	1177
2. Composite contact rail	9	4	521	16.1	13.2	2.9	785
3. Composite contact rail	10	4	490	19.1	15.7	3.4	1103
4. Composite contact rail	9	3	486	17.1	13.7	3.4	959

In case 4, we took composite contact rail, kept the train length at 9 cars and reduced the rectifier rating from 4 to 3 megawatts. This is done on the assumption that the rectifier is being sized by voltage drop and not by train current considerations. Voltage drops down to 486 volts. We should have connected this current upwards a little to keep the power constant, or we could have fudged a bit and said this was 490 volts. The loss is now 959 kilowatts. This is another example of the advantages of composite contact rail: lower rectifier rating, same number of cars, same minimal voltage, and still lower losses in the contact rail system than we had with the original steel contact rail. You can go through a number of variations with this simple two substation case but I think this is sufficient to make the point that there are tradeoffs, and these are some of the examples of the tradeoffs.

I now want to consider economic tradeoffs. There is no point in doing an economic tradeoff on the simple two substation example. I believe that the speakers from the transit properties who have profited by economic tradeoff studies made on their own systems will give you some hard statistics. Table 3 presents some of my economic tradeoff thoughts. Anyone can argue about whether I am right or wrong. And really an argument is moot, because if you're doing a tradeoff study on your system you must use those costs peculiar to your system and to your time. But these are orders of magnitude. Typical costs for portions of the electrification system are also shown in Table 3.

TABLE 3
ECONOMIC TRADEOFF COSTS - ELECTRIFICATION SYSTEMS

. Additional material and installation cost of composite over steel contact rail - \$1/ft

. Energy cost - 4-to-5¢/kWh

. Substations

Transformer-rectifier units	- \$75/kW
All substation electrical equipment	-\$200/kW
Complete substation, including building	-\$500/kW

The additional material and installation costs of composite third rail over the steel contact rail is about \$1.00 a foot. Now I'm sure that this figure is going to go all the way from \$0.00 a foot to \$3.00 a foot today. There is an extra cost, and it typically is about \$1.00 a foot. The tradeoff in the contact rail is basically among other things, such as energy costs. Typical energy cost of today is 4 to 5 cents per kilowatt hour. If you were projecting this study for 10 or 20 years into the future, you would certainly have to do sensitivity variations on energy cost. You would model various ways in which your energy cost is going to increase; and you can almost make the projected costs come out to whatever you want with your models. Even good economists fight about energy costs modeling in the future, so I'll just use 5 cents per kilowatt hour.

One of the potential advantages of composite rail is to allow increased substation spacing or reduced substation rating. Typical costs of transformer-rectifier units are about \$75.00 per kilowatt. These would be current costs, and do not include the breakers. All the other substation electrical equipment--the AC breakers, the DC breakers, the auxiliary equipment, the blowers, the feeders and all that--are of the order of \$200 per kilowatt. The complete substation, including the building, the equipment, the installation, land, and everything else is, in the order of \$500 per kilowatt. The reason I bring these three items up is that in the simple examples I gave previously we talked about reducing one substation by 1,000 kilowatts in capacity. Well, 1,000 kilowatts is \$500,000. However, it would be naive to assume that reductions in the entire substation, land and other related expenditures would be proportionate to the reductions in the power rating. When you install a 1000 kilowatt substation you need sufficient space to get transformers in and out, and that results in a lot of empty space around the equipment. Conversely, if you were to go from 1000 kilowatts to 2000 kilowatts to 4000 kilowatts, the substation would not go up in proportion to the kilowatts. On the other hand you must recognize that using $75 per kilowatt in tradeoff studies is unrealistic, because it becomes necessary to use a figure that encompasses the whole substation, and not just the electrical equipment alone.

Another factor to be considered, which was touched on briefly, is the discount rate used in present worth analysis. On this subject the economists differ just as much as they do on energy costs. In order to do these tradeoff studies, as previously indidicated, you have several alternatives. You can do them with present worth analysis and bring everything back to today, you can do them on an annual basis, or you can do them by whatever method you are willing to use, provided that you are consistent in what you are doing and you do the electrical modeling correctly.

What I said before I will summarize in the reverse direction. Chopper cars are more critical than cam controller cars. Chopper cars tend to draw constant power as the propulsion system only asks how much torque is required and provides it. The cars then draw whatever power they need out of the contact rail to get that torque at that speed, so the chopper car can aggravate voltage drop problems in the electrification system. When cam controller cars get on the last step of the cam controller and are running in the field weakening mode, the vehicle runs with whatever torque-speed curve it is on at that particular contact rail voltage. If the voltage is depressed, the current drawn is depressed, the speed is depressed, and the torque is depressed. This is not so in chopper cars; they are thirsty and hungry for power and can depress the contact rail voltage even more severly than cam controller cars.

The second thing is--and you know it as well or better than I--that new cars require more power to get more performance and higher acceleration rates, higher top speeds, and more services such as: air conditioning, communications, control and so forth. Consequently, these cars take more power and more current per car. They either require more closely spaced substations, larger rectifier ratings or higher contact rail voltages. Maybe in time all contact rail voltages would become 1,000 volts like BART, and BART no longer will be non-standard.

The third point is that if you want to do these calculations correctly you have to do good modeling. From the modeling we have seen in some of the electrification calculations, the models might be good enough to locate substations from voltage drop considerations, but they are probably not good enough to give overall energy losses from both the propulsion system and the contact rail system. There is still work to be done in the modeling area to get a model that is good for energy trade-off studies.

Finally, in any economic analysis the name of the game is certainly dollars. The analysis must include all the costs: initial cost, cost of energy loss, salvage value, substation cost, and maintenance costs.

TRANSDUCTOR™
A COMPOSITE CONTACT RAIL

Richard E. Lillard

TRANSDUCTOR ™ - A COMPOSITE CONTACT RAIL

Richard E. Lillard, Product Manager, Transit
H. K. Porter Company, Inc.

Composite contact rail, as already pointed out, has not been around for 50 years, and experience with it is very limited. So at this time, we at H.K. Porter Company, Inc., consider it a privilege to share with each one of you, including our competitors, the expertise we have developed over the years. We could probably spend two or three days on an in-depth study of this subject to the delight of many of the engineering people present, for as I look around the room I see many familiar faces. However, the slide presentation which will be given in a little while, and which will highlight some of H.K. Porter Company's efforts in the development of a family of composite contact rails, will be brief. The sections we have designed, built and furnished, are called TRANSDUCTORS ™.

For years transit systems of the United States have used various sizes and configurations of conductor rails tailored to their individual systems and requirements. With the advent of larger auxiliary loads, the upgrading of the vehicles that we now have the opportunity to ride in, preheating, anticipated increase in the life of conductor rails, and the desire for some type of uniformity of conductor rail in the system, many transit authorities "zeroed in" on "standard" sizes. This is something which we, as well as others, learned some years ago. Authority A may use one size of contact rail, whereas Authority B may use a different size. And Authority C may have a mix of sizes. Well, that's understandable, up to a point. But then in the development stages of TRANSDUCTOR ™ and in conversing with very knowledgeable people in the industry, we found that on Transit Authority C property they may have 2, 3 or even more sizes of contact rail that they use in daily running.

The ever existing problem of voltage regulation was initially combatted by the installation of booster cables. In many instances the use of booster cables meant additional duct lines which resulted in prohibitive costs. H.K. Porter Company, working with various transit authorities, correlated design criteria for the ideal conductor. On the basis of this correlation, we developed the requirements for our composite rail, TRANSDUCTOR ™. Very simply, after many years of study, many hours of back to the drawing-board efforts that we will get into later, we came up with 6 basic, or you might say kindergarten-level criteria for the ideal conductor.

First consideration is the wear aspects. Transit Authorities have brought it to our attention that the 80 lb. steel contact rail has been shown from experience to have 60 years of life. We have actually seen this to be so. We put our hands on it when they turned it off. In some cases there are other sections that have an expected life of 100 years. That's point 1, wear.

Point 2 is electrical ampacity. We realized from our transit studies covering many years that the ampacity requirements of the various authorities were increasing. It's the same way in the development of the automobile - the Model A's and the Model T's are beautiful units at the Antique Car Show. But you don't see many of them out here on the highways coping with the traffic of today. We needed an increase in available voltage at the vehicle to handle the more severe power requirements of the newer vehicles.

Here in the Boston area you have th opportunity of riding on many different types of vehicles. This was pointed out by speakers at the LRT conferences three weeks ago. There are vehicles here that cover the range from the days of wooden seats right on up to the most modern types of vehicle. But the older vehicles do not have air conditioning and many people complain about the low lighting levels. We needed to increase the available voltage at the vehicle and decrease the IR drop. We needed a decrease in the power losses or I^2R loss in the contact rail. It has been pointed out already, power costs money. In the last 2 or 3 years we have been made aware that power losses are even more important when we pick up the morning paper and find article after article about the increasing cost of power.

An increase in electrical ampacity was also needed to increase the available short circuit currents for track section openings under fault conditions, a safety feature. Also in the design of the composite rail there was a splice joint. Now many people can look at it and say, "Well a splice joint is no engineering problem." It's true. But we are looking for a design concept that would connect this length of contact rail to that length of contact rail without increasing the rail resistance, and eliminate the need for rail bonds around it, as almost all steel bolted splice joints require. So this was Point 3.

The fourth point of concern was rail fasteners. The people we dealt with at the CTA in Chicago, the MBTA in Boston, the New York City Transit Authority, and other transit authorities were in this game day after day. We were the new kids on the block. So we had the advantage and the real privilege of being able to converse with knowledgeable individuals. They told us their recommendations, and we followed them. Sometimes we wondered why. We asked many times questions which I classified as dumb. They turned it back and said that's not a dumb question, that is why we recommend this. So we followed their advise. We had a 200 foot test section located on the CTA property of what we called the Model A version of the samples of TRANSDUCTOR TM. At the splice joints we used the recommendations of the authorities. We used track bolts, Belleville washers, lock washers, track nuts, torque levels and so on. But you who have operating properties, and you in the consultant field that have been out on the properties, know that there is no thread form that is 100% vibration proof. Many authorities have track walkers who walk up and down certain sections of track tightening bolted joints. To avoid such problems we have gone to the lock bolt. The lock bolt at H.K. Porter is not anything new; we have been using it since 1965 when we came out with a composite rail for what we consider our standard industrial product line. We tried all sorts of fastening devices in the development of that contact rail conductor and settled on the lock bolt. Now I don't mean to imply or indicate that all of the ideas of H.K. Porter people have been tremendous and right up front. We have 2 to 3 trash cans full of the back to the drawing board type of approaches.

We considered the rail section. This ties back into wear, in one way, but it also goes back to the comment I made with reference to the different sections used by different authorities. The CTA has used for years a special 144 lb section for contact rail. Now if you picked up a steel catalogue or handbook, unless you have inserted pages into it as I, and other people in the authorities have done, you don't find this section. Nor do you find the 150 lb Bethlehem section; however, if you go back to the old Lackawanna steel book on Page 38, there is a 150 lb section, the all steel rail section. In most steel catalogues you are going to find ASCE sections. You're going to find the 80 or 85 lb sections, and you're going to find the ARA-A and ARA-B sections.

We started working in the development of the composite rail with the authorities. One authority used an 80 lb rail section for contact rail, and we leaned towards that size to develop a TRANSDUCTOR TM or composite rail section to meet their specified needs based on that envelope. For another authority we used the 85 lb section. These are the basic highlights of the design criteria that were used in the design of what we call TRANSDUCTOR TM or our composite rail. Now the CTA has in the neighborhood of 92,000 feet of TRANSDUCTOR TM rail in revenue service on their property. The MBTA's Haymarket North Extension which we will see tomorrow has in excess of 91,000 feet of TRANSDUCTOR TM in revenue service.

We go back to the wear on the steel head. I saw some 85 lb rail that had in excess of 50 years wear on an elevated section of track in Boston some years ago. Its head was about two thirds gone but it was still in use every day. This rail is a high carbon ASCE steel rail. Now many people have asked why we have not gone to what I consider the non-standard softer steel. The softer contact rail (144 lb or 150 lb) is just that - contact rail. Our choice allows us to use a standard rail section available from the steel companies. This allows an authority that may have this particular size of steel rail in stock to make use of it for yard leads or end approaches. It has the same height, same configuration, and the same wear characteristics. The aluminum extrusions provide the lower resistance and higher ampacity, and the splice joint we have touched upon, which we will talk about again. The lock bolts in our case are actually Huck bolts which we buy from Huck Manufacturing Company. You'll see a demonstration on these tomorrow.

The interface between the steel and the aluminum comes up time and time again in all discussions. To prevent galvanic corrosion we protect the interface with no-ox so that we don't have the formation of oxygen cells. You'll see tomorrow the evidence of the no-ox. Excess no-ox applied during fabrication is clearly evident, and you'll see that after the rail has been in use for some time the no-ox is still there and does not drip down. Now it might be noted as I mentioned a few moments ago that Porter didn't start this last week. We've actually been involved in this project since 1964-1965, and have worked with the Chicago Transit Authority and the MBTA test track installations in the development of our TRANSDUCTOR TM, and this is a sample of one size of TRANSDUCTOR TM. We have other samples we will get into in just a moment.

I want to touch very quickly on Transductor TM installation. It is an important part of our presentation and I know it will be brought up in the discussions tomorrow. In a regular slide display installation takes up about 75% of the total time, however in this particular presentation I shall be very brief. Figure 1 is a slide showing the off-loading of the TRANSDUCTOR TM from the work car to be set upon the transit insulators set at intervals along side of the tracks. In Figure 2 we view the positioning of the rail, and you will notice that the splice joint is self aligning, and therefore, alignment is not as critical as it might be with welded steel rails. Figure 3 shows the installation of the Huck bolts through the splice joint. Observe the misalignment of the contact rail in Figure 2 versus Figure 3, and the Huck gun in the lower left of Figure 3 being used to install the Huck bolts to finish the splice joint. Figure 4 is simply a blow up of our composite transit conductor. The actual splicing of the joint in the sequence you have just seen took only three minutes. I would hope that those of you who may have been skeptical about splicing a joint in such short time, after having observed this presentation are now believers.

I've hit many of the highlights of the design criteria for the ideal conductor, the wear, and the steel rail. We also have our TRANSDUCTOR TM 80-2.3 on CTA, our TRANSDUCTOR TM 74C-2.3. The only difference between them is that the 80-2.3 uses the basic 80 lb. ASCE rail. The 2.3 is the resistance per 1,000 ft. That's .0023 ohms per thousand feet, or 2.3 milliohms per thousand feet. People have asked how H.K. Porter came up with 2.3 milliohms per 1,000 feet. It so happens that the CTA specified the rail in

FIGURE 1 OFF-LOADING OF TRANSDUCTOR ™ RAIL

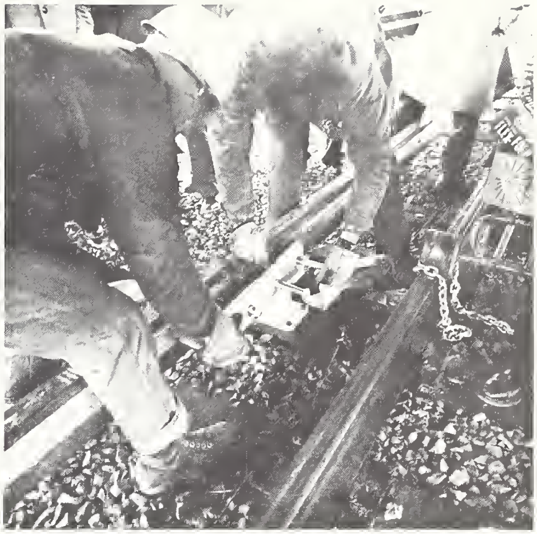


FIGURE 2 POSITIONING OF TRANSDUCTOR ™ RAIL

FIGURE 3 INSTALLATION OF HUCK BOLT THROUGH SPLICE JOINT

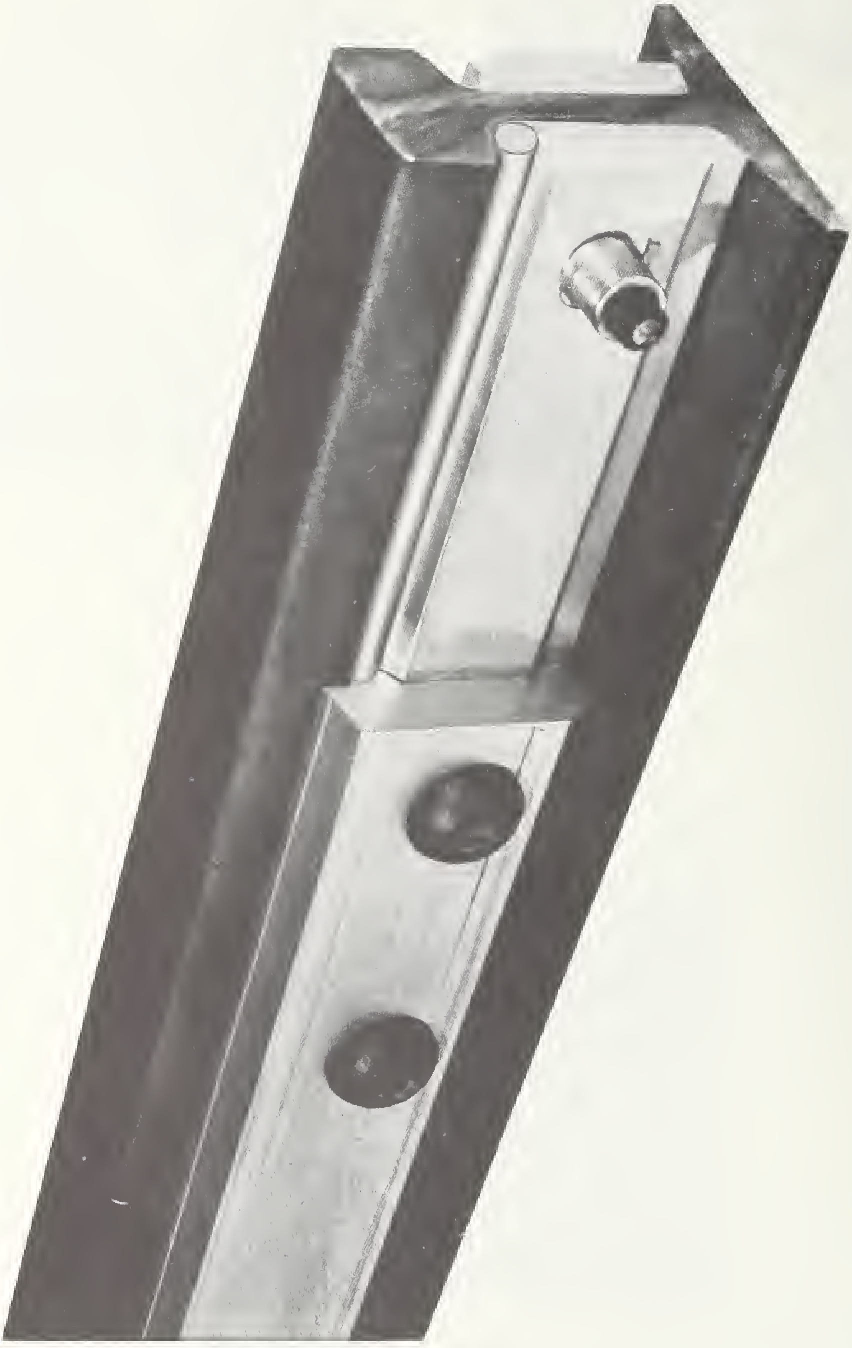


FIGURE 4 COMPOSITE TRANSIT CONDUCTOR

circular mils of copper, and this gave the resistance stated.

Also, on the CTA we have 41,000 ft. of our 74C-2.3. Resistance is the same. The steel is a different section. It has the height and head configuration of the 85 lb rail but a narrower base. The 74C stands for 74 lbs per yard. It is a rolled section made by and obtained from Connors Steel, which was necessary because neither U.S. Steel nor Bethlehem Steel would furnish the steel rail for that program. The rail which you will see tomorrow is a TRANSDUCTOR TM 85-2 in use at the Haymarket North section. This section is also being specified in some other programs.

The 85 lb steel rail is 1,800 amps and 12 milliohms per thousand feet. This TRANSDUCTOR TM, the composite section (85-2) is a 5,100 amp rail, 2 milliohms per 1000 feet. We also have designed what we call our 84C2. That's 84 lbs of steel per yard, 2 milliohms per 1,000 feet resistance. People ask, what's the 84C2. All of you recognize this section. It is the 150 lb steel section, rolled in the United States only by Bethlehem. That's a 3,000 amp conductor, 4 milliohms per thousand feet.

The 84C2 is an exact overlay of the 150 lb steel contact rail section. The 24 inch head radius, the 4 1/8 inch wide head, the 4 7/8 inch wide flange, are identical to that of the 150 lb steel contact rail, which is 3,000 amps. and 4 milliohms per thousand feet. What we've done with our 84C2 is to add aluminum and make a 5,000 amp, 2 milliohms per thousand feet conductor.

Figure 5 shows a cross section of a splice joint made using Huck bolts. The Huck bolts are not threaded; they have annular rings. When the collar is swagged onto the Huck bolt by the Huck gun and engages these rings, it is firmly in place. There is no threaded nut to back off or come loose. Figure 6 shows sections through the TRANSDUCTOR TM rail itself, and through a typical splice joint. Note that two sizes of Huck bolt are used: 5/8 inch diameter for securing the aluminum to the steel rail, and 7/8 inch diameter for assembling the splice joint.

The question has come up of whether we ought to put in a test track on various properties. Eight or nine years ago I think it may have been advisable. It may still be advisable for certain specific requirements. But we have had test tracks on the CTA and the MBTA and we're not the only composite rail manufacturer that has been involved in these test tracks. We have in excess of 6 years of revenue service experience with composite rail. Now I know for a fact you transit people talk to each other more than housewives over the back fence,and there is nothing that happens in the transit industry here at 11:00 o'clock this morning that is not known in San Francisco by 3:00 o'clock this afternoon. What we need to do is to get you involved in the mail system so we can get a letter back and forth across town in a week. The point is that people talk about the pluses and the minuses of various approaches. We have worked with and are still working with, various transit authorities. Hopefully from my position as Project manager of the Transit Division of H.K, Porter Company we're going to continue to work with the transit authorities.

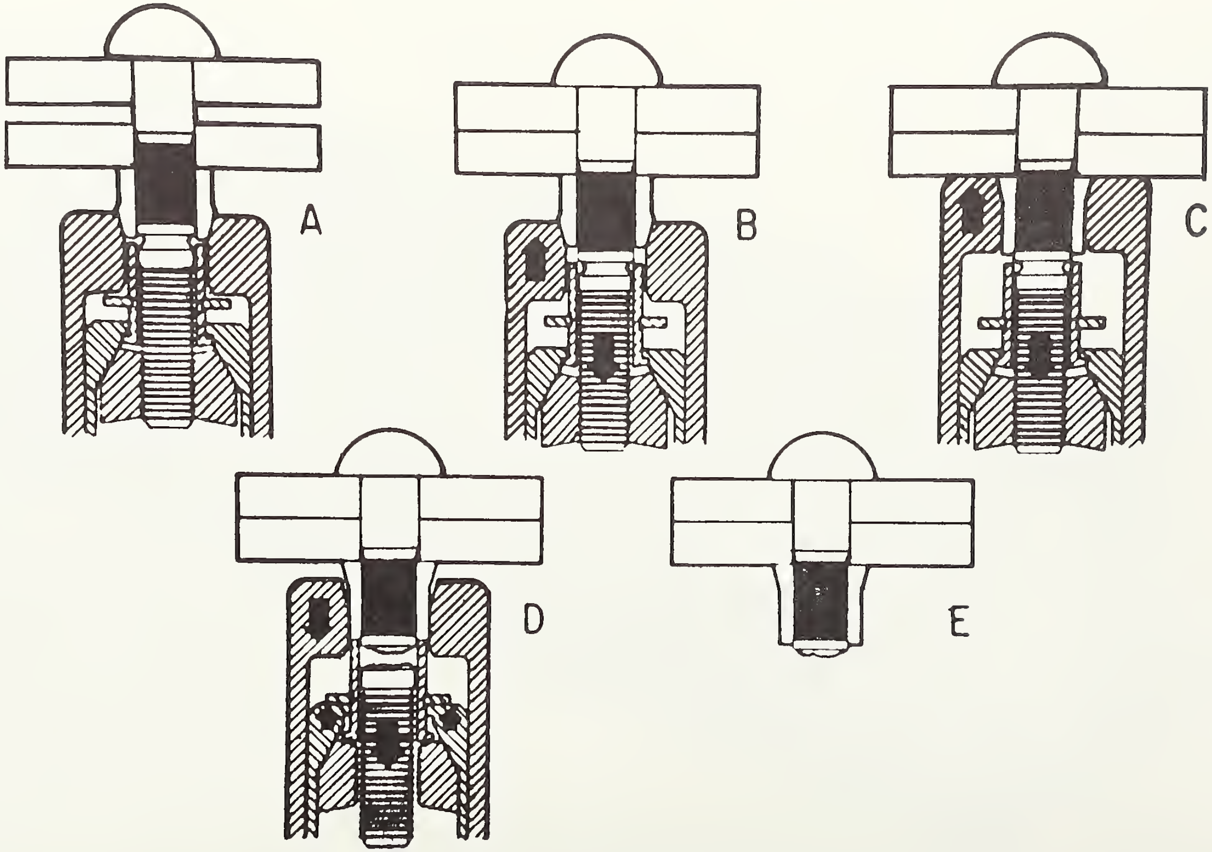


FIGURE 5 CROSS SECTIONAL OF OUR SPLICE JOINT ARRANGEMENT

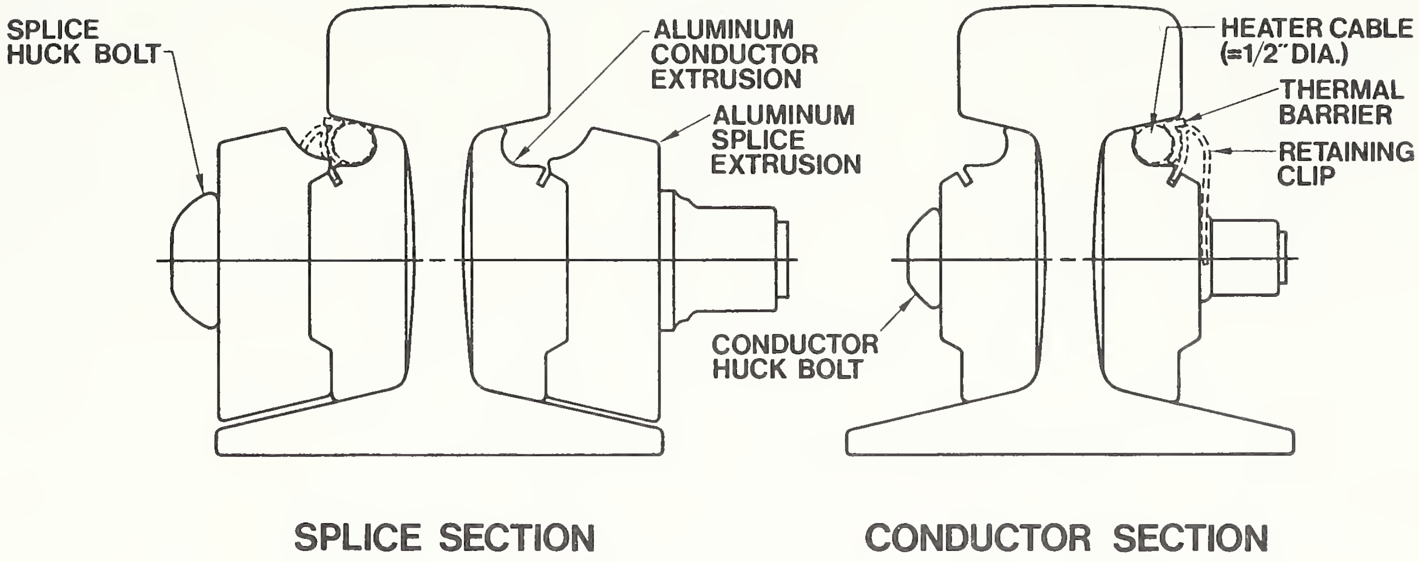


FIGURE 6 TWO TYPES OF HUCK BOLTS

We started back in the early 1960's to develop an ideal contact rail. And this is a very quick, very short, and maybe not too concise summary of what we have done since then. As I mentioned earlier, installation, operations and other problems will be brought up by subsequent speakers. The installation you will see tomorrow, and so I haven't really dwelt upon that. You can't take 12 to 13 years of engineering design experience and boil it down into 33 minutes and hit all the highlights.

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Following the presentation by Mr. Lillard of H.K. Porter Company, Inc., the meeting was opened to questions from the audience. The following material is the transcription of this question (Q) and answer (A) Session.

Q: V. Mahon, BART - I'd like to ask Dick Lillard what allowances are made for contraction and expansion on this installation. How are you taking care of that?

A: R. Lillard - The two properties on which we have installed our composite rail do not use expansion joints; they use expansion gaps. We had a workshop seminar here about two years ago and the expansion joint question came up. We are furnishing expansion joints at the present time for Washington Metro TW3 and TW4 contracts. We redesigned these expansion joints for the TW3 contract. Right at the moment we are redesigning the TW3 expansion joint for TW4. If you are speaking of the expansion of the contact rail by itself, basically the differential expansion of the two metals, we have had no problems. We do not have a long section of 39 or 100 feet. We have broken it down into short increments. Our lock bolt centers are normally 18 inches. The thermal contractions and expansions that the operating authority will see will vary. BART will see one differential versus those of Boston, Chicago or Dade County. Very quickly and very easily you'll see from the expansion rates of the aluminum and steel that the 18 inch differential is so minute you'll never notice it. In our proprietary design we have built in a couple of features, and there is nothing proprietary about using a 2 inch hole and a 1 3/4 inch fastener. Those sizes aren't exact, but they make the point.

Q: L. Pinkney, WMATA - What is the composition of the no-oxide used by Porter?

A: R. Lillard - The no-oxide inhibitor we use is bought from Dearborn Chemical. This is a conductive grease that has been used in the electrical industry, the marine industry and just about every other industry for years and years. If you want to get right down to the basic concept it's a soft grease type rust preventative, used in many cases on plain and structural steel. Specifically we use it to prevent 1) iron-oxide, or rust, reforming on the steel rail, and 2) reformation of the aluminum oxide on the aluminum.

The actual chemical constituency is a proprietary situation with Dearborn. Here again we're looking at it a little closer in working with the W.R. Grace people in getting the breakdown. I thought we used a lot of no-oxide. Jim Spearinger and I were in Chicago 6 or 7 years ago showing our new composite rail. On these sections you don't see any no-oxides because its very thick, like cosmoline. Even though under thermal expansion and contraction it thins out, you don't see a big glob of it. But it's there, and it doesn't go away. We tore apart a particular test track we got back from CTA, looked at it, and while we were explaining this, that, and the other thing, one of the track gentlemen said, "What are you talking about, this no-oxide?", and I described it. He said, "Oh you mean like that over there," and he must have had 2 dozen 55 gal. drums of no-ox. Up to that point I thought the biggest container was a 5 gal. drum or a 5 gal. bucket. We use it for the galvanic corrosion elimination. Does that answer you? Comment by L. Pinkney: I know what you leading up to from previous discussions, and we're going to get the actual breakdown.

Q: A. Houston, Maryland Mass Transit - Isn't it a silicone based grease?

A: R. Lillard - It is a silicone based grease, which is one thing I should have mentioned.

Q: R. Ganeriwal, DeLeuw Cather - Has any thought been given to increasing the shipping length from 39 feet to say 50 feet to offer a saving in the number of splice joints required?

A: R. Lillard - This has been considered with regard to the (steel) rail sections. What Mr. Ganeriwal is speaking of is that instead of 39 feet sections, let's double it, or make it the same length as 150 lb. rail.

You are talking about special shipping, you are talking about the need for the steel rail to be shop welded to get these added lengths. I think you will find in the analysis of the installation that your minuses will outweigh the pluses for the longer rail. Now handling it is one thing. When you look at a piece of 85 lb steel 39 feet long, and you are talking about close to 1,200 lbs of steel. To us, because in our standard industrial product line we are looking at aluminum conductors which are kind of flimsy compared to this steel, this steel looks pretty rugged. They talked about this type of steel in the transit industry as being like a wet noodle. In light of that you can see curves on Haymarket North and also on the CTA that weren't factory formed. The rail had just been bent around on top of the insulaltors. We have given it thought. I don't see the advantages. Cost wise it's going to be prohibitive. Incoming freight from the steel mills and outgoing freight from Porter need special handling. The production is special. Here again, all I can say or address myself to, is our own little portion in the production of TRANSDUCTOR TM sections say 60 to 70 feet long. I can see some very, very distinct production problems. But we have given it thought.

And I do know that the lighter rail sections are available in the longer lenghts.

Q: A. Wacker, LIRR - I'm wondering about what happens to the composite when it gets a temperature change from -10°F to say +140°F. and the no-oxide which is in there may be squeezed out and the shape of the aluminum changes. Do you have to change the Huck bolts on this every so often? What happens to the contact surface between the aluminum and the steel? Usually temperature changes. Let's take it when the resistance may be low. As the years go by the no-oxide gets squeezed out of there and you get a loose contact surface. You may then have a high resistance connection.

A: R. Lillard - It's a good point, it's a valid question. As I mentioned in hitting the highlights I didn't go into all the details. But what we're speaking about in regard to your question is thermal expansion and contraction of two different metals. Coefficients of expansion are steel $7x10^{-6}$, aluminum $13x10^{-6}$ giving a differential of $6x10^{-6}$. Our design is such that we are wedging this block of aluminum between two locking surfaces of a harder tougher, stronger metal. We have run our 500 hour salt spray test. We've run thermal cycles under CTA specifications. This consisted of 12 cycles from room to plus 150°F to room to freezing to room temperature. The contact rail had 7 1/2 hours heat dissipation time. So you can realize it took more than between breakfast and coffee break time to run those tests. We found out, and as has been mentioned in discussions on Haymarket North, in 3 years the resistance of the contact rail decreased and is now actually lower than when it went in. When we ran the first thermal cycle tests we saw the resistance dropping off in each cycle.

We, the all-knowing smart engineers, were in there scratching our heads and all of a sudden it came to us. What we were doing was improving contact at the interface. There was no contact in the web area. That gap is supposed to be there. Now if you look at the 84C sample you see a machined piece of aluminum and you don't see the gap. It should be there. But this is actually giving a better interface connection under thermal contraction and expansion. As far as squeezing the no-oxide out, you don't. It develops a microscopic film and under the various contractions and expansions; it just gets more seated into it.

As I mentioned, we conducted a 500 hour salt spray test, thermal cycles, heat rise test, DC resistance test, and some others including a bend test. We took a section from the MBTA and we took a section from the CTA, bent them, checked resistances, bent them again, checked resistances, and found no problem. At the conclusion of the CTA bend test, I requested a section to be sent back to the Lynchburg Works in Lynchburg, Virginia so that we could tear it apart and see what happened to the interface. About a week later I got a call from our receiving department. They said, "Dick there is a 10 foot section of that rail that you are playing around with out here." I said "Yes it's formed, it's bent." The gentlemen said "No it's not, it's straight." So I went out there and it was basically straight. We brought it into the lab, looked at it, and checked the resistance. The resistance was even lower than the last numbers the CTA had on it. So I went back to my office and I called Mr. Swindell and I said, "Ron, I thought you were going to send me back a section of the rail which was bent up there," and he said he did. I said, "Well, I'll tell you one thing. We got the wrong carrier, or else they thought they were responsible for the bend, and straightened the hell out of it." He said, "We straightened it out. We had a section of rail that started it out like new, was bent with a 90 foot minimum radius, was straightened, and sent back. There was no deformation or tearing out of the aluminum. The aluminum that we use is not the soft FC grade which has a higher conductivity but is like peanut butter. The aluminum we use is not the aircraft series aluminum which is much stronger but has lower conductivity. We use a compromise. We developed it back in the early 50's when we came out with the first aluminum conductor section in the industry.

Q: A. Houston, Maryland Mass Transit - What did that face look like when you took it apart? Was there more aluminum interlaced with the steel? Was the molecular structure, if you will, if you went that far with it, indicative of the rubbing of the two surfaces together which you would get in a thermal cycle or physical cycle, a better electrical connection?

A: R. Lillard - That's what we saw. Many people, including our own incoming inspectors who look at aluminum extrusions every day have the idea they are quite smooth. But if you examine them and realize what you are looking at, they are not that smooth. They have longitudinal lines and also produce waviness in a plane as a result of the extrusion process. What we saw was the actual smoothing, the rubbing of the high points into a better interface connection.

Q: H. Decker, TSC - When you assemble that rail with the Huck bolts I think it would be of interest to note what the tension in the Huck bolt is at a joint.

A: R. Lillard - Let's break it down into two pieces. We use 5/8 inch Huck bolts in the conductor section. The cracking force on the 5/8 inch Huck bolts is 21,000 lbs. On the splice joints in the field installation we use 7/8 inch Huck bolts. We use a flanged collar, which is part of our specification. This gives a greater contact area. We have 39,000 lbs clamping force at this joint per fastener. Now this was a very, very complicated complex engineering design decision. Why 7/8th? Why 5/8th? Well, first of all the biggest one we ever used on our standard HC bar section was 1/2 inch. We have some sections bigger than this but not as heavy, so we naturally went to the next larger size or 5/8 inch. We ran a number of design studies to determine what we should use at the splice joint. A 3/4 inch Huck bolt will do the job. That joint is rated to exceed 25,000 lbs. longitudinal hold before any deformation occurs. We set up a meeting with the MBTA.

We didn't have any 3/4 inch lock bolts to put in a sample but we had the 7/8 inch bolt. We had the short section there laying on the table in John Carey's office and a couple of very knowledgeable track people saw it. One said, "I like that. That looks good because it gives you the feeling that it is not going to fall apart." So that's why you have a 7/8 inch Huck bolt in the splice joints.

INSUL - 8 COMPOSITE RAILS

James Corl

INSUL-8 COMPOSITE RAILS

James Corl, Chief Engineer
Insul-8 Corporation

I'd like to tell you a little bit about our company. We have been in the mobile electrification business for over 25 years, and that's our only business. Our home office and main plant is in San Carlos, California and we have manufacturing facilities in Melbourne, Australia; Manchester, England; and Toronto, Canada. In most of the English speaking countries of the world we are well represented. I am Chief Engineer of the company, and you will find very shortly public speaking is not one of my strong points. I am not an electrical engineer, which most people think you ought to be if you are in the conductor business. A lot of problems we experience are mechanical, sometimes caused by the electrical, sometimes not. The electrical problems are solved by an electrical engineer who works for me.

We initiated an extensive research program about 14 years ago in Insul-8 to determine the best materials for conductors. The best current carrying materials are not good for wear; the best wearing materials are very poor conductors. So there was only one thing to do, and that was to put the two of them together. Our original stab at this using what we thought was the best combination of material didn't work very well. We threw that idea out in a matter or six months or less.

Today I will cover basically two kinds of composite rails. We actually manufacture both of these so I will try not to be prejudiced one way or the other. On the other hand, there has already been a lot said about what we call sandwich rail, a railroad rail or crane rail with aluminum sides on it, that has some excellent features and it is a definite step up in savings, current carrying capacity, and other good things over a straight steel rail. I have always looked at the plain steel rail as trying to run the equipment with a big long resistor, and that's really not what you want to do. You are trying to get the most current carrying capacity and wear, and a resistor is not the way to go. So that's why we went into the composite rail. The processes for manufacturing the composite rail, which you have seen already, are not difficult. In other words, there is no fancy machinery needed. But putting it together has to be done properly. One of the main things is the cleaning of the material, the inner faces especially. They have to be cleaned properly, coated properly, and put together properly. Now that is not done with lots of fancy machinery; it is done with good common sense and good supervision. And that is what is required. Any high carbon steel rail would do the job and as has been pointed out, a wide variety of these sizes exists. So the whole thing depends on what your requirements are. If you need 5,000 amps or .002

ohms, you use a little larger rail and more aluminum. That makes an infinite variety of composites available that can be put on a system. It can also be done with standard rail. I know a lot of specifications are written that call for number 1 rail to be used for the composite conductor. That is really not necessary, and because you are not looking at a load bearing rail you can have slight flaws or defects in that rail without changing the end product one bit. Therefore, you don't need Class A number 1 rail because the end result is not a load bearing rail; you are carrying very little current with it. What you are doing is using the rail for rigidity and wear surface.

Now as far as fasteners go, you will see that on our composite rail over there we use bolts, Bellevilles, and lock nuts such as ESNA. We put those together with whatever method the particular facility wants. If they want Huck bolts, great. We don't have to stock any one of them. We sell rail. So I'm not fussy at all about how they want it, although if they do want it bolted I definitely insist on high tensile bolts, flat washers, Belleville washers, and a good self-locking nut. Now wherever practical we try to assemble all of the accessories in the factory, i.e., the expansion sections, sliders, the isolation pieces, and the on-off ramps. If the quantities and kinds of accessories are known ahead of time, we try to do that work at the plant. There is no cheaper place to do it. When you start doing all the assembly necessary in the field the cost obviously goes up.

We made quite a study of where the current flows in these composite rails. The current pattern is dense around the bolt and decreases as you go out to half way between the bolts, and then, of course, you pick up the ones from the other side. There has been a lot said about the absolute perfect electrical connection between the aluminum and the steel. I agree that you have to have a good electrical connection, but it doesn't have to be as good as everybody seems to think. If you go back 35 years and look at the crane rails in the steel mills, they merely took a 500 mcm or 750 mcm piece of copper, ran it along beside the crane rail and cadwelded it or bolted it to the steel rail every 10 to 15 feet. Those were the only connections to the rail that they had; and they did a great job. Now I don't profess that we should make the composite rail any differently than we are now doing it because it works, it works well, and we might as well keep on doing it right. I can't see backing off on that interface to save a buck. It isn't worth it. If you have success with that kind of thing, I don't think you ought to change it.

Now the current distribution pattern with the collector shoe on the rail runs very similar to the current pattern around the bolts in a composite rail. The current density is very heavy right under the collector shoe as it travels. The current flow diminishes as one goes out each way from that collector shoe. That is, you might say, obvious. But it is sort of a touchy thing because it is constantly moving. It is not a good solid connection like you have with a bolt, and it is a little more difficult to study. We've gotten some pretty good numbers on current distribution. Now you can talk about having a wide rail and therefore you get more area of contact. I haven't seen one yet that doesn't run on a line contact. The shoe is either on the rail here, or it is over there, but it is never on the whole rail except when it goes from one side to the other. I'll say 99% of the time you have a line contact the length of the collector shoe.

The other rail that I'd like to talk about has been on the market for 8 years, and is aluminum with a stainless steel cap. Now the inductance, the voltage drop, the losses decrease when you don't use any ferrous metal. The magnetic field reduces. One question everybody raises: With a 0.100 inch stainless steel cap, isn't that going to wear out in 2 years? Our further studies show that if a steel conductor rail is used all the time it will last longer than one which is used part of the time. What is happening is that the rail is rusting away and it is not wearing it out at all. You polish off that rail everytime you come out of the yard. I'm sure everyone of you has seen a rooster tail of sparks out of the back end of the shoes when a car is first run on the line on any morning. That rail has a microscopic layer of rust on it because it has just been sitting there overnight in moist air. It might be dew, it might be salt air. The same thing may not happen in Albuquerque since it is pretty dry there. You have already polished the rail down to shiny steel before you put the cars to bed at night. In the morning the rail has the rust on it. You come out of the yard and wear the rust away. Even if it is only one - 100,000th of an inch, you do it every day. That's where the rail is going.

With the stainless steel cap on the rail we have gotten some pretty good data which it has taken time to get. It seems to make no difference whether you use cast iron shoes or carbon shoes on the rail. It wears approximately 1/2,000 of an inch per million shoe passes. It makes no difference whether the rail is out in the snow, ice, subway, or elevated. All of the data we have shows wear of just about 1/2,000 inch per million shoe passes. The atmosphere has literally nothing to do with it because you don't get the microscopic layer of rust on it. The aluminum alloy is a trade off. You can use softer alloys that can carry more current. You can use the harder, stiffer more rigid alloys and they carry less current. You have a tradeoff between rigidity and current carrying ability. The purpose of that conductor is to carry current. It also has to hold itself up through fault forces, daily beating, and what have you. So there again you have a tradeoff. We use 6101-T6 aluminum and we use 304 stainless steel on our conductor rail. The 300 series stainless has given us much better results than any of the other alloys tried. Now I'd like to point out that the smaller of those two aluminun rails is the conductor that is being used in Barcelona. Up until BART placed an order with us it was the only other transport system comparable to those that you people work for or look at. That rail has been in service 3 1/2 years in Barcelona. They are extending the system there this year and next, and they are using exactly the same rail in the extension. So it's doing a job for them. Now in 3 1/2 years they have not had any problems with it, or they wouldn't be buying more. It's a very busy system. The current draw on that system is less than that on most of the systems in the United States but the number of train passes and headway of the cars and the number of people that they carry is unbelievable. I know that BART would like to have that ridership.

I would like to cover an area that bothers me a little bit and which will take me slightly out of my field, because I'm a mechanical engineer, and I've been given this information by my electrical man. One of the problems with steel rail is that the low speed or rate of current rise creates difficulties with a chopper controlled car. The rate or speed of the current rise in the steel conductor is slow just because of its relatively high self inductance. In the aluminum rail we haven't found that. In other words, there is a definite improvement from that standpoint as well as voltage drop.

As for the electrical forces everybody talks about, I've run into some figures that are absolutely ridiculous. When people talk about resisting 250,000 amp short circuit forces on the job, they are really just raising the cost of the job. The contact rail will never see that large a current. What was originally specified in our Caracas project, we finally had reduced to a more logical figure like 150,000 amps. Now we find in all our tests the rail itself is not the problem under the electrical short circuit forces; it is usually what supports the rail. If the rail is large enough to carry the current, rigid enough to have a harmonic vibration rate compatible with the car, it will handle the electrical forces. It's the support system that has failed in the tests that we have done.

The materials that we use in the aluminum-stainless conductor are high priced. But the end product is not. We have automatic machinery that we set up. We roll the cap on a Yoder mill, and we have automatic machinery set up where we just put those two together and run them through almost as one piece. We use a rust preventative grease inside. We also use no-oxide and we also use one made by Chevron. They all do the same job. The steel is automatically greased as it goes into the machine. The grease sticks to the sides of the stainless. The machine rolls the aluminum and the rail comes out the other end, gets so far out, trips a flying cutoff, and punches a hole. We punch holes in the other end by backing it up. Now we have spent a lot more for materials making the conductor. But we have cut the labor on it down so that what you are buying is material and not a lot of labor. You end up with a product made of admittedly more expensive materials. But it's the bottom line you should look at, not how much we pay for the material. What you should look at is what you pay for the end product.

We put together our first aluminum rail about 12 years ago. About 10 years ago we changed to this method of doing it, and have been doing it that way ever since. We have 91 miles of aluminum-stainless steel rail on transit systems throughout the world. Most of these are in what we call and you would call people movers. One of those facilities that has a real high ridership is Walt Disney World in Orlando. They know how to move people. Lots of them. The system down there was put in 5 years ago or so, when they opened up Disney World in Orlando, and it has been running ever since. I have some numbers from the operating engineer down there. They have records of costs and ridership and people moved per hour, etc., that anyone should envy. It's a good system.

I have touched very little on the railroad rail with the aluminum siding. About everything has been said about that rail that can be said. The only apparent manufacturing difference we have on that type of rail is that we use a bead of Hypalon sealer at the top and bottom edge of the aluminum as is put together. That really is an additional sealer to keep any moisture out of the interface. It is the biggest difference, and that's the only additional thing that we do to it.

The main purpose of any of these conductors is to carry a heavy current. The methods and materials that are available today weren't even talked about or on the drawing board 25 years ago. To have a composite rail with 25 years experience behind it is unreasonable. I think that the industry has come up with some very good workable improvements for carrying current on transit systems. Those improvements and savings are available today.

Electrical energy is expensive, and every day it is becoming in shorter supply. The facilities you people operate have higher and higher electrical requirements every day. Faster trains, more acceleration, air conditioning and other things we never had 25-30 years ago. So the requirement for electricity is going up and the cost of it has gone up. I think that our job is to deliver that very valuable commodity in the most efficient way it can be done, and at the least cost. Everybody talks about various costs, but it is the bottom line that is important. For example, consider the installation of 150 lb steel rails. They are welded together. Hours are spent on grinding down the joints. Even with the crane rails or the small railroad rail, the grinding of the joint after it has been put together is one of the things that takes a lot of time. And just due to the nature of how rail is hot rolled the tolerances in the height of that rail are such that even on the same mill run you aren't going to get two rails to match exactly end to end.

At Pueblo we put in wayside power (contact rail) for TACV. Now TACV is a 150 mph system. It ran at 143 miles per hour. The contact shoes are only three quarters of an inch long. The contact rail was all put together with very little touching up or dressing of the joints because the contact rail was extruded aluminum and stainless steel. The aluminum extrusion, by the nature of the extrusion process, is very accurate. It may not be absolutely to drawing. But it is absolutely the same, mile after mile, within thousandths of an inch. The mill tolerance on the stainless steel is such that you are going to have a joint differential of maybe a total of 1/2 a thousandth of an inch. That kind of installation savings begins to pay back on the high cost of the materials that are used in aluminum-stainless steel rail. Again we want to look at the bottom line - installation cost, material, performance - the total installed cost. I don't think that we can any longer sit around and use things that just happen to be available and not try and improve them. We're going in that direction and I think this seminar is really the first one I have seen that is devoted specifically to the problem of third rail power distribution. We can't afford to sit around and watch operating costs go up and up and up when we know what to do about it. What we are doing about it is to increase the efficiency of the third rail system.

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Following Mr. Corl's presentation there was a second question and answer session.

Q: A. Wacker, LIRR - I see you have been using it in Barcelona and in Florida. How does it stand up in cold climates where you have ice build-up and arcing? --(inaudible)--. Do you scrape it?

A: J. Corl - We have some up in Anchorage, Alaska. I only mentioned the other two because those are more high volume transit systems. We have some in Anchorage and it gets pretty nippy up there.

Q: A. Wacker - When they run the trains, do they have ice on the rails?

A: J. Corl - Sure. Sure. Not on the conductor itself. I don't care what kind of conductor you have it is not going to run if you have ice on the rail. Ice is a very poor conductor. (inaudible).

Q: How do you get the ice off? With a scraper?

A: J. Corl - That is pretty brutal, I know. You get arcing. Joe Dyer and I already went over that about 6 years ago on another kind of system. You should not use an ice scraper on that conductor. We also make that rail with two little holes and use them to put a resistance heater wire inside to melt the ice off the contact surface. There are two resistance wires inside there. When it gets cold the heater wires can be turned on and melt the ice off the rail. Incidentally, the actual rail that was supplied to BART is neither of the two I mentioned, it's half way between the two. This I think is a good point to bring up because it shows the wide variety of shapes and sizes that can be had with very little cost difference. For example, the tooling to extrude the aluminum, you might say, doesn't cost anything because as soon as you have bought 20,000 lbs of aluminum they give you back the money for the die. And even if you don't the dies are only about $400.00 apiece. When you are talking about tooling, $400.00 is peanuts. So you can change the size and shape of the aluminum at almost no cost to meet your specific requirement.

Q: You mentioned the rate of rise of the steel versus the aluminum, with the steel being longer. I was wondering if you had run any inductive tests on it. It is an interesting problem not only in car acceleration but also on a low grade, long time fault where the joules of energy is substantial and puts tougher duty on the breaker than a close in fault with a high energy level or high current level at a short time rating. I think it is an area that many of us on the properties want to look into very carefully. We have done some measuring on those properties with 132 lb steel running rail and 150 lb steel contact rail, measuring about 8 microhenries per running mile. Just recently I was down on some short circuit test in Washington (WMATA) and their calculations turned out roughly to be about 6 microhenries per mile. They are using 150 lb steel contact rail and 115 lb running rail. I think the manufacturers could help us if they could give us some (inductance) values that could be used in electrical calculations.

A: J. Corl - That we can do. We have come up with some numbers, but I can't give them to you off the top of my head. All the numbers have told me is the reason that they have a problem with choppers is the rate of rise is too slow and the voltage is low at the same time.

Q: A. Houston, Maryland Mass Transit - There is another area, and that is circuit protection. If you have some values I'd appreciate it if you would forward them to me. I'm very much interested in this area.

A: J. Corl - Besides my own people who have worked on this, there is Don Gardner, City of Los Angeles, and Art Smith of Garrett. They have done some work on it also, and part of that was because of a problem they were having in Montreal. Art Smith was working in Montreal at the time, and he determined that the inductance was the reason for their problem. He's come up with some pretty good numbers too. Now if you give me your card, I'll get back to you.

Q: H. Decker, TSC - Excuse me for interrupting, but I'd like to state that if you have that information and would like to disseminate it, I will see that it appears in the proceedings of this meeting as an addendum.

A: J. Corl - Allright . When do you need that?

Q: H. Decker, TSC - In approximatly two weeks.

A: J. Corl - Fine, I'd be glad to do that.

Q: You also mentioned that you had some data on current distribution in the contact rail.

A: J. Corl - Yes, around the fasteners.

Q: You also indicated that you had data on a short circuit test that you made on composite rail.

A: J. Corl - Yes, there is data on aluminum and stainless rail. Doing it on steel rail, I think, is spinning your wheels. It's been done 500 times. Yes I do have data on that.

Q: V. Mahon, BART - Jim, I think it's important to mention that with our order for BART, on our configuration we in maintenance are really interested in seeing that the section we receive is compatible with what we already have. At any time we're liable to change it out because of a derailment. I think you didn't note why we went to that.

A: J. Corl - You're right, I did not cover that. This fits in beautifully with the fact that if you don't like it exactly this size all you have to do is extrude a different piece of aluminum. What we do is extrude a different piece of aluminum, and that is what we did to insure compatibility between your existing system and the new lower resistance rail.

Q: Just one other thing, on your extrusion, is that cold rolled extrusion that you are using or is it hot rolled that you are getting the close tolerances with?

A: J. Corl - Hot, and then it is stretched. It is put hot on a table stretcher and they really do a fantastic job. I've seen them do it and it amazes me that it comes out like it does. It's a beautiful job.

Q: I'm just going to say that you can't do any better with steel when running it hot unless you are very, very careful in quality control.

A: J. Corl - On either one of them, really. But they seem to take more effort to do that because even the mill tolerances in aluminum are close. For example, say on a 1 inch section, it is ±0.012 inches. Well, in the steel mill they measure with yardsticks.

Q: G. Gardvrits, Sverdrup & Parcel - In the life cycle analysis, comparing any recycling features -- (inaudible) --. For example, when the stainless steel wears down, do you discard the aluminum?

A: J. Corl - From the labor standpoint, yes. You could save the aluminum and put stainless steel back on it. And I'm sure by the time you finish doing that, it would cost as much as new rail because the scrap value of the aluminum is high compared to new aluminum. You are paying 70¢ a pound for new aluminum and the scrap value of aluminum is about 25¢ a pound. So it doesn't pay to tear it apart. I don't like to say it, but its a throw away item.

Q: What do you think of end approaches for aluminum-steel rail?

A: J. Corl - We usually use just the straight rail. We half cut out the web and bring the head down just like you do on steel ones, or we just bend it down if there is enough room in the guideway.

Q: You use steel end approaches?

A: J. Corl - Yes, and having nothing to do with that particular rail, I personally prefer (electrically) isolated end approaches. There are pros and cons on that subject, too.

Q: Do you use a different extrusion or other formation for end approaches?

A: J. Corl - No, none at all. We use the same rail.

Q: D. Newman, NYCTA - Is there any problem in connecting copper cables to aluminum sections?

A: J. Corl - No. We use a tin plated flag. In other words we use tin plated aluminum to hook up the copper cables to, and you use an aluminum to copper connector. Burndy makes them and Porter makes them.

MBTA EXPERIENCE WITH COMPOSITE RAIL

Edward J. Rowe

MBTA EXPERIENCE WITH COMPOSITE RAIL

Edward J. Rowe - Power Engineer
Massachusetts Bay Transportation Authority

A few weeks ago I asked the Power Engineering Division to run a resistance test on the composite rail that we had installed. For some reason or other the thing didn't get done. On this past Monday when I returned from vacation, I found that it wasn't done. I was told that it wouldn't be ready for Wednesday, at which time we changed signals immediately. Yesterday when I came in, the supervisor came down and said we ran the test last night and things look pretty good. He said the resistance was an ohm per thousand feet. I sat back and thought for a couple of minutes after he left the office. Then I went running upstairs and said that at an ohm per thousand feet we can't run any trains. I asked if he realized what the IR drop is going to be on the rail. So we immediately went out in the morning and yesterday afternoon we found that the resistance of our composite third rail is just the same as the day we installed it--about .002 ohms per thousand feet. Some areas were a little less, some areas just a hair above. We measured .0023, and I think we had another area that was .0021. It appeared that the resistance of our composite rail which has been in transit service for about 2 to 2 1/2 years is remaining constant. I will be talking a little more about that. We were sure it was going to be that way as the result of some testing we had done between 1969 and 1972.

For many years the authority's standard for third rail was 85 lb ASCE steel rail. We like to rate it at about 812 thousand circular mils, a little under a million circular mils. We round it off and say it is worth about a million circular mils of copper equivalency. This was installed originally in the main line, which is now called the Orange Line, in the early 1900's, and the majority of that rail is still in service. There are some areas such as on curves where, due to the leaning over of the train and other reasons, we have had to replace it. But generally speaking, most of it is still in service and we expect it to stay there for quite a while.

Shortly after I joined the Authority, we commenced a testing program of composite third rail. This would prove to be the largest testing program of its kind the authority had ever undertaken for anything. After we started I don't think anyone ever realized how extensive the testing program was going to be.

We set some goals which we felt the third rail that we finally selected had to meet:

1. Be compatible with existing third rail.
2. Operate with existing transit vehicle third rail collection systems.

3. Be unaffected by the use of steel third rail ice scrapers.
4. Have a life expectancy of at least 60 years.
5. Have a very low maintenance factor.
6. Provide an acceptable means by which we could connect our 1,000,000 cir mil existing cable system.
7. Be economically feasible.
8. Have the ability to be installed and removed for maintenance purposes utilizing our standard maintenance procedures, equipment, and personnel.
9. Maintain low electrical resistance throughout its life.

During our testing program, which lasted over six years, the authority tested many rails made by different manufacturers. I brought some samples today. I see a few others around like them, but we had some that I guess no one else tested.

The first section we tested was manufactured by the Cleveland Crane Company. It was basically a rail that was used in overhead crane systems. It consists of a structural tee with an extruded aluminum body. The aluminum is riveted to the steel every 18 inches. We tested this for about 2 years. The problem that we found was that the rail was wearing on its edges due to our third rail collector system. The shoe on the car has a radius of 12 inches and this rail was flat on the top and wearing on both edges.

After Cleveland Crane we heard from other manufacturers. The next piece that we tested lasted about 3 weeks and was manufactured by Alcoa Aluminum. It is a straight aluminum extrusion. Some other properties I believe tested a similar type except that it has some carbon content on the top. Now I don't know how the carbon was put in the top. This sample was put in service in October. We had ice, and the authority uses what it calls an ice scraper - a piece of metal on the train that is placed in contact with the top of the rail to remove the ice by scraping. The next morning we were quickly called out to the test site and somebody said there was aluminum all over the place. The ice scraper acted like a miller, shearing little pieces of aluminum off the top of the rail. That piece of rail came out that very day. It was very unfortunate that it worked out that way.

We next went into a testing program with Kaiser, and this lasted quite a period of time. We wound up testing quite a few pieces of Kaiser rail. The first one, I believe, was their BART prototype. I also think we were probably one of the first to get it. I believe Chicago tested it also. It was a pair of baby channels welded back to back. The Kaiser principle has been, or was, that they molded the aluminum around the rail and I believe they did it in a vertical position. The web of the rail has a hole in it every 3 inches into which the aluminum flows. Due to contraction of the aluminum from the sides of the channels on cooling, Kaiser went back and pressed the aluminum back up against the steel so that they had a very, very solid bond to the steel.

We felt that at that time, and feel today, that this is a basically superior method of putting the aluminum on the steel. This didn't work out for us, with this type or even 85 lb steel ASCE third rails. The problem that we were advised of with the ASCE third rail is that it was not economically feasible, and we were told that there were some engineering problems associated with the contraction of the aluminum from the steel due to the heavy head on the 85 lb rail. The mass of the head of the steel rail is quite a bit greater than that in the bottom, and you have some fabrication problems.

What happened to this piece of rail that actually came out of service was that it wore down. Since the rail was symmetrical it could be seen what the original piece looked like. The amount of wear in 8 months on our property could also be determined.

Kaiser wasn't about to give up, and I don't blame them. At the same time we were testing that piece of third rail, Kaiser produced prototype samples of an aluminum rail with a stainless clad head on it that adhered to the top of the aluminum. This cap lasted less than six months. What happened was that the stainless cap wore off in our application and we were down to the basic aluminum. As I recall it, this is one-sixteenth of an inch thick and I believe that it was a 300 series of stainless.

The final section we tested for Kaiser was their prototype, original rolling they had made of the BART rail. It is 3,000,000 circular mils. We tested the six million circular mil rail also. This I believe remained in service about 18 months. Again, the Authority experienced excessive wear on the head of the rail. The piece that we took out was substantially worn. We continued to tell all the manufacturers that we felt that we needed a substantial head or wearing service on the rail and we were indicating to them that there ought to be at least an inch thick wearing surface. This was from our 60 to 70 years of experience with third rail systems.

Two other manufacturers came along, almost at the same time. The H.K. Porter rail was a basic 85 pound ASCE steel rail with Huck bolted aluminum extruded side pieces. The rails were standard 39 foot lengths and the joints were also Huck bolted. This rail remained in service for about 2 years. It had excellent properties, excellent wearing characteristics, resistance, etc. There were no problems that we experienced with the test section of that third rail. About the same time we tested its complement, which was Insul-8-rail. There original rail used the same principle except that they used a nut and bolt fastener instead of a Huck bolt. We didn't have any problems with this rail.

After some six years of testing, we really reached two basic conclusions that were very, very important to us. Number one, we felt that we had to have a wearing surface or head as you might call it, on a rail at least one inch thick. Regardless of the type of steel that we tested, regardless of the laboratory tests that were performed by the various manufacturers, the tried and the true tested method out in the field shows that all our convictions were true: that we had to have at least an inch of wearing service in order to meet the 60 year life criteria. Number two was that the radius of the head of the composite rail had to be compatible with that of the rest of the third rail which was going to be used with the same transit vehicles on that line. That is, if the rail was 85 pound ASCE and had a 12 inch radius, the composite rail had to have the same radius. If it was 24 inches like the New York City standard that we also use, then the composite third rail had to have a 24 inch radius head. We did conclude that for most of the test sections that the resistance of the aluminum--steel rails remained constant. This didn't appear to be the big problem that everybody had anticipated.

By 1972 we had completed what we felt was adequate testing to make a selection. The authority issued plans and specifications for competitive bidding for the H.K. Porter or Insul-8 type of third rail. Also included in the bidding documents was a proviso for a manufacturer to supply the authority with the Kaiser type third rail which has the aluminum side pieces that are cast in place. However, upon opening the bids none of the bidders chose to bid that type of third rail. H.K. Porter was subsequently awarded a contract with UMTA funding for 89,000 feet of 0.002 ohms per thousand feet composite third rail, 600 end approaches and another 400 terminal pad assemblies, all the accessories excepting the insulators and any other hardware that would be attached directly to the ties.

Prior to the selection of the composite third rail for our Haymarket North extension, the authority had intended to install the Bethlehem 150 lb NMC New York City standard third rail. We had intended to originally build a traction substation at Community College, which is the first stop on the Haymarket North extension. In addition to that, in a few remote areas some supplementary cable was recommended by the consultant who was working on the job. As a result of our selection of composite rail we were able to eliminate this substation and the supplementary copper that was recommended. It saved us a mere million dollars in 1972. I wish we could buy a substation for that kind of money today. And not included are costs for the 215 thousand volt power services that were to run a mile and a half from Sullivan Square.

During the testing period there was still some apprehension of the electrical resistance of the composite third rail, the joints, and the resistance between the aluminum and the steel. During the bidding process we found an old piece of the H.K. Porter third rail that had been removed for a year or so and had been lying in the dirt in the yard and we brought it into the laboratory. We tested the sample. We used a water barrel method of testing which gives us high current with 600 volt DC. Using the millivolt drop method we determined that in the three or four year period that it had been on the property since its fabrication and test, the resistance and the resistivity had remained constant and that there was no increase at all. It left everybody happy.

As part of our specifications the authority required that the manufacturer perform a 500-hour salt spray test on his third rail, test the resistance both before and after the test, and in addition perform the same test on the terminal pad assembly to which we attach our one million circular mil copper feeder conductors. H.K. Porter did this successfully. There was no apparent change in the resistance of the rail or any of its properties other than its appearance.

All during our testing program and the design phase of the Haymarket North power project we looked into methods of allowing for expansion and contraction in the third rail system. We felt, then, and still feel today, that any mechanical type expansion joint has a high maintenance factor. So we decided at some cost to merely put a 3 foot gap in the third rail at expansion points, and we tie around it with copper conductors which run in a conduit, or run exposed on a stanchion. You'll see this when you go out and look at the installation tomorrow on the Haymarket North extension. It's probably quite a bit more costly, but there is no maintenance to it whatsoever. We just put two end approaches or risers, whatever you want to call them, one on each end, and leave a 3 foot gap. It works out fine for us. I'd say obviously the cost is quite a bit greater, but maintenance is one of the prime factors. We felt that the mechanical joints that were examined by the authority required regular maintenance.

Finally, we were ready for construction. And I have a little story to tell. I was asked to give a talk to the IEEE Boston Power Society. In preparing a slide presentation which happened just before we started to install the rail, I asked H.K. Porter to give me some slides. One of the slides they provided said you can put a joint together in three minutes. I was sitting at home one night looking at it, and I said that this is a lot of baloney. I threw the slide aside and said I'm not going to put that kind of sales talk in my presentation because I don't believe it. Well, I was wrong because the installation of the composite rail went along so fast on that extension and it worked out so well that we had difficulty keeping up with the contractor to count how many feet of third rail he had put in. Even in the most severe weather conditions--and we were out one day when it was below zero in the winter, a group of about 50 people--the contractor was moving right along without any trouble. I believe he put in between 2,000 and 3,000 feet in one day with a 5-man crew.

The selection by the authority of the 85 lb composite rail was very well founded because the hardware items, that is the insulators, the electrical items that attach to the third rail, the lugs, and the other accessories are all standard. We use them on the other third rail systems in the Authority, and therefore our maintenance stock can be kept at a minimum. The only specialized thing that we had to use was the Huck bolt and the Huck bolt machine. Many of the people in the Authority were very apprenhensive about its use, the time element, the removal of the Huck bolts, and how rapidly we can put Huck bolted joints together. Our experts so convinced the Authority that we bought three machines for use in our maintenance of both power and right of way systems.

The biggest problem that I had with the contract our there, if we are looking for problems on installation, was for us to get the contractor's people to clean off the joints prior to applying the no oxide paste. He just didn't think it was necessary but we continued to insist that they clean the aluminum thoroughly before applying the no-oxide. It was a basic policing problem. I cannot think of any other difficulty we had. The only other difficulty was self-imposed when we knocked a piece of third rail off with a snow plow one night. But we reset the same piece of third rail the same night.

Now as to the installation cost of our system. I would say that based on experience on our South Shore with 150 lb NMC (NYC standard) third rail and on the Haymarket North Extension with composite rail, the cost to install composite rail was quite a bit less than the cost of installing steel rail. The composite rail is a lot lighter, a lot easier to put in. It weighs about 105 lbs a yard vs 150 lbs per yard. We used exothermic welding on 150 lb rail joints. They are a lot more expensive and time consuming than Huck bolted joints. So our cost figures show that composite rail is less expensive to install.

I guess the next hurdle that we had to get over was the bending of composite rail. We bent a couple of pieces in our shop before we made a selection and it looked pretty good but our bending facilities were not ideally set up to bend composite third rail. It was left to the contractor to bend satisfactorily the sections that were required to be bent during the installation and we had to demonstrate to the Authority that he could do it. We supplied him with a couple of sections. So during '74, I believe it was, the contractor shipped several pieces to Bethlehem Steel's shipyard over in East Boston. They have a special bending rig which we saw, and they bent the sections without any problem. We could not determine any mechanical or electrical failures or stresses that were set up as a result of the bending operation, and there was no separation of steel and aluminum. I believe the bend was about 350 foot radius.

Finally, we got our big day. I don't think I was ever so nervous in my whole life because I had worked on the whole extension and I said I didn't believe this day was coming. I worked on the Haymarket North extension from 1968 to 1975 without seeing a train run. The Governor and everybody else was on the train, and I said if this thing doesn't go I'm in big trouble. And to boot, my boss at that time, the director of construction, before he got on the train said to me "I'll bet you it doesn't work." But all went well. It was the first time that we had run a four-car train on the extension. It was jam-packed with all kinds of dignitaries on the inaugural run of April 2nd 1975. Then on April 6th 1975 the extension went into operation in revenue service and has been in good operating shape ever since then.

Historically in the authority we are told that we're operating in a two hat mode, that is the construction hat and an operating hat. This means that others build it, meaning the construction people, and we, the operating people, have to operate it, and live with the "junk" that those people give us. This is probably a cry in every Authority in the country, and believe me, when we were the constructors, and I was a constructor, I heard about the junk I gave the operators. Now that I'm both an operator and constructor I can't say anything about either.

Fortunately the power system on the Haymarket North extension worked out well. We had minimal operating problems with it. Our maintenance people were apprehensive about the use of anything new, composite rail or whatever it is; if it's new it's "no good" in many cases. Now our track department, not the power department, replaces third rail systems. The power people attach the power cables to the third rail, and then the track department owns the third rail and the insulators and the joint bars and everything else. About 8 o'clock on Friday night, about a month after we've been in service, who's on the other end of the telephone but the supervisor of track maintenance. He said there's a piece of your third rail lying on the ground, you better get over here in a hurry. So I got there in a panic, and all he wanted me to do was borrow some insulators from the contractor to reset it. That was our first derailment on the extension. The maintenance people had no problem whatsoever in replacing the composite rail. Subsequently we had two or three derailments and the maintenance people are handling this third rail probably easier than they handle the 85 pound rail. It's very, very simple to maintain as far as replacement is concerned. They just take a hammer and a cold chisel and knock the collars off the Huck bolts, drive the bolts out and pull out the piece of damaged rail and put in another piece of rail.

Some people who aren't familiar with third rail systems might ask if we have to clean the rail. There is no periodic cleaning required of the third rail. The only cleaning that is required is of our insulators that are in subway tunnels where we build up an accumulation of brake shoe dust on the insulators, and about every three years we have to wash off the insulators in the tunnels.

Outside, in the air, they get washed off naturally by rain and snow. Other than that there is no maintenance whatsoever to the third rail system. I suppose that after seven to ten years we should go back and regage it. This is normal standard procedure that all Authorities use to check that the third rail and its relationship to the running rail is correct, both in height and distance from the running rail.

One other thing that we were told was that the no-oxide paste was going to leak out all over the place and your right-of-way is going to look like a grease factory. Well, that didn't happen. Even we were apprehensive about it. We did some flash point testing and some melting point testing and we found that it would satisfy all of our requirements. You'll probably see tomorrow when we go out there that there are globs on the base of the third rail in places. That's the original excess no-oxide paste, as we specified, and it is the same as it was the day it was delivered. The contractor might have greased some on during joining, but it hasn't leaked out. You'll see very clearly that the no-oxide paste is exactly the way it was when it went in. The third rail itself has seen a very, very severe winter and a very, very hot summer, and it has been through a minimum of 2 and probably 3 winter-summer cycles because it was in about a year before we even used it.

There's no question in my mind, and maybe I'm overselling it, but it is a really fine item. I think that we have directed all our consultants that are doing extension designs for us to consider the use of composite third rail. We're most concerned that they are economically conscious. We feel that the new extensions, both the northwest and southwest, will more than likely utilize this type of third rail.

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Following Mr. E. Rowe's presentation, there was a period devoted to questions and answers.

Q: R. Ganeriwal, DeLeuw Cather - You mentioned the use of expansion gaps rather than expansion joints. Do you have any problems with the shoes breaking off? Do they break off shoes more often (than expansion joints)?

A: E. Rowe - No, the shoes just go up a small rise and stay there, then drop down and then go back up again. We have very, very low breaking off of shoes. I have only seen one or two.

Q: R. Ganeriwal - Are they simple to repair?

A: E. Rowe - Oh yes, no problem at all.

Q: R. Ganeriwal - How often do you have these expansion gaps?

A: E. Rowe - 1200 feet on curves and 1500 feet on straight-away.

Q: R. Ganeriwal - I think that's the operation you're having no problems with?

A: E. Rowe - No problems at all.

Q: Do you use a 5 foot 6 inch end approach?

A: E. Rowe: It's 8 foot total length, but the rise is in a 5 or 6 foot length.

Q: And what's your speed, there, now?

A: E. Rowe - The maximum speed we reach over that part is about 50 to 55 mph. They're high speed runs, so we use a high speed end approach. We were using a three foot end approach, which had a very, very rapid incline, and the high speed end approach has a very shallow incline.

Q: A. Wacker, LIRR - You mentioned that you put in bolts in all weather conditions. Can you apply the grease when it is raining?

A: E. Rowe - No, you can't, not when it's really raining heavy. During a day like today, if it rains a little bit, it's no problem, but if it's really coming down, you can't do it. Not only that, but the union doesn't work in the rain.

Q: A. Wacker - What do you do in the case of a derailment? Do you have to wait until the sun shines?

A: E. Rowe - We put it in. In the case of a derailment, you do everything you can to get the line back in service.

Q: D. Newman, NYCTA - You made a decision to eliminate a substation when you decided to go to composite rail. Can you make an estimate of what your energy savings would have been had you left the substation in and went to the composite rail?

A: E. Rowe - I think that you wouldn't have an energy savings, I figure you would have an increase in cost. Are you just thinking of the added resistance of the third rail between the two substations?

Q: D. Newman - I'm saying if you use the composite rail, with low resistance, and still kept your substation in place, rather than not constructing one, did you estimate what your energy savings might have been over the years?

A: E. Rowe - I hate to say it, but I have a little difficulty understanding the question.

H. Decker, TSC - If I understand the question correctly, it's that you are looking for a trade-off between the energy lost or saved versus the cost of the added substation. Is that correct?

D. Newman - Yes. That is correct.

A: E. Rowe - I'd say that there is insignificant (?) to be (inaudible)?

Q. A. Wacker - Are you in a position to give us the cost of rail that's on a separate order? What did it cost you?

A: E. Rowe - What the rail itself cost? We did it on a supply contract and a separate install contract. I know what those figures are, per foot, if you'd like.

Q: A. Wacker - Yes, the supply contract.

A: E. Rowe - We're talking about 1972 and 1973 dollars, so you must remember that. It cost us $10 a foot to install it, which included the insulators and any other accessories. The anchors were also included in that figure. The supply costs were $8.50 a foot, I believe.

Q: A. Wacker - For the composite rail?

A: E. Rowe - For the composite rail.

Q: A. Wacker - Including the end approaches?

A: E. Rowe - No, the end approaches were separate. The end approaches were $8.50 apiece, something like that.

Q: A. Wacker - Eight dollars and ---?

A. E. Rowe - Yes, $8.49 or $8.50 a foot. That was for 0.002 ohms per thousand feet rail.

-END OF QUESTION AND ANSWER SESSION-

CTA EXPERIENCE WITH COMPOSITE RAIL

Ronald O. Swindell

CTA EXPERIENCE WITH COMPOSITE RAIL

Ronald O. Swindell, Superintendent of Power and Way
Chicago Transit Authority

I want to tell you our experience with our Evanston branch. We started installing composite rail on this back in 1973. I'll show you, first of all, what we're talking about.

FIGURE I
CHICAGO TRANSIT AUTHORITY RAPID TRANSIT SYSTEM

Figure 1 is a map of the Chicago Transit Authority rapid transit system. It includes about 200 miles of third rail. The portion we're talking about is darkened at the top, which is our Evanston branch, more detailed as in Figure 2,

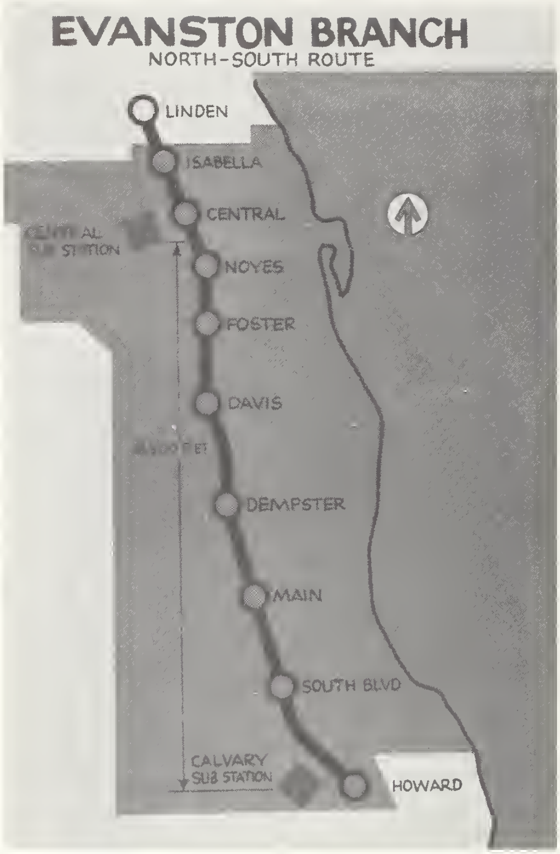


FIGURE 2
EVANSTON BRANCH

and has about six miles total of third rail, three miles each way. We're very, very poorly situated, as far as our substations are concerned. They are some 16,000 feet apart, which is way in excess of what we feel we should have. Evanston was originally a trolley wire line.

During the latter part of 1971, the Chicago Transit Authority determined it was economically sound to replace approximately 6 miles of trolley wire on the Evanston Branch with third rail. Factors entering into the decision were such items as the maintenance of the trolley pole mechanism with the old 4,000 series rapid transit cars, the differential cost between the maintenance of third rail and trolley wire, the wages paid to employees to raise and lower trolley poles at the end of the line and the fact we did go from there (at Howard) into a third rail system. We ran some cost figures on this, and we felt that, at that time, we'd save about $144,000 a year in labor costs by changing to third rail, so it's rather obvious that we did want to change to third rail. In addition to the dollar savings that we realized, we also decreased our time between one end of the line and the other because we no longer had to put up trolley poles or take trolley poles down. It also became a much more reliable system. We didn't have to worry about a sleet storm taking a trolley wire down, as we had in the past.

FIGURE 3
TROLLEY WIRE SYSTEM

Figure 3 is a picture of the old trolley wire system. You can see it's a span type system. It's not catenary system, and it does create more problems with ice and snow than a catenary system.

FIGURE 4
TROLLEY POLE ON 4000 SERIES CARS

Figure 4 shows one of the men putting up a trolley pole or taking it down, I'm not sure which. Now if we were running a one or two car train, one man would take the pole down. If we had a four or six car train, we had to have men stationed on the platform to do the alternate two car sets, so we did run into quite a bit of money.

Once we decided to go into third rail, we had really three alternatives, and we'll get back to talking about standards.

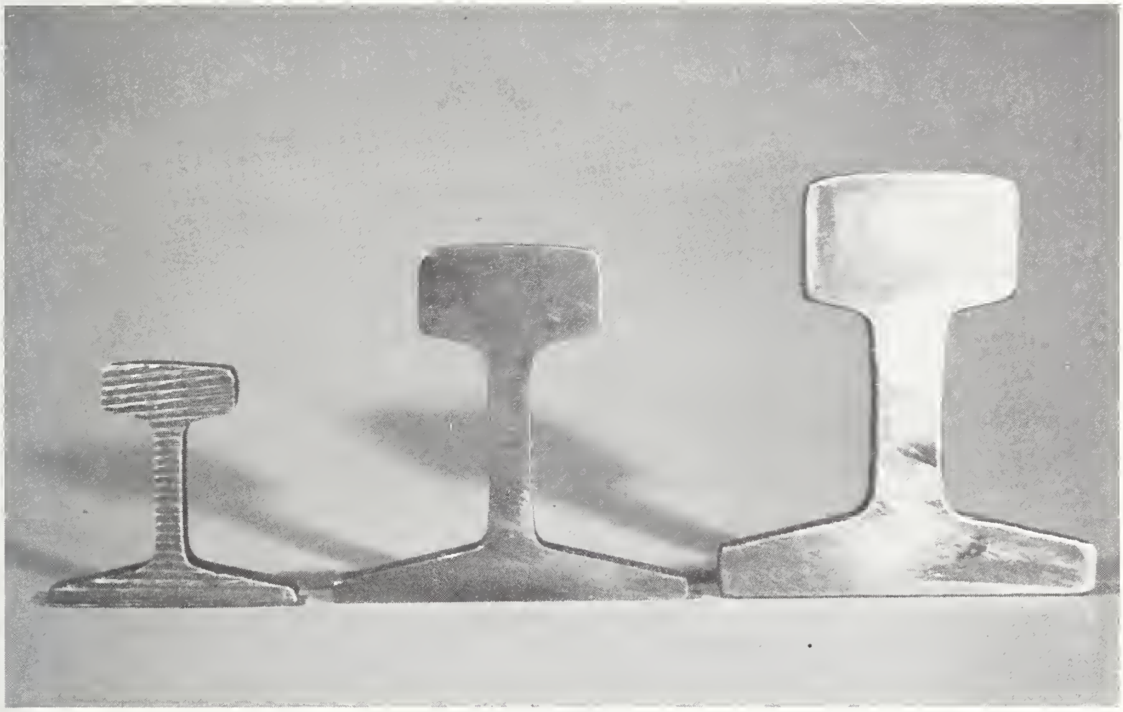


FIGURE 5
CTA STANDARD CONTACT RAILS

Figure 5 shows our standards. The rail on the left, is a 48 pound rail which was a standard but we haven't used that in years. The rail in the middle is an 80 pound rail, and again, we talked about rail ampacity or electrical capacity, and its copper equivalent. That is equivalent to 800,000 circular mils of copper. The rail on the extreme right is 144 pound steel rail. Now that's a low carbon steel rail. It has an electrical capacity of 2,300,000 circular mils. Now other alternatives that we had were to go to some kind of an aluminum-clad rail, or some kind of a composite rail. Incidentally, we did test at one time a copper clad rail, which was heavier and more expensive than anything we ever tested before. We decided that we would take a look and see what was available. We started testing and Boston's efforts seemed to go on about the same time on parallel paths, and to my knowledge, with not too much communication between us. We, I think, did talk about it occassionally, but we tested our system, they tested their system, and generally we came out with the same opinion of what we were testing.

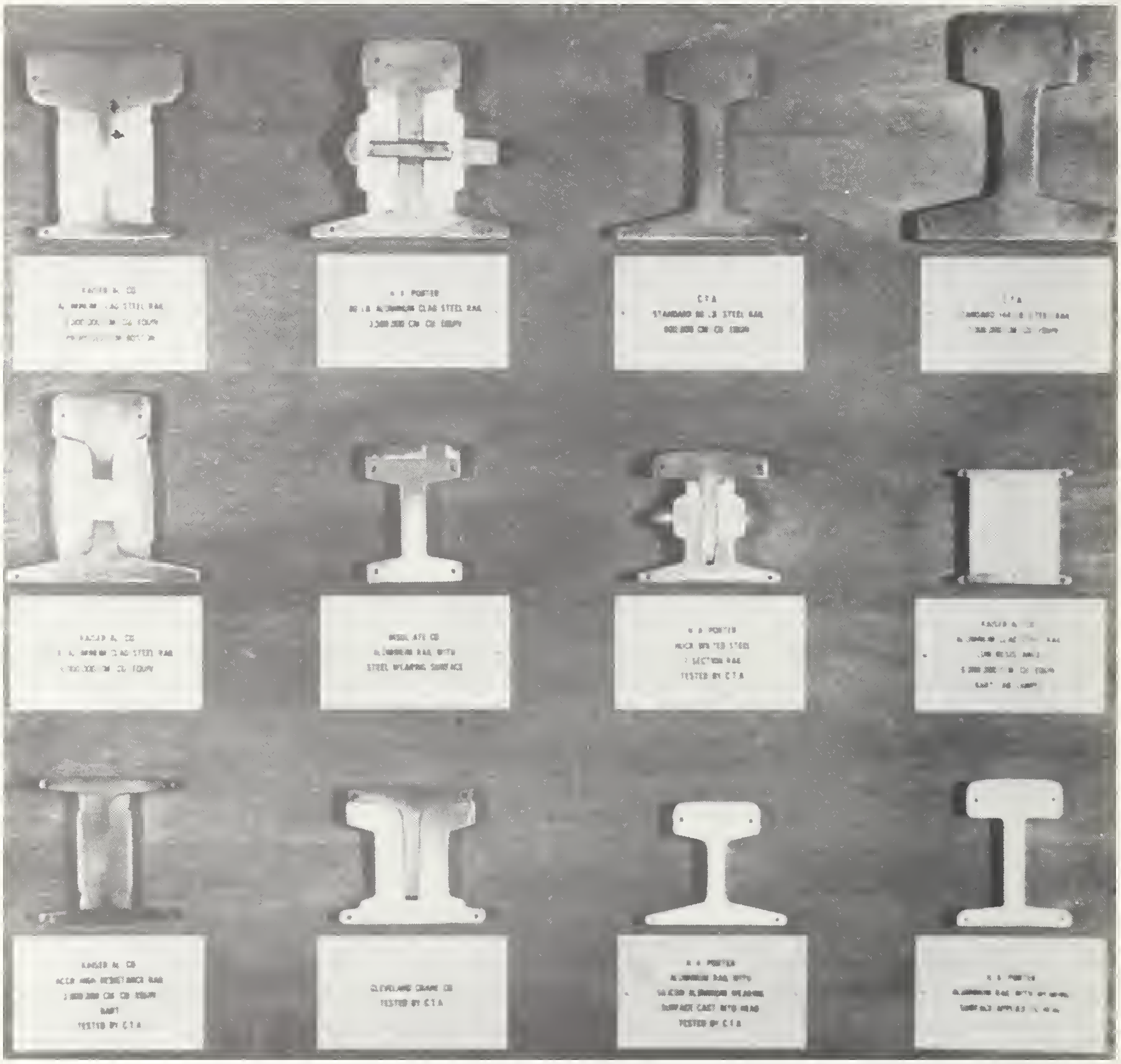


FIGURE 6
CONTACT RAIL TYPES

Figure 6 shows the rail types available. On the lower left is a Kaiser rail similar to what is used on BART, which we used on our system for two years. We tested it and told the Kaiser people that the head was going to wear out too soon. I think that every few months they came out and told us we did not know how to measure the rail, because it was obvious that we were wrong, and that our worries were premature. To the right of the Kaiser rail on the lower tier is the Cleveland Crane rail very similar to the one Boston showed you, with a very narrow head. The rail itself seemed satisfactory, and its conductivity very good. But, again, the head was small and it wore out. Next to the Cleveland Crane rail is an H. K. Porter rail with a silicon-aluminum insert in its head. The idea behind it was that as the rail wore out the silicon would become impressed more and more into the aluminum, the rail would become harder and harder, and would wear less and less. I'll show you a slide of that a little later. In the upper right tier are the two standard rails used at C.T.A. The rail we finally ended up with is the H.K. Porter rail displayed in the upper tier just to the left of the C.T.A. Standards. There was an attempt by Kaiser Aluminum to give us something with a thicker head. What they did here was to take one of their other rails and weld a steel head on it. Now we thought well, maybe that's alright. We were a little concerned--and this is where we differed from Boston --about this method of putting the aluminum onto the steel. The problem with H.K. Porter rail that we were concerned with was that, if we got heating and cooling of the rail and differential expansion, we might tend to create gaps between the aluminum and steel, with no way to get them back again. That's the type of thing that we went through over a period from 1964 until we finally decided on what we were going to do.

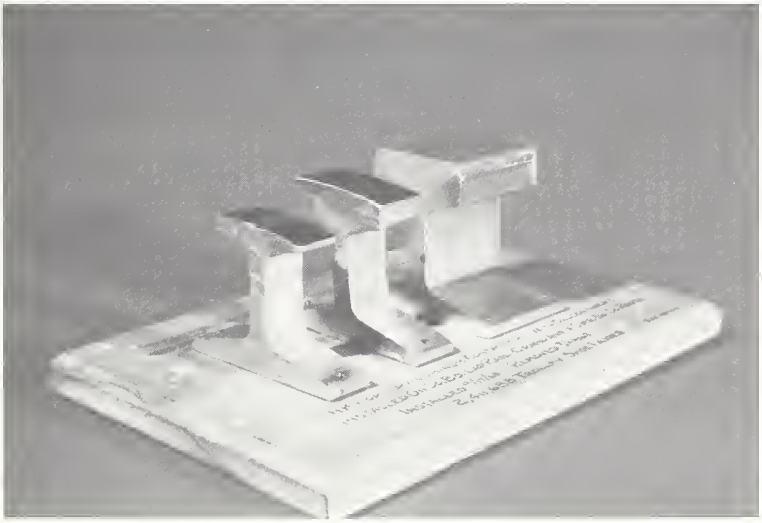


FIGURE 7
COMPOSITE RAIL WITH SILICON INSERTS

Figure 7 shows the aluminum rail that H.K. Porter gave us about two years later, with the silicon inserts on your left. Now I don't show this to embarass H.K. Porter or anyone else. Really the reason I show it is to tell you that the manufacturers involved, be it Insul-8, be it Cleveland Crane or H.K. Porter, were interested in what we were doing, and still are, and this was just one of many, many different types that we tested. The problem here is that the silicon might have pressed back down into the aluminum, and become more compact, if we didn't run an arcing shoe over it. As we understand it, and what we feel, is that the shoe arcing as it ran along the rail,--and believe me, they will, you can't ever get anything smooth enough to prevent arcing--would cause the aluminum to puddle, and when puddled, the silicon brushed out. The rail lasted about two and a half million shoe passes, or a little over two years, on our property. So that idea was abandoned.

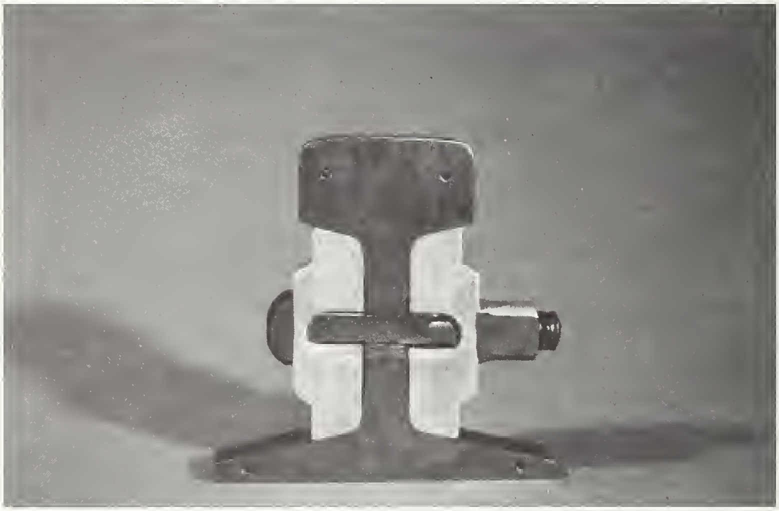


FIGURE 8
COMPOSITE RAIL SELECTED

Figure 8 shows the rail we finally settled on. We decided on 80 pound steel rail because we wanted it to match other rail on our existing system. It's what I pointed out to someone today who asked why do we run 600 volts on our system. Well, we run 600 volts because in 1908 someone put in 600 volts, and all our equipment is now 600 volts. You don't change a whole system for a new product. This system worked out very nicely for us: we could use our existing third rail chairs, we could use our existing bonding techniques for putting our cable on, our existing anchors for the third rail system, and we knew how to handle the rail. We knew what we were getting into.

Now, let me talk about some of the things that we did to justify the use of aluminum clad third rail, or see if we really needed it. We did run some comparisons on our system.

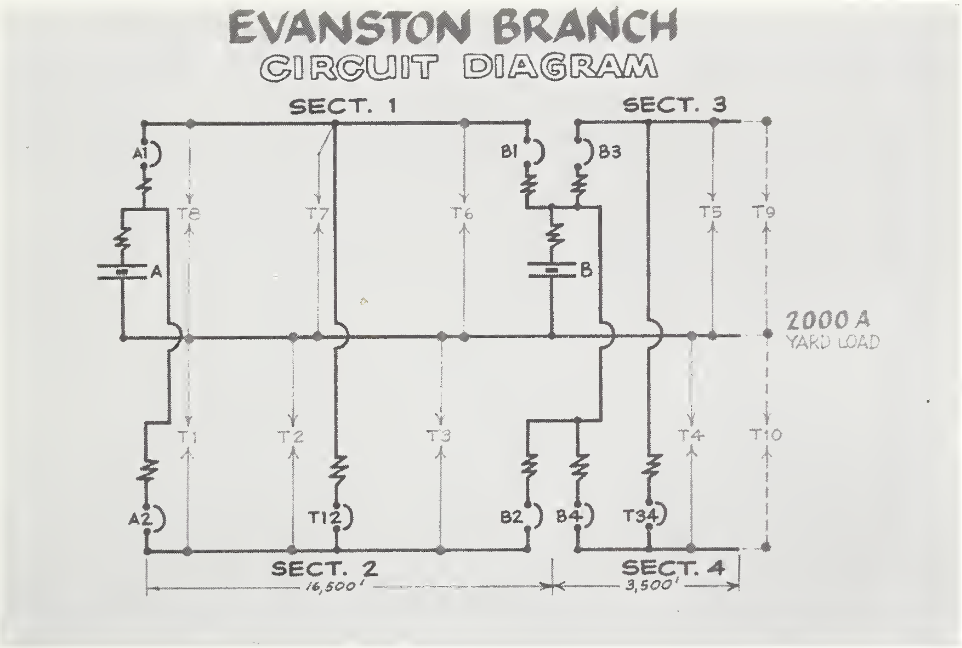


FIGURE 9
EVANSTON BRANCH-CIRCUIT DIAGRAM (SIMPLIFIED)

Figure 9 shows a circuit diagram of the Evanston branch; very, very simplified, but nonetheless the type of circuit diagram that you can put into a computer. We did put this into our computer, ran sample trains on it, spaced the trains according to our headway, and we had them start and stop at various times. When you're looking into this, you've got to look into your signal systems, your interlocking plants, your entire system. You can't look at the aluminum rail and say, that's one unit from here to here. It involves a lot of research, a lot of time. It's quite obvious, I think to all of you, by now, that since we had twice the ampacity on the aluminum clad rail, we did have improvements. We found out, for instance, that on this relatively short branch, we would save something like 216,100 kilowatt hours per year. Now that's just the losses. At that time, they amounted to something like $2500 a year. Now it's escalated upwards. But those are the things that you've got to look at.

We finally went out for bids. We asked for three basic things. First of all, we asked for the aluminum to be put on 80 pound rail. Secondly, we asked for the rail to be equivalent to 4,600,000 circular mils of copper, which comes out to .002 micro-ohms per foot. Thirdly, we asked that the resistance of the joints be no greater than the resistance of an equal length of rail. In other words, the joint had to be 100% efficient compared to the rest of the rail.

FIGURE 10
ACKNOWLEDGEMENT OF UMTA GRANTS

We started construction April 5, 1975, and quite frankly, we're very, very thankful to UMTA (Figure 10), without which we, and I'm sure several other transit companies in the United States, would be in very serious trouble. We originally thought that we could install about 40 pieces of rail a night. We were working at night because we were running trains all day long over this branch. We ran trains on the track next to us during the nighttime when we were putting the rail in. We ran single track and we did our work without very much interruption of service. Our estimate, which gave us a figure of about a dollar a foot more for aluminum clad rail than for 144 pound rail, was based on that estimate of 40 pieces a night. The very first night we went out in the field, we installed 80 pieces, and in one 12 hour period, we put in 161 pieces. The reason for this is the Huck bolt. We were basing our estimates on the plain steel rail and on the aluminum clad rail, with Huck bolting, without really much knowledge of what it was or how long it would take. We found out that it takes about 12 1/2 minutes to bolt two pieces of 144 pound rail together, using conventional track bolts, washers, etc.; it takes us about 2 1/2 minutes to put two pieces of aluminum clad rail together with a Huck bolt. Now, I can't say that's a good reason to buy aluminum clad rail, because we now use Huck bolts on the steel rail, and it takes us 2 1/2 minutes to put two pieces of steel rail together. But we didn't know that then. The other savings that we realize is due to the absence of a requirement for bonding third rail joints. We no longer bond our third rail joints. It took us about 15 minutes to bond steel rail joints;

that's to put two bonds on it, one on each side, that will give us a current-carrying capacity equal to that of the rail. That's two less men we have on the job because they're no longer required.

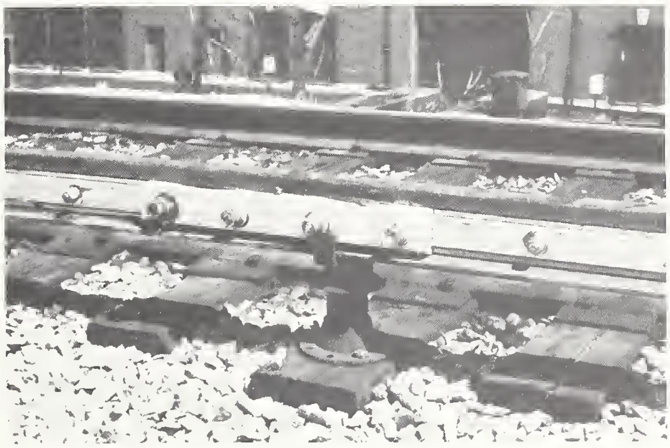


FIGURE 11
COMPOSITE THIRD RAIL JOINT

Figure 11 shows a typical joint. We clean the joint with steel wool and a thinner, apply as much no-oxide as can be put in there, and then put the Huck bolts in. You'll notice one thing that we have done here, and I don't know if anybody else does it. We put all the Huck bolt collars on the outside of the rail, so that if there does happen to be a problem of shoe slipping off the rail, it will generally fall on the inside. If it does go on the inside, we don't want it to hit the Huck bolts and knock the collars off, and add damage to the car itself.

FIGURE 12
INSTALLATION IN PROGRESS

Figure 12 is a view of the installation before planning any third rail. The picture shows you our third rail chairs, probably the only major mistake made in the installation. We used what is called a Blair chair, which is of maple block with a steel top casting and steel bottom casting. If we were doing it over again, we'd use our standard subway construction, which uses a porcelain chair. The maple block tends to get waterlogged after a while, and will arc across and subsequently burn. Now that causes no serious damage. We go out and knock out the bad chair and put in a new one. I think that in this case, we would have been well advised to go to porcelain. But we use maple block on the elevated structure, because porcelain has a tendency to break. If it does break, we don't want to get any people hurt down below the structure. On the surface, generally, with this one exception, we do use the porcelain third rail chair.

You'll notice in the upper right hand side of Figure 12 some feeder cable. The decision to go with aluminum clad rail or with steel rail did not take into consideration the fact that we already had paralleling cables in this system. We had to have the paralleling cable for the original trolley wire system. Had we left the paralleling cables in and still used the 144 pound third rail, we would have ended up with just about the same capacity we have with aluminum. The thing that we didn't want was the maintenance of these cables forever. I told you the difference in the cost between aluminum composite rail and steel turned out to be something like a dollar a foot or $36,000 for the installed rail--it was slightly over that. When we took the cable down, we sold it for scrap for $104,000. It cost us $30,000 to take it down. The removal of our maintenance headache earned us somewhere in the neighborhood of $70,000. These are some of the things that you must consider when you look into the entire job. This happened to be an existing line, and we were trying to do the best with what we had and improve upon it.

Since we completed the Evanston branch, we have installed an additional 52,000 feet of aluminum clad third rail, some of it on our main line which has our heaviest traffic. Because of construction we have had the opportunity to take some of those pieces of rail apart after they were in service for approximately a year and a half. We inspected them very carefully to see if we were getting any kind of moisture infiltration, or any resistance, any electrolytic action between the aluminum and the steel. We inspected the joints very carefully to see if there were any signs of heating or any signs of problems in the joint itself. We were a little concerned with the joints, and our out has always been that we could bond them if we had to. That hasn't been necessary. We really feel that the life of our aluminum clad rail, the way we have designed it, is 60 years.

The aluminum clad third rail has one advantage that a 150 or a 300 pound steel rail can never have. In a steel rail as the steel wears down, the electrical conductivity goes down rapidly.

A steel rail with an inch and a half thick head, by the time it wears down to the point where we throw it away, has lost the majority of its electrical conductivity. This doesn't happen with aluminum clad rail, because the major conductor is the aluminum itself. The steel portion of the composite rail will lose an equal amount of conductivity at equal wear points, but the overall conductivity of the composite rail will not be greatly decreased.

One of the deciding factors in going to aluminum clad rail on the Evanston branch was the fact that with 144 pound steel rail we had short circuit capacity of only 300 amps more than we expected our maximum normal load would be. This meant that we would not be able to effectively distinguish between a short circuit and a normal load, which would create a tremendously dangerous condition if we happened to have a short. With the aluminum clad rail, our short circuit capacity or short circuit current, if you will, was 1800 amps greater than our anticipated maximum load, which did give us some room to adjust our circuit breaker settings.

Like everyone else who is in the transit industry, we talk to other transit people. There was a rumor going around that, in particular, railroads had their Huck bolted joints falling apart. That came to us, and it got to our general manager. He asked about the condition of the joints on the Evanston branch. The same day we ran visual inspection, and were convinced that we had no problem. Two days later, we ran some electrical tests. Now we specified from the manufacturer that the composite rail joint would be equivalent in resistance to the same length of unjointed rail. We measured three feet across the joint, and compared that with three feet of unjointed rail down the track. We found that three feet across the joint was equivalent to the following unjointed rail lengths at different locations: 2'3", 2'4", 2'1", 2'6", 2'5", 2'4". In every case, the joint was better now than it was when it was installed in 1973. Now that settled it for my general manager, though it didn't satisfy me. I then began to think, did the joint improve, or did the rest of the rail get worse? And am I worse off than when I started? We went out and ran some resistance tests on the rail itself in the area where we had tested the joints. Our rail was specified at 2.3 micro-ohms per foot, and our test results varied from 2 micro-ohms per foot, up to 2.3, and on another track, down to 1.93. It looks like we are getting an improvement in the rail, and the only thing that we can attribute this to is the fact that we are getting improved seating between the aluminum and the steel and reducing the rail resistance slightly.

Now, I know we're talking about aluminum clad rail; but I want to say something about Huck bolt. I think the Huck bolt is a feature that's going to make its use on not only aluminum clad rail, but on any kind of rail, very, very advisable. It has cut our installation time down considerably, and right now, we're in the process of testing Huck bolts on running rail. If it's successful, we may be able to reduce the number of our track walkers that were discussed a little earlier.

One other thing that I want to point out is that your third rail system is only as good as your negative return system. I think that was pointed out by a speaker this morning. We have one location on our Ravenswood branch, very remote from a substation, where we have a yard. We are talking now about the possibility of buying aluminum clad rail, laying it on its side between the running rails like you would a guard rail, bonding it together at the ends, at road crossings, and using it strictly as a negative return system. We don't have a problem here with our positive, but we do with our negative return, and there are other applications for composite rail.

***

Following the presentation by Mr. R. Swindell of CTA, there was a brief period for questions and answers.

Q: R. Sheldon, WMATA, - I think you've partly answered one of the questions I had in mind, but what is the nature of your periodic maintenance? Is it just the track walking or the -- rail?

A: R. Swindell - For running rail--or for third rail?

Q: R. Sheldon - What is the nature of your periodic maintenance for your third rail?

A: R. Swindell - We really don't do any maintenance on the third rail system.

Q: R. Sheldon - Just look at it?

A: R. Swindell - Not unless it falls over. Our present policy developed twenty years ago when we cleaned chairs in the subway for the last time. One of the reasons we quit was not because we weren't sure we were doing any good, but people were complaining because the fellows would sit on the third rail and take a shoeshine rag and clean the rail between their feet. We just stopped, and haven't cleaned an insulator since. I don't think you have to, with porcelain insulators; they don't usually arc. If they get excessively dirty, they'll arc across and clean themselves, and you're back in business.

Q: Did you consider the capped aluminum rail at all?

A: R. Swindell - No, I think that's relatively new by Insul-8, and we did not have a chance to test that. My offhand opinion is that the head is very, very narrow. Without testing it, I wouldn't want to comment on it. One thing I want to say about tests is that you can run a test at a laboratory till hell freezes over, and not prove a thing. Kaiser Aluminum, for instance, sent me some rail. They tested it in a laboratory, and they were convinced it would last 40 million shoe passes, which in our system is somewhere around 35 years. We tested the same rail in our system, under atmospheric conditions, in rain, with arcing shoes, and bouncing shoes, and different shape shoes. All these things bear on the amount of wear you're going to get on a rail. Our indications were that it would last about eight years.

-END OF QUESTION AND ANSWER SESSION-

BART EXPERIENCE WITH COMPOSITE RAIL

V. P. Mahon
H. Fleige

BART EXPERIENCE WITH COMPOSITE RAIL

V.P. Mahon - Director, Power & Way
H. Fleige - Electrical Engineer
Bay Area Rapid Transit District

In the Power and Way Department at BART, our budget this past year was $17 million to cover our operations and maintenance efforts. Out of the $17 million, we had seven million dollars which went for traction power. I'm very much interested wherever we can cut power, and the expenditure for it, and put that money into other places where we can use it. In order to reduce the effects of the increases we've had in the power rates, we are starting to shut cars off whenever they go into the yard, and kill the third rail power when it is not needed. This saving amounts, just over the weekend, in each yard, to about $52,000. So I am very much concerned in the economics of maintenance and operation of our property.

We have a total of 37 substations, and as you know, we use 1000 volts DC. We have a system that has 75 miles of double track. In our Traction Power Division, which has a total of 115 people, we have around 46 people involved in maintaining the substations and all of the wayside traction power equipment.

We're going to go back to the early stages of our California operation at the Diablo test track, which is located in Concord, where we tried seven different types of rail to determine which we really wanted to use. Most of you are aware that we went out on a performance specification. Exhibit A (Attachment 1) shows the seven types of rail we tested. We finally selected the standard I-beam, Type 7 or the Kaiser rail based on our findings. The performance specifications allowed for bidding on a bimetallic rail, as well as solid steel rail. However, an installation adjustment was included in the total bid price which penalized heavy rail at 1 1/2¢ per pound in excess of 15 pounds per foot. A 50 pound per foot steel rail compared to a 15 pound per foot bimetallic rail, based on 902,000 feet total, would have penalized the bidder of steel rail by $474,000. The low bidder was Kaiser, and we used their modified I-beam with the aluminum cast and rolled in place. The rail was made at their Benetia, California, plant.

Figure 1 shows our standard 3,000 amp contact rail and the low resistance 6,000 amp contact rail. The low resistance (6,000 amp) which is on your right hand side, is used in the Berkeley Hills Tunnel, the Trans-Bay tube, and our underground structures on the San Francisco line. The original contract called for 652,500 feet of the standard rail, resistance at 30° Centigrade of .004 ohms per 1000 feet, and 86,700 feet of the low resistance rail at .002 ohms per 1000 feet. The rails were manufactured at the Kaiser plant at Benetia, where they bonded the aluminum to the I-beams which were furnished by Bethlehem. The rail was made from the I-beams, with inch and a half holes three inches apart, punched

FIGURE 1
BART STANDARD CONTACT RAILS

in the web and the aluminum, cast integrally in place. The I-beams were dipped down into mold. As the rail cooled, the aluminum was pulled into very tight contact with the steel web. This same action caused the aluminum to shrink away from the steel flanges. In subsequent operations, sperm oil is sprayed into this space and then the aluminum is cold rolled to wedge it up against the flange.

We have removed a short section from our system on the Oakland line, and we have samples of it here. It has been in operation since September 1972. We separated the aluminum from the steel to look for possible deterioration between the mating surfaces due to corrosion or electrolysis and whatever else might have happened to it. The samples examined have had 2 million collector shoe passes over them in five years, giving evidence that the wear is very nominal. We have not had a lot of problems. Exhibit B and C, (Attachment 1), give the physical properties, specifications and weights of the two rails.

Two-thirds of our contact rail system is welded. For the first portion that we constructed, the line from Lake Merritt to Hayward and Fremont, Kaiser had not come up with a suitable welding process to make these welds. Shortly after that, we started construction on the other lines, and we did accomplish the welding. We find that the welded joints, (See Figure 2), although the initial installation may be a little costlier to start with, are maintenance free. We do not have to worry about periodically going in and torquing bolts, we don't have to worry about the expansion in them. We are thorough believers in welded contact rail. We do have qualified welders in the department who are familiar with the process, and we are now capable of doing our own in-house welding. We have experienced no failures to date in any of our welded joints on our third rail.

FIGURE 2
WELDED JOINT

FIGURE 3
BOLTED JOINT

Figure 3 shows a bolted joint on an end approach on the 3,000 amp rail.

FIGURE 4
BOLTED JOINT

Figure 4 shows the other side of the joint. These joints are made with aluminum splice plates bolted with three-quarter inch aluminum bolts on both sides of the splice. There is approximately one hundred foot-pounds of torque in each bolt. After they are torqued in, the last thing we do is to give them an application of no-oxide grease. To date, we haven't had a lot of problems with the bolted joints.

I'd like to mention one very interesting thing that happened as we started putting our system into service. After the contact rail was laid, it was out in the weather for approximately nine to ten months. You could see a lot of corrosion on this, or rust on the top of the rail. We had a terrific amount of arcing and it was giving us a lot of problems with our cars. We devised a grinder that was mounted on a maintenance vehicle that rode on the track. It had eight air motors with brushes that cleaned the rust off. Then we came right behind it with an application of light gun oil, and that solved our problem. Since then we haven't done anything else. But one thing that did happen to us. Sometimes we would get a little too much gun oil on, and it would get down on the insulators. We would then get debris on the insulators, especially in the subway, where we did have some arcing. One philosophy is similar to that of CTA. We try not to do any cleaning with the exception of emergencies. If the insulators do arc and we have problems, we just go in and knock the bad insulator out. After restoring service, we change the insulator.

FIGURE 5
CONTACT RAIL WITH BOLTED ALUMINUM SIDE PLATES

Figure 5 shows a contact rail with the aluminum bolted to the modified I-beam. About four years ago, we put this in our test track at Hayward. At that time Kaiser was not making rail, so we had to go on the test track with a contact rail having the aluminum bolted to the modified I-beam. That test track is a little over two miles long, and it is used every night for testing revenue vehicles that have been through the repair shop. The track has a train control setup to check out all the ATO features on the car to make sure that they are operating properly.

Most recently, we have had a need for an express track. It will be built from McArthur through the Oakland area and come out on the Oakland West station side. This gives us immediate access from coming around through the wye with some of the expedited service that we need in the morning. That is about three miles long, and we have gone out on bid for three miles of contact rails. The contract was awarded to Insul-8, and we are going to give their rail a try. Exhibit I (Attachment 1) shows some technical details of this rail. We want to make sure that this rail is compatible with what we have in the present system, so that in case we have problems, or a derailment, we do have the alternative of going back to some of our bonded (Kaiser) rail that we have in storage. We have, I think, approximately three miles of the Kaiser rail in our stores inventory.

Figure 6 shows our expansion joints. They are located every 500 feet, and they have worked very successfully for us. They have been a very low maintenance item and have not given us any problems. The expansion joints are made from two interlocking steel castings, which provide for a fourteen inch thermal expansion. Dependent on rail capacity, six to twelve 500 MCM extra flexible aluminum cables with butyl insulation and a neoprene jacket are used as a shunt around the expansion joint. Pairs of the aluminum cables are welded to aluminum terminals which in turn are welded directly to the aluminum of the third rail.

Exhibit D, (Attachment 1), is a drawing of the joint and shunt cables. We generally lay the cables in a 6 inch PVC duct to protect them from damage. The expansion joints are greased once a year with heavy grease and graphite.

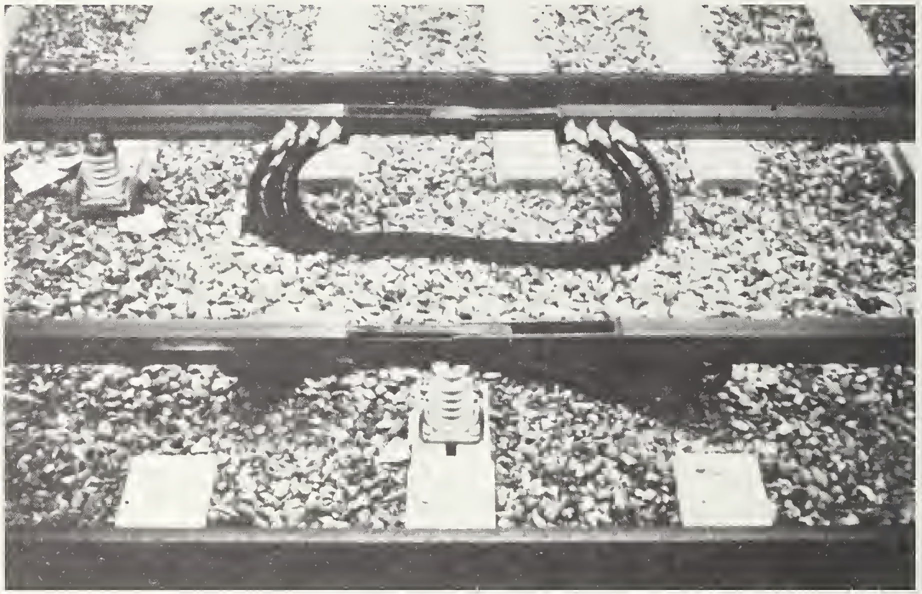


FIGURE 6
EXPANSION JOINT

FIGURE 7
TYPICAL INSTALLATION OF EXPANSION JOINT

Figure 7 shows an expansion joint installed with the shunt cables and the protective cover board over the expansion joint. You'll notice on the top that the short piece of cover board gives us the flexibility for movement. We did have some problems with the cover board at the expansion joints because we designed the top piece a little too short. When the rail contracted and moved out, the cover board fell into the gap. When the joint closed up, that piece of cover board popped out. So we resolved that problem by redesign and field modification.

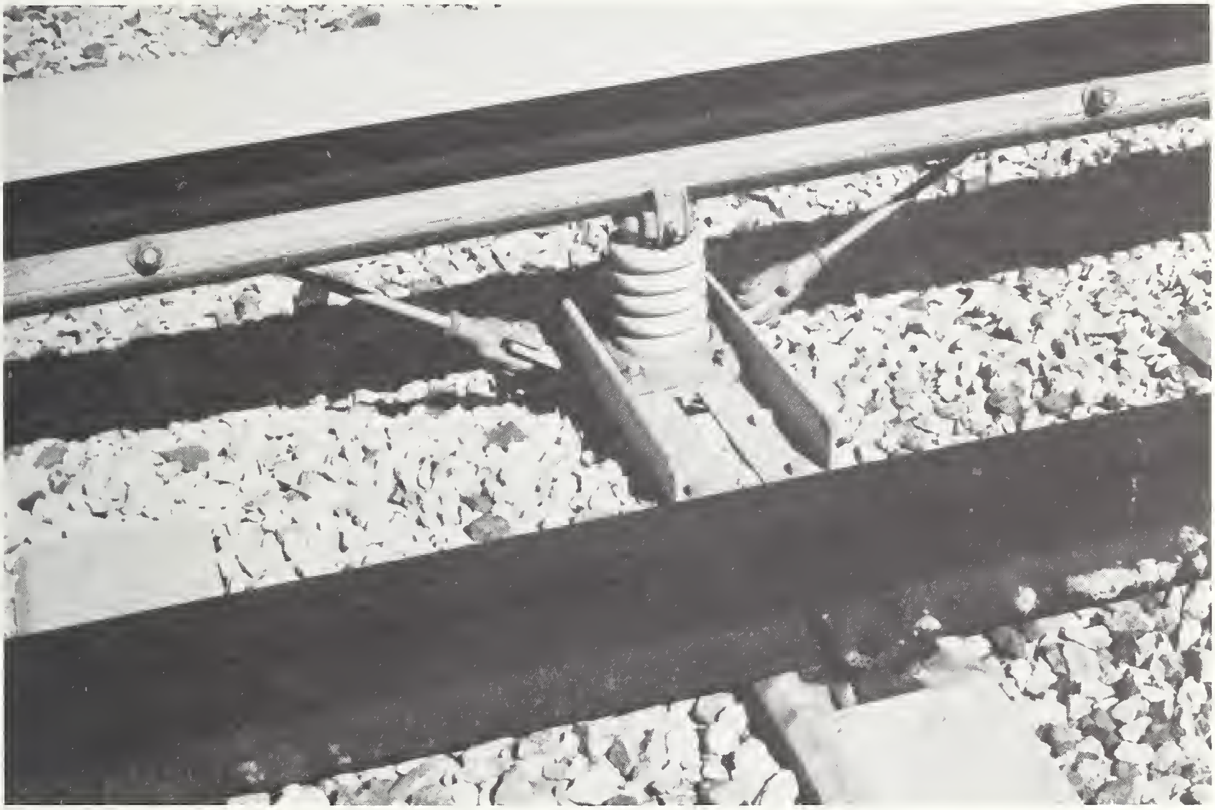


FIGURE 8
CONTACT RAIL BRACKET ON CONCRETE TIE

Figure 8 shows our contact rail bracket on a concrete tie. The anchors on the cantilevered bracket prevent the contact rail from traveling due to expansion and contraction caused by temperature changes. They are installed at the midpoint of each contact rail section between expansion joints. They are made from fiberglass epoxy rod, the necessary hardware, and are bolted to the rail with three quarter inch galvanized steel bolts.

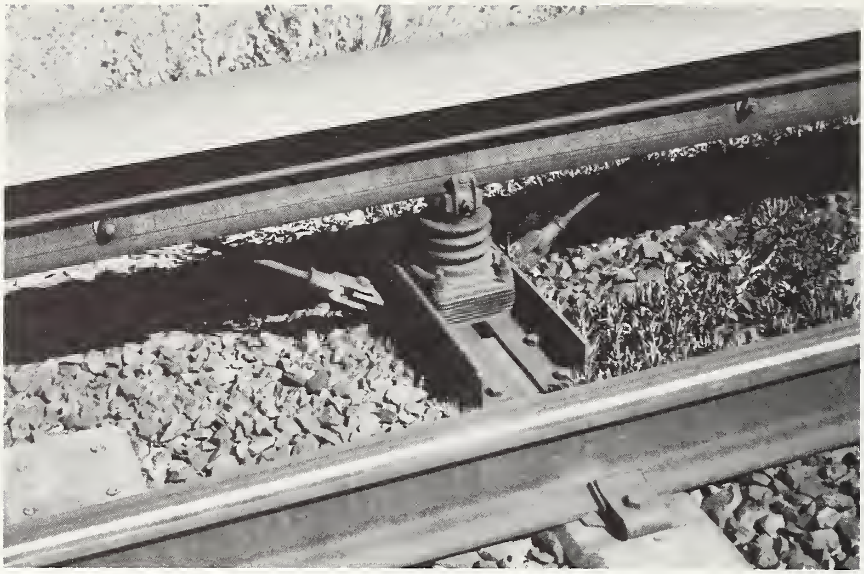


FIGURE 9
CONTACT RAIL ANCHOR ON CONCRETE TIE AFTER
FIVE YEARS

Figure 9 shows an anchor on a concrete tie that has been in service for five years, about which I would like to comment. It is very important, when you mount an anchor on a concrete tie, to make sure that you have equal expansion and contraction on your third rail and your running rail. If you don't, it does not take much to pop out the bracket mounting bolts. To date, we have had one problem at one isolated location, and I will come back to that. You will notice that this insulator isn't the cleanest looking one in the world, because it was hit by that extra gun oil. We have a program of spot cleaning, but we just cannot afford to go out on a large scale cleaning program. We're kind of playing it by ear, and I'm glad to hear of the CTA experience because that gives us a little more confidence in what we are trying to do. As I mentioned a little earlier, our most critical areas with dirty insulators are down in the subway where we have seepage of water with a high chemical content. This has caused some arcing across the insulators.

We also have contact rail anchors on wood ties as shown in Figure 10. This is a view before the cover board was applied. The anchor was mounted on a long tie in a turn-out. We found that in the wood tie sections we had to go to a 10 foot tie to take care of the insulator and anchor. Figure 11 shows an anchor on a 10 foot wood tie, close to the end. This is a typical installation on a wood tie.

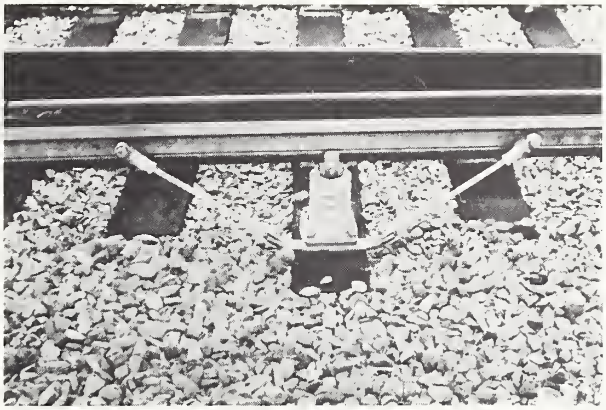


FIGURE 10
CONTACT RAIL ANCHOR ON WOOD TIE

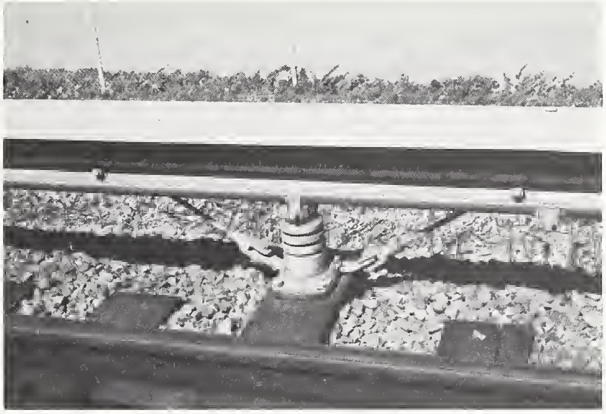


FIGURE 11
TYPICAL INSTALLATION ON WOOD TIE

FIGURE 12
INSULATOR INSTALLATION-CONCRETE TIE SECTION

Figure 12 is a view of our installation with the insulators and the brackets on concrete ties installed on every fifth tie. This picture was on the "A" line during the construction period. All the insulators are wet processed porcelain with a minimum creepage distance of eight inches from any energized metal component to ground. In spite of heavy contamination on certain portions of our system, they have performed very well for us. We just haven't had any problems.

One thing that is of real importance to us is the maintenance of adequate clearance between the ballast and the bracket. If the ballast builds up, or even if it gets on the inside of the bracket, it will cause a working action which loosens the bolts in the brackets. We anticipated that prior to the installation and we held the contractor to it. Even in our maintenance procedures for track we give our brackets and our insulators a lot of tender care because we do not want to break the inserts out of the concrete tie.

FIGURE 13
CONTACT RAIL INSTALLED ON WOOD TIES

Figure 13 shows details of an insulator on a wooden tie. This one is on special track work (turnouts or switches). We are getting close to the end of the tie, but the tie hasn't split its end yet.

FIGURE 14
COVER BOARD BRACKET

Our cover board brackets are attached directly to the contact rail, as shown in Figure 14. That bracket can be fastened anywhere on the third rail. The cover board and brackets have been a very low maintenance item for us.

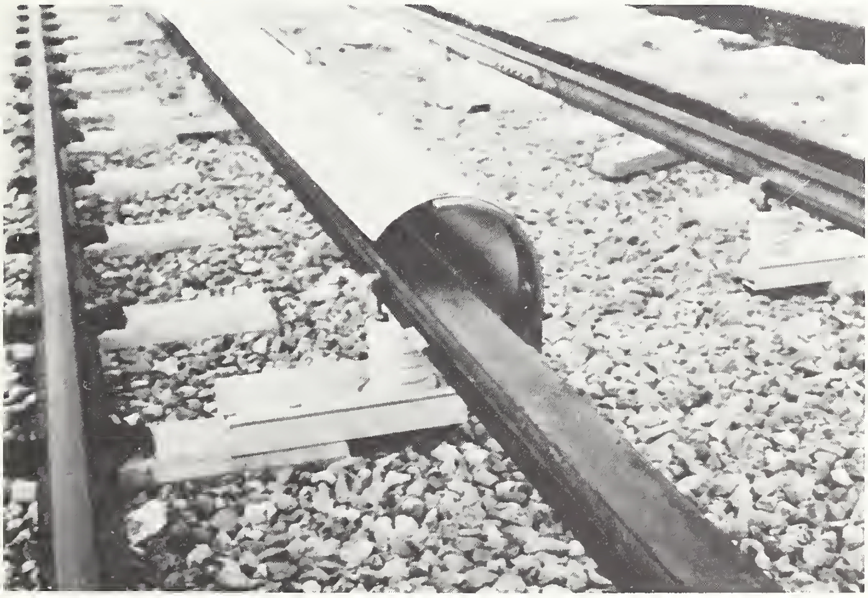


FIGURE 15
COVER BOARD AND BRACKET INSTALLATION

Figure 15 shows essentially an end view of the cover board and the bracket mounted on the third rail. The cover board is made of one and one half ounce continuous fiberglass mat and polyester resin mix. It is compression molded in sections ten feet in length. A DuPont Tedlar film is used on the outer surface to improve the weathering resistance. When we first went into operation, we did have problems, especially on the aerial portions of our system, with the fastening pins on the end. They had to be modified because we were getting high wind pressures up on the aerial sections from the heavy winds in the Bay area. The wind was pulling the coverboard loose, and we were losing cover board. We had to come back in and make a modification at the end. Our entire system has the cover board installation, even in our subway. It has worked out fairly well. I'd also like to say that the cover board was flame resistant, but we have had a few derailments where we have had some pretty hot fires. We are now in the process of making some tests on the cover board material to see just how much heat it can stand.

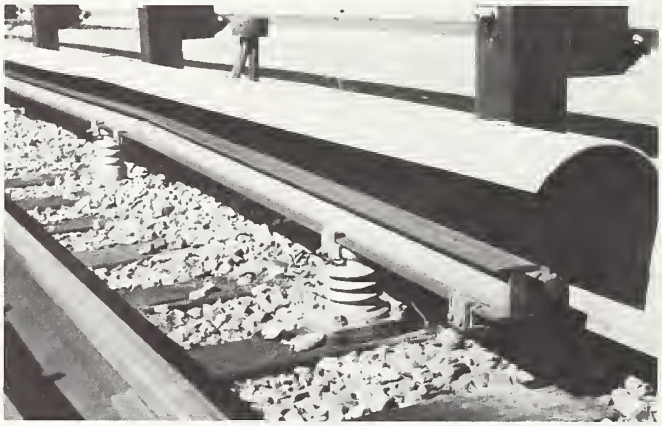


FIGURE 16
END RAMP

Figure 16 shows one of our end ramps (end approach). It is seven feet long, and you see where the weld was made and we come down on the taper. The cover board bracket allows a three inch vertical adjustment, in one-eighth inch increments. To date, we've had no problems that I can recall with our ramps. We have locations where there is some severe arcing, but the arcing didn't present a problem.

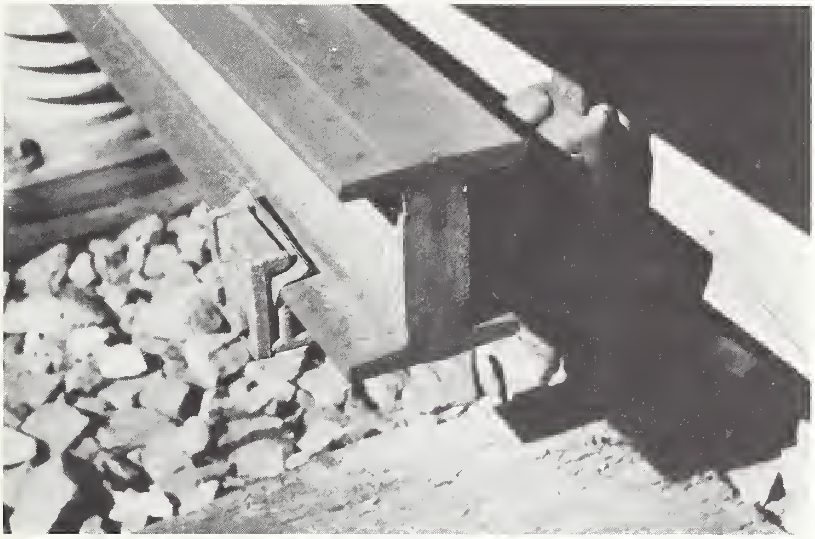


FIGURE 17
END APPROACH AND COVER BOARD BRACKET

Figure 17 is a closeup view of the end approach and the adjustable bracket that I just mentioned. We had some initial problems with the adjustable bracket slipping down because of the clamp bracket not gripping and locking the vertical cover board bracket because of the coating on the bracket. Although we have a lot of sparking at end approaches, there is little evidence of excessive burning on the top of the rail with these end approaches.

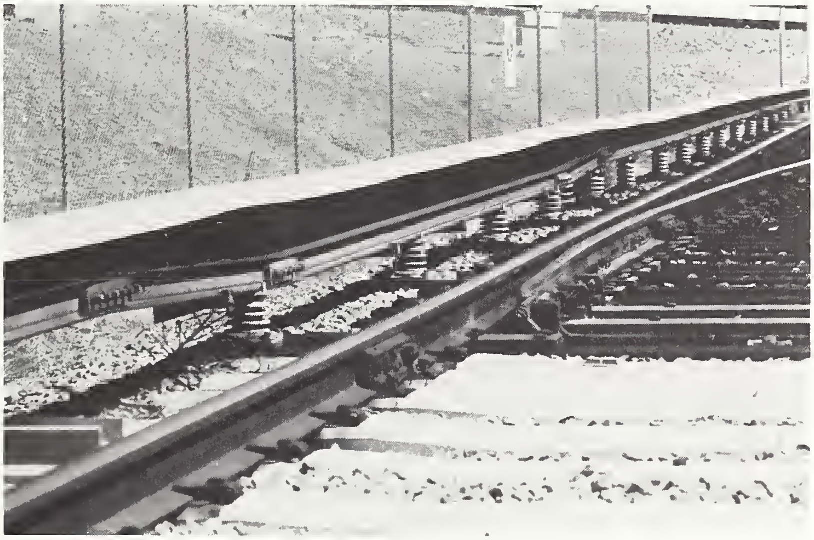


FIGURE 18
DIPPED CONTACT RAIL SECTION

Figure 18 shows a dipped contact rail section at a switch or turn-out. The rail dips 3 1/16th inches in 88 inches. The length of the dipped section is 20 to 80 feet, dependent on the system design. The long-skirted cover boards, adjustable brackets and low insulators were used at the dipped rails. A gap in the contact rail would serve the same function. Because of the long span of cables needed if we used gaps, we found that it was more feasible to use the dipped rail sections. They have worked out fairly well for us.

Exhibits E, F, G and H (Attachment 1) present the design details of our third rail accessories--insulators, cover board and bracket, and dipped rails.

FIGURE 19
COLLECTOR SHOES

Our collector shoes are shown in Figure 19. They are made of a ductile iron, ASME-80-60-3, and they are rated for 10 to 15,000 miles. You can see a new one and a worn one. We haven't had a lot of problems with them. When we first went into operation, we tried another type, but it did not wear well. We went to this type, and it has been very successful from a maintenance standpoint on both the third rail and the cars. We like to see the shoe wear instead of the third rail, so we must find a happy medium.

The original contact rail specification called for a wear surface sufficiently thick to withstand 50 million passes of a vehicle collector shoe, but not less than 3/8ths of an inch thick. Our best estimate at this time is that it will take approximately 30 years to subject our contact rail in our most heavily traveled sections of the system to this amount of wear.

Figure 20 shows a worn rail head, with approximately 2 million shoe passes on it. Figure 21 shows the unworn rail head, and Figure 22 is a section through the worn rail. The wear is scarcely noticeable.

In the rail sections that had two million shoe passes on them, we have estimated that they have worn about 4 percent. We find some of our new rail that had been in storage for several years has about the same dimensions as the slightly worn examples. I think, therefore, that five years service may be inadequate to predict our contact rail life.

FIGURE 20
THIRD RAIL HEAD AFTER TWO MILLION
SHOE PASSES

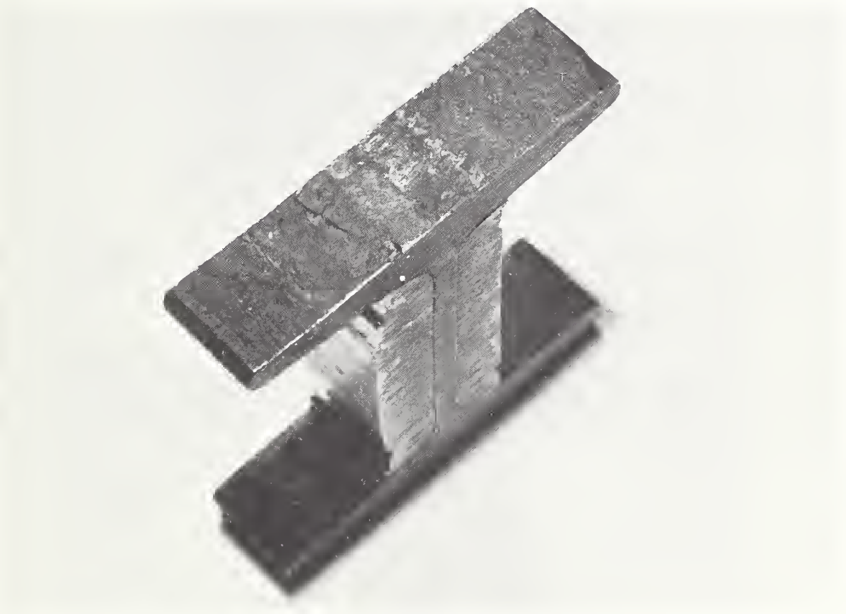


FIGURE 21
NEW THIRD RAIL HEAD

FIGURE 22
SECTION THROUGH WORN THIRD RAIL

FIGURE 23
TEST TRACK

Figure 23 shows our old test track at Concord. At one time, the installation was made with all fir ties, and we had problems with our insulator brackets on the fir ties. We replaced every fifth tie with a concrete tie. We have watched this closely to see what type of problems we would encounter. The installation was made a little over four years ago, and it's working out very well.

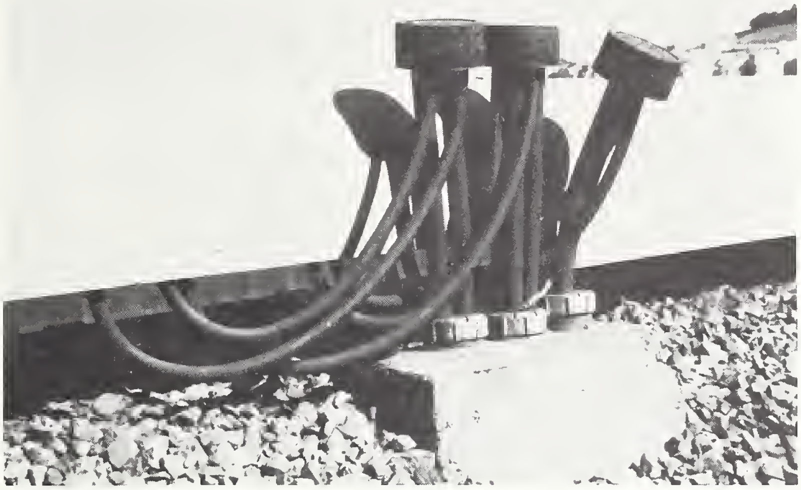


FIGURE 24
FEEDER CONNECTION

A substation feeder connection to the contact rail appears in Figure 24. The connection is made with an insulated rosette type connector, which takes up to three 750-MCM feeder cables, and three 350-MCM extra flexible cables. We have had some problems with these cables. Where they come up through the stub-ups, we have had some cable movement, and it has exposed some of the 1000 volt conductor. We have shorted to ground and lost several of them. At the present time, we are working on the most critical areas, and are trying to provide adequate insulation where they come up. With our luck, the problem always happens right during the heavy commuter periods and everything goes to an extreme emergency. So this is a priority problem.

FIGURE 25
BROKEN THIRD RAIL ANCHOR AND CONCRETE TIE

Figure 25 shows a unique problem we encountered between Lafayette and Orinda, on a section of railroad that has a 3.8 ruling grade. This occurred on the downhill track. We started getting movement in the third rail, and the bracket carrying the insulator and anchor started breaking away from the concrete tie. Another thing was happening to us at the same time. The trains coming down grade, braking, and entering the station were pushing the track structure forward and that contributed to the problem. We went back and re-adjusted our running rail, and made a modification on the bracket. We consider the running rail on our system as a very critical part in the successful maintenance of our third rail. All of our running rail is 119 pound, continuously welded rail. We have some stretches up to three miles in length. During construction we had the contractor prestress all of our continuous welded rail so that it is in tension. We noted the ambient temperature, worked out a scale for him, and had him put a dutchman or a small piece of rail to make up for the specified gap. We required him to come back and close the gap at the right temperature. A close up view of the displaced bracket is shown in Figure 26.

FIGURE 26
CLOSE-UP BROKEN THIRD RAIL ANCHOR
AND CONCRETE TIE

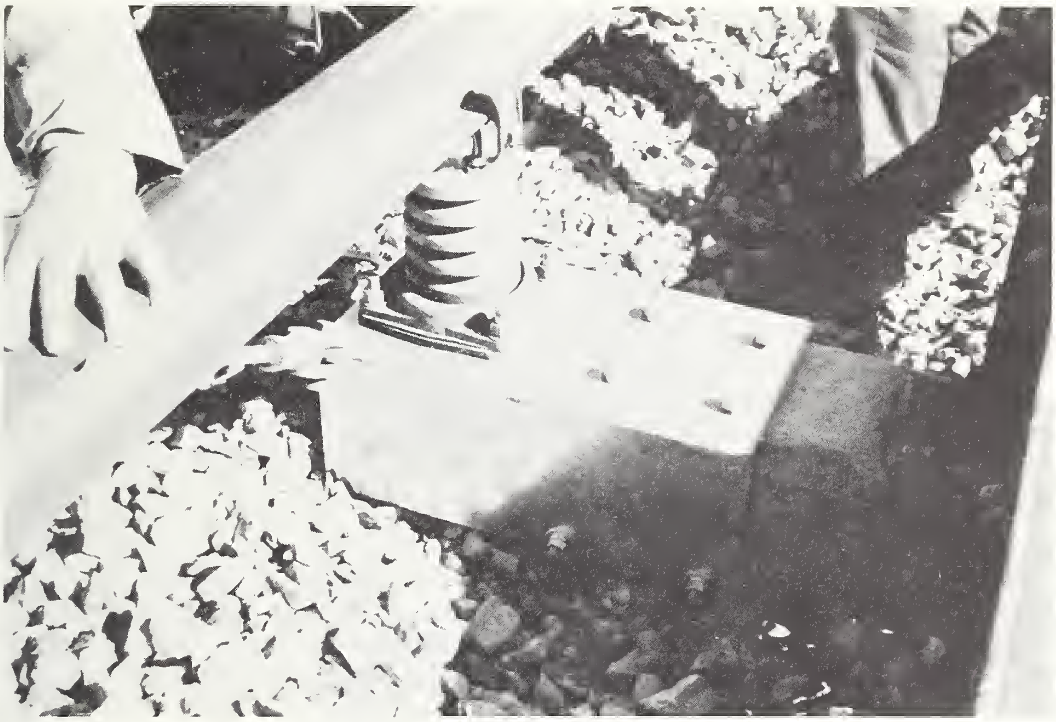


FIGURE 27
MODIFIED ANCHOR INSTALLATION ON
CONCRETE TIE

Figure 27 shows the modification we made to overcome the problem just described. The end of the concrete tie was reinforced with a welded steel box that was bolted to the tie, and the insulator and anchor were mounted directly on top of the box. Since we readjusted the running rail and made this modification, we have not had a repetition of this problem.

We attribute the success of our third rail in part to our maintenance program on our running rail. Figure 28 shows an Electromatic tamper. This differs from a standard piece of equipment in that it will raise the curves up to 8 1/4 inch superelevation and is built to accommodate our 66 inch guage. The machine is a fully automatic tamper; the operator can get out, walk alongside, and dial necessary settings in. The machine is controlled with an electronic beam and keeps our tolerances within 1/8th of an inch, plus or minus. Because our third rail is rigidly located with respect to the running rail, alignment of the running rail automatically insures alignment of the third rail.

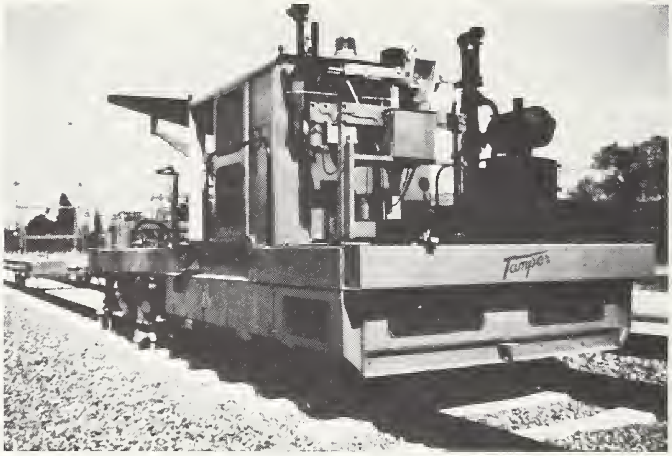


FIGURE 28
ELECTROMATIC TAMPER

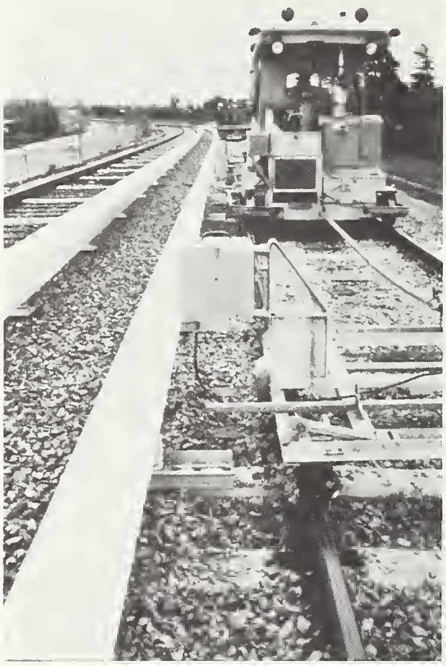


FIGURE 29
FAIRMONT TRACK LINER

Figure 29 shows a Fairmont track liner. It will line our track horizontally with an electronic beam, and keep our main line maintained within those previously mentioned tolerances. Again with this equipment, the third rail has to follow right along with the running rail. We keep a pretty close eye on it, because we want to maintain the third rail to the same tolerances as the running rail.

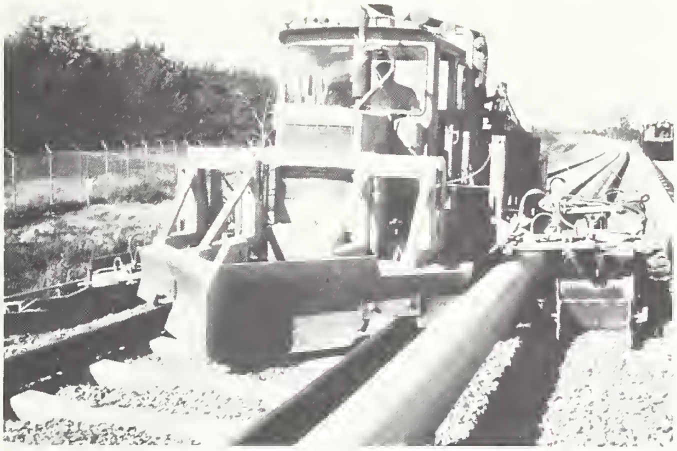


FIGURE 30
BALLAST EQUALIZER

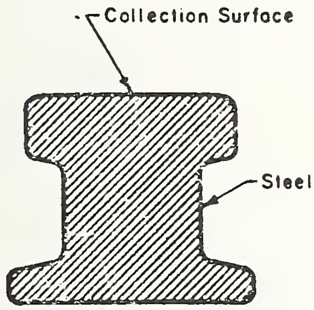
The problem that we had on the Lafayette-Orinda grade was partly due to what we call skeletonized track. Figure 30 shows that we did not have a sufficient amount of ballast in between the ties, or a full crib. That is what started the running rail moving, and it pulled the contact rail along with it. This ballast equalizer, which will work over the cover board, is what we use when we make our ballast dump. We are very tough on the track crews, making sure that they keep the cribs right up to the top with ballast to prevent movement in the running rails, so we do not end up having both running rail problems and third rail problems.

FIGURE 31
TRACK AFTER COMPLETION OF MAINTENANCE

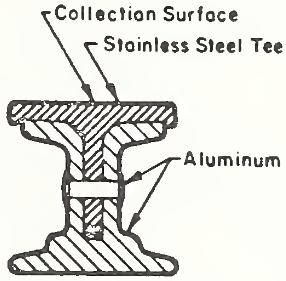
Figure 31 shows the finished product, after the maintenance equipment was over it. It gives you an idea of the perfection that we are trying to maintain on the system. You will notice that the cover board on the third rail is in almost perfect alignment. Our maintenance equipment does a very good job for us, and we are probably 99% mechanized. We do very little work by hand.

FIGURE 32
CURVE AT ORINDA

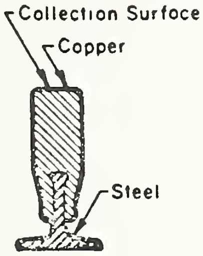
Figure 32 shows a portion of the curve at Orinda. This curve carries about 6 inch super-elevation. The figure shows that the welded contact rail conforms very nicely to the welded running rail. As long as we can keep our track maintained that way, we think that we can keep the costs of maintaining the contact rail down. We think this is a very important feature of our successful maintenance program.



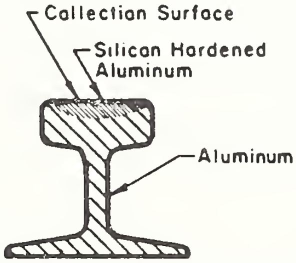
Type 1



Type 2

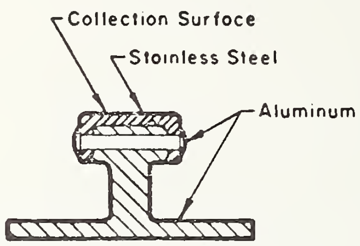


Type 3

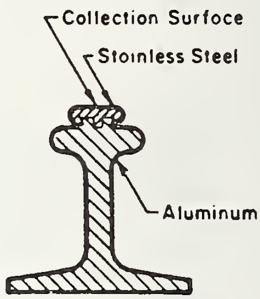


Type 4

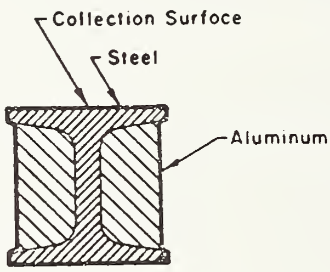
ATTACHMENT 1 - EXHIBIT A
SEVEN RAILS TESTED AT DIABLO TEST TRACK



Type 5



Type 6



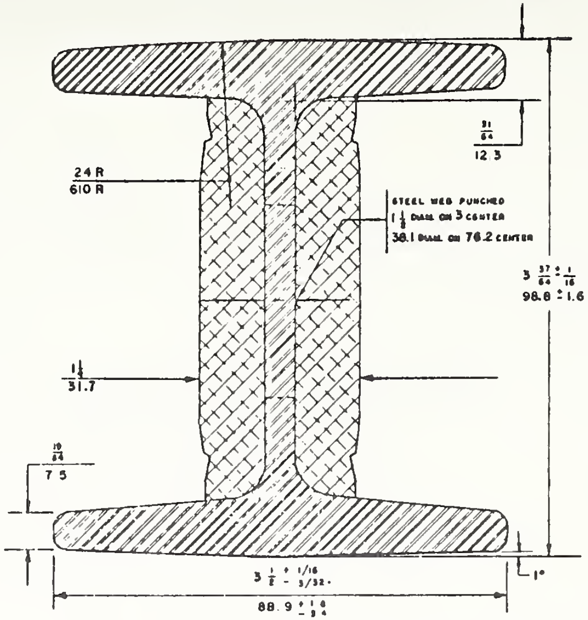
Type 7

ATTACHMENT 1 - EXHIBIT A (CONTINUED)
SEVEN RAILS TESTED AT DIABLO TEST TRACK

	ENGLISH	METRIC
WEIGHT	14.6 lb./ft. 43.8 lb./yd.	21.8 kg/m
STANDARD RAIL length weight	 60 ft. 876 lbs.	 18.29 m 399 kg
STANDARD PACKAGE 9 rail bundle	7,884 lbs.	3,589 kg
MODULUS OF ELASTICITY steel aluminum	 29.8×10^6 psi 10.0×10^6 psi	 21×10^5 kg/cm² 7×10^5 kg/cm²
D C RESISTANCE at 30°C	0.0040 Ω/1000 ft. 0.0212 Ω/mile	0.0132 Ω/km
SECTION PROPERTIES Area steel aluminum Section Modulus S_{xx} S_{yy} Moment of Inertia I_{xx} I_{yy}	 3.32 in² 3.02 in² 4.8 in³ 1.5 in³ 9.1 in⁴ 2.5 in⁴	 21.4 cm² 19.5 cm² 78.8 cm³ 24.6 cm³ 379 cm⁴ 104 cm⁴
COEF. THERMAL EXP.	8.38×10^{-6} in/in/°F 15.08×10^{-6} in/in/°C	15.08×10^{-3} mm/m/°C

NOTES:

1. All dimensions in inches and millimeters unless otherwise noted.
2. Steel: A36 (10.1% IACS)
   Aluminum: EC (59.5% IACS)
3. All bundles steel strapped.
4. Both ends prepared for welded joints.
5. Ampacity: 3000 40°C rise over 30°C ambient.
6. Thermal time constant: 75 minutes
7. Section modulus and moment of inertia computed using E = 29.8 x 10⁶ psi, 21 x 10⁵ kg/cm²



BART

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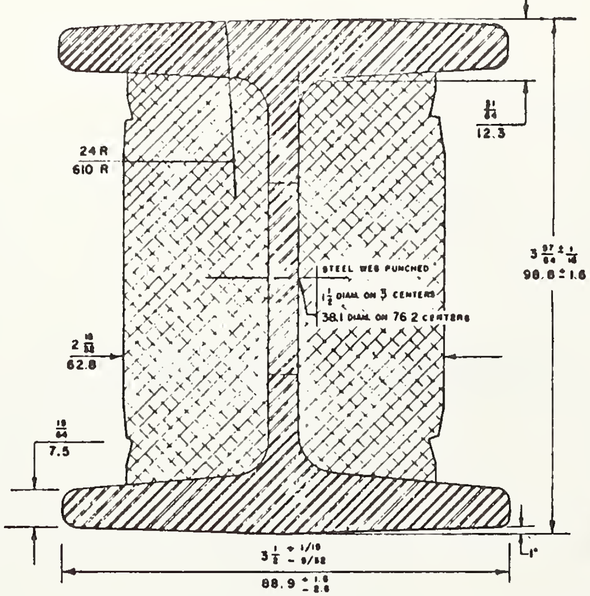
Telephone 465-4100

3000 AMPERE ALUMINUM CONDUCTOR CONTACT RAIL

ATTACHMENT 1 - EXHIBIT B
3000 AMPERE ALUMINUM CONDUCTOR CONTACT RAIL

	ENGLISH	METRIC
WEIGHT	18.8 lb/ft 56.4 lb/yd	28.1 kg/m
STANDARD RAIL length weight	 60 ft. 1128 lbs.	 18.29 m 514 kg
STANDARD PACKAGE 9 rail bundle	10,152 lbs.	4,625 kg
MODULUS OF ELASTICITY steel aluminum	 29.8×10^6 psi 10.0×10^6 psi	 21×10^5 kg/cm^2 7×10^5 kg/cm^2
D C RESISTANCE at 30°C	0.0020 Ω/1000 ft. 0.0106 Ω/mile	0.0066 Ω/km
SECTION PROPERTIES Area steel aluminum	 3.32 in^2 6.64 in^2	 21.4 cm^2 42.9 cm^2
Section Modulus S_{xx} S_{yy}	 5.3 in^3 2.1 in^3	 87.0 cm^3 34.5 cm^3
Moment of Inertia I_{xx} I_{yy}	 10.1 in^4 3.7 in^4	 420 cm^4 154 cm^4
COEF. THERMAL EXP.	9.30×10^{-6} in/in/°F 16.74×10^{-6} in/in/°C	16.74×10^{-3} mm/m/°C



NOTES:

1. All dimensions in inches and millimeters unless otherwise noted.
2. Steel: A36 (10.1% IACS)
   Aluminum: EC (59.5% IACS)
3. All bundles steel strapped.
4. Both ends prepared for welded joints.
5. Ampacity: 6000
6. Thermal time constant: 70 minutes.
7. Section modulus and moment of inertia computed using $E = 29.8 \times 10^6$ psi, 21×10^5 kg/cm^2

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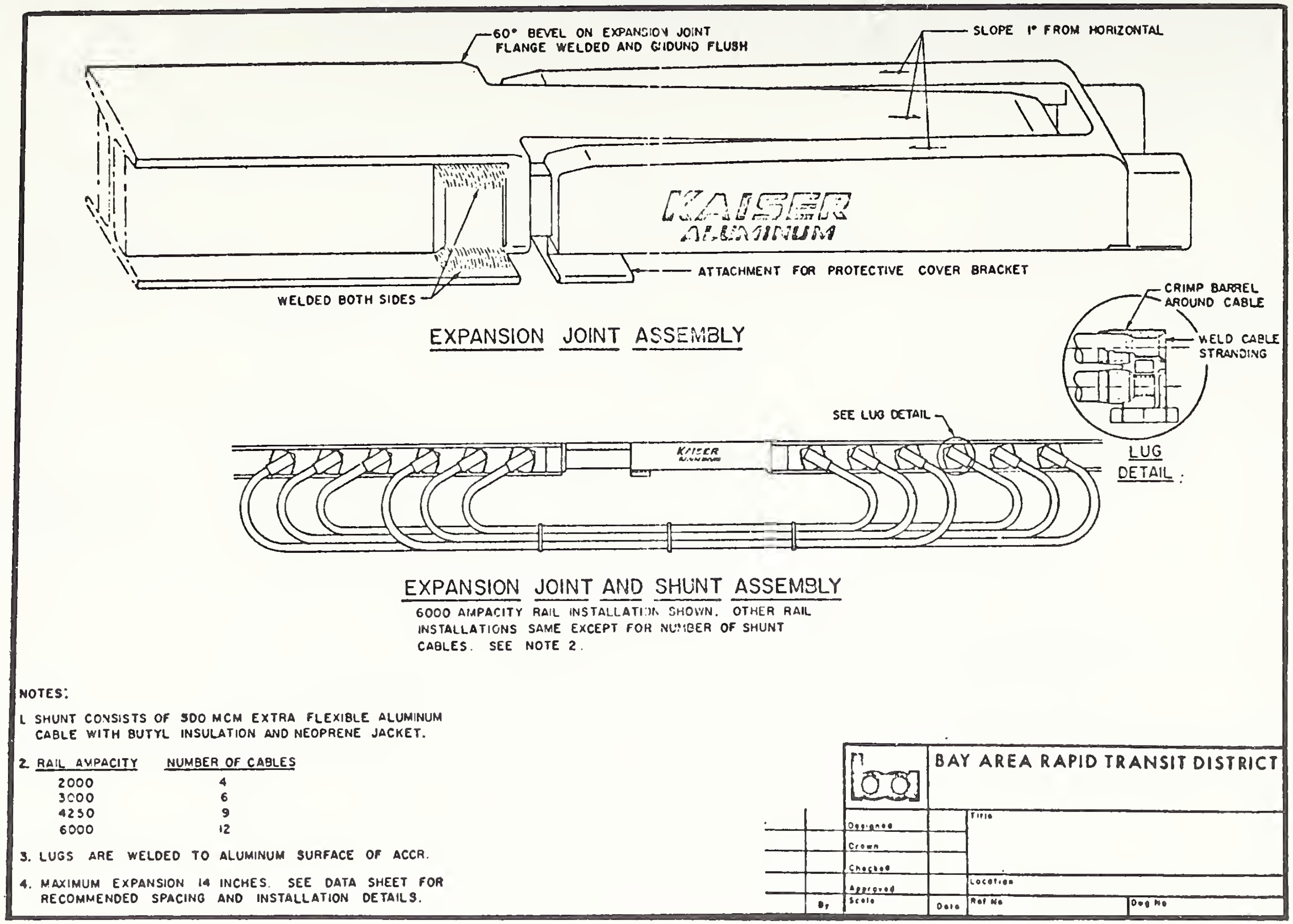
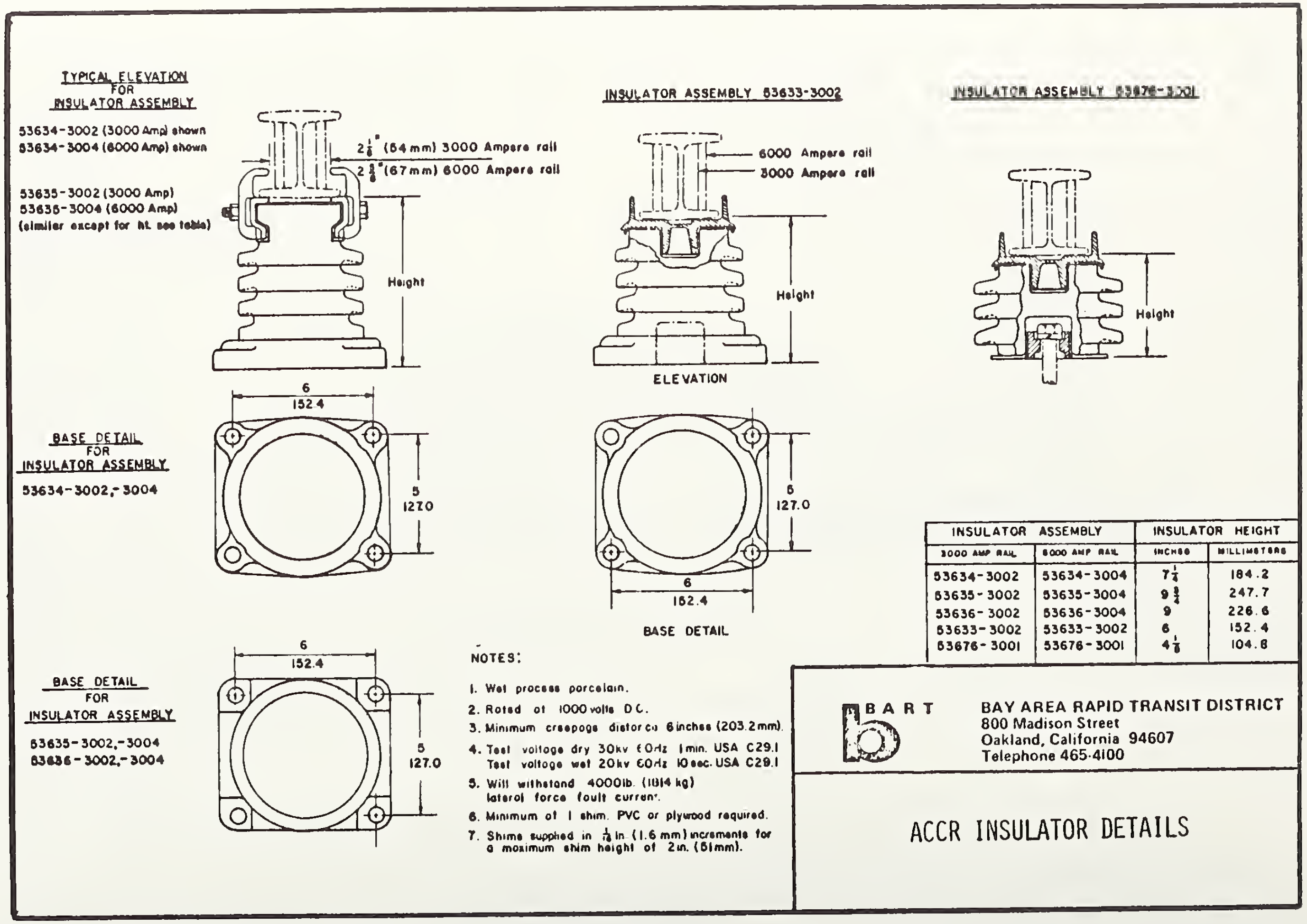
6000 AMPERE ACCR

ATTACHMENT 1 - EXHIBIT C
6000 AMPERE ALUMINUM CONDUCTOR CONTACT RAIL



ATTACHMENT 1 - EXHIBIT D
DRAWING OF JOINT AND SHUNT CABLES



NOTES:

1. Wet process porcelain.
2. Rated at 1000 volts D.C.
3. Minimum creepage distance 8 inches (203.2 mm).
4. Test voltage dry 30kv 60Hz 1 min. USA C29.1
   Test voltage wet 20kv 60Hz 10 sec. USA C29.1
5. Will withstand 4000 lb. (1814 kg) lateral force fault current.
6. Minimum of 1 shim. PVC or plywood required.
7. Shims supplied in 1/16 in. (1.6 mm) increments for a maximum shim height of 2 in. (51 mm).

INSULATOR ASSEMBLY		INSULATOR HEIGHT	
3000 AMP RAIL	6000 AMP RAIL	INCHES	MILLIMETERS
53634-3002	53634-3004	7 1/4	184.2
53635-3002	53635-3004	9 3/4	247.7
53636-3002	53636-3004	9	228.6
53633-3002	53633-3002	6	152.4
53676-3001	53676-3001	4 1/8	104.8

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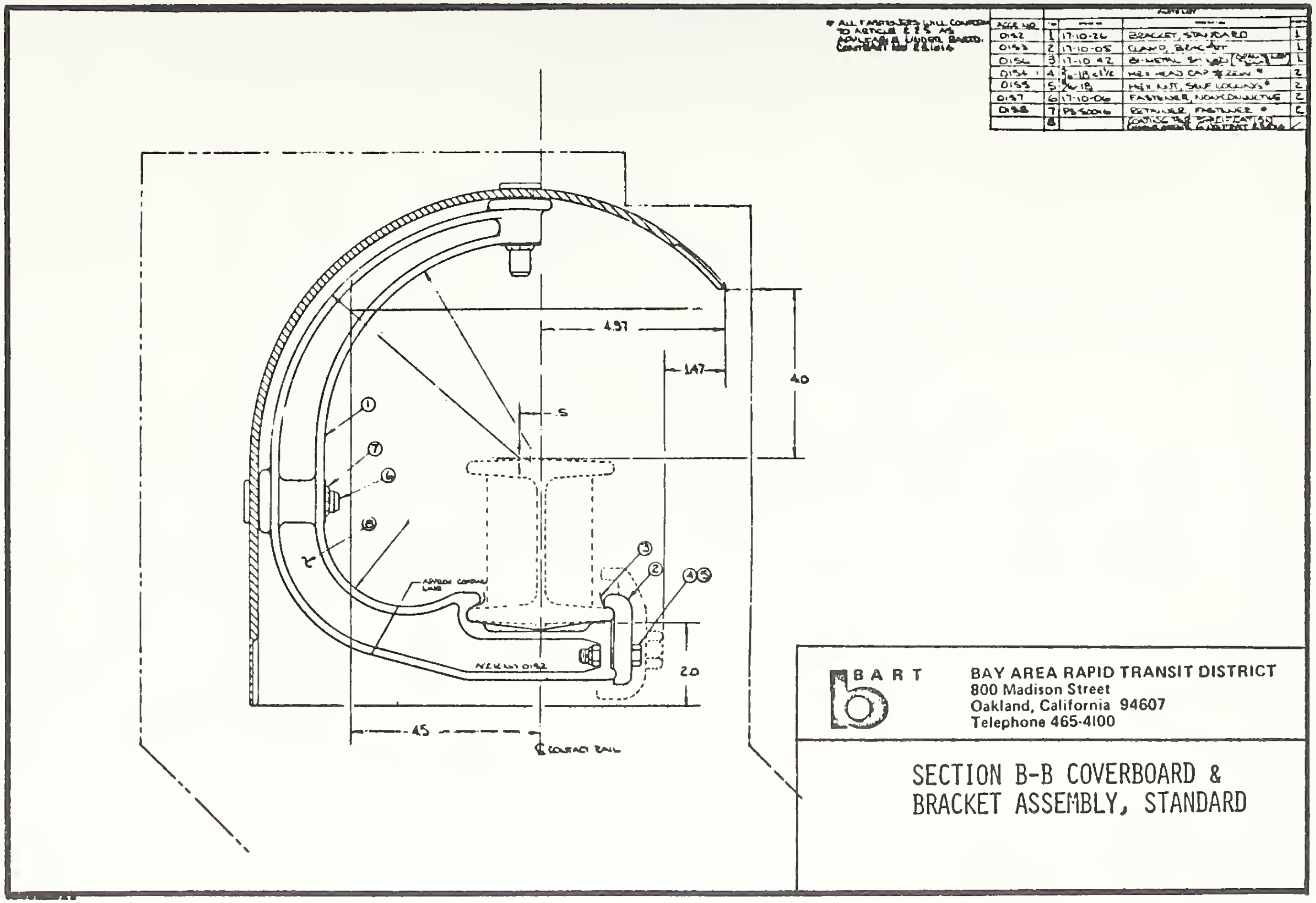
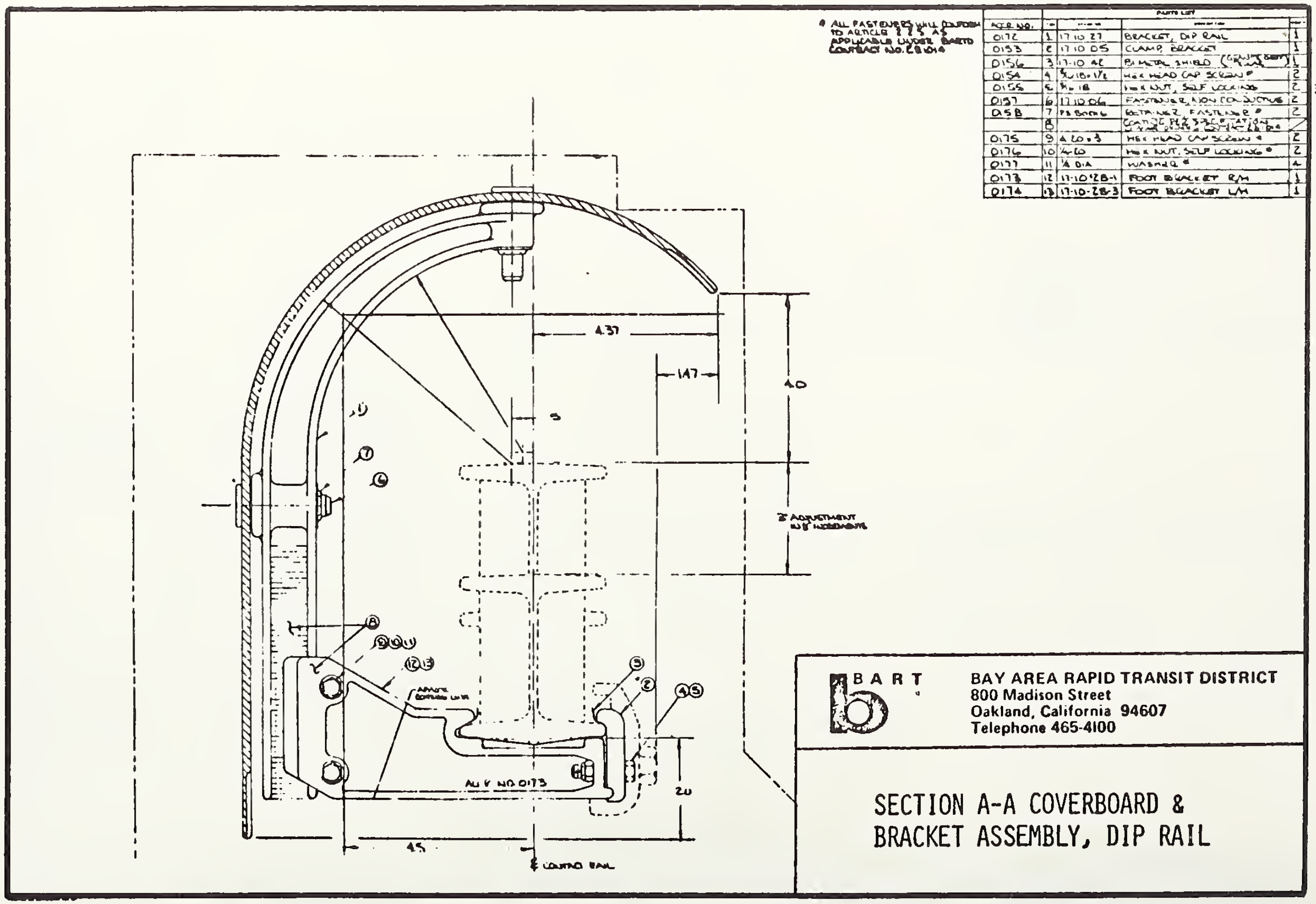
ACCR INSULATOR DETAILS

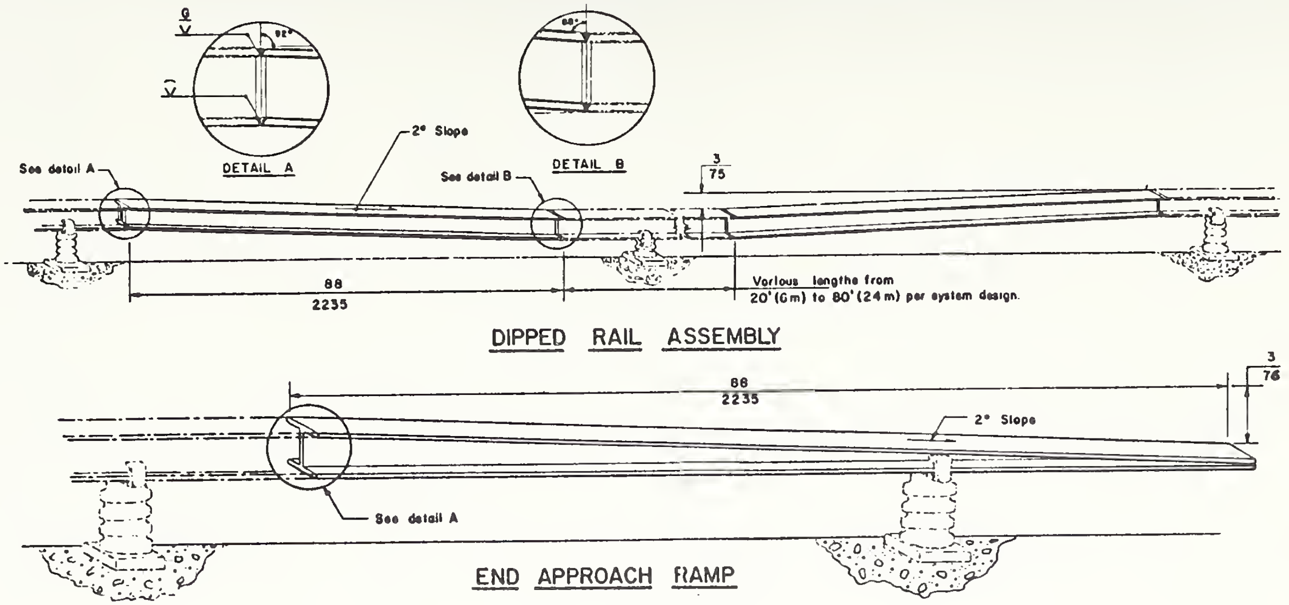
ATTCHMENT 1 - EXHIBIT E
ALUMINUM CONDUCTOR CONTACT RAIL INSULATOR DETAILS



ATTACHMENT 1 - EXHIBIT F
SECTION B-B COVERBOARD AND BRACKET ASSEMBLY-STANDARD



ATTACHMENT 1 - EXHIBIT G
SECTION A-A COVERBOARD AND BRACKET ASSEMBLY-DIPPED RAIL



NOTES:

1. Dipped rail installations eliminate the need for side approach ramps on crossovers and turnouts.
2. Dipped rail assembly consists of two factory cut dip rail sections and one straight segment field cut to fit.
3. End approach to be made from steel section used in the manufacture of composite rail.
4. Ends of dip sections and ramps will be factory beveled for welded joints.
5. All dimensions are in inches and millimeters.

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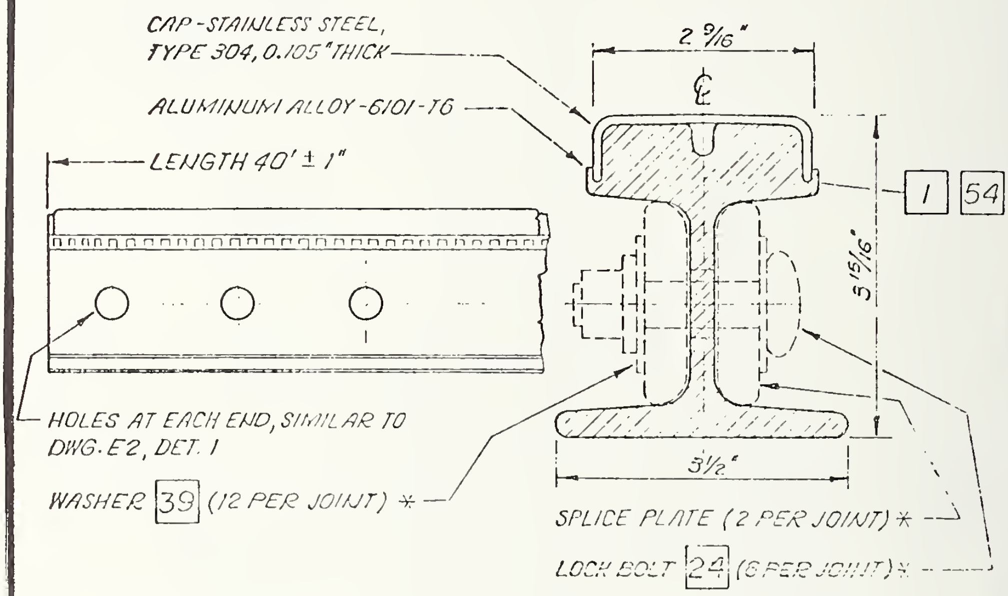
ACCR END APPROACH AND
DIPPED RAIL DETAILS

ATTACHMENT 1 - EXHIBIT H
ACCR END APPROACH AND DIPPED RAIL DETAILS



ALUMINUM CONTACT RAIL 1 54
ALTERNATIVE Z

* Splice plates required shall be furnished as indicated in the Specifications.

** Lockbolts and related washers shall be furnished as indicated in the Specifications.

1 ITEM 1 (TYPICAL)

ATTACHMENT 1 - EXHIBIT I
SOME TECHNICAL DETAILS OF INSUL-8 RAIL

GENERAL QUESTION AND ANSWER SESSION

GENERAL QUESTION AND ANSWER SESSION

Following the Presentations
September 14, 1977

Following the presentation by Mr. V. Mahon of BART, the seminar continued with a general question and answer session. All persons attending the seminar were encouraged to ask questions of the speakers and of each other on matters concerning the design, selection, installation, maintenance and operation of composite third rails.

Q: R. Ganeriwal, DeLeuw Cather - Why wasn't the Porter or Insul-8 composite rail considered as one of the seven options?

A: V. Mahon, BART - You mean, in the original contract? Porter was considered but Kaiser was low bidder.

Q: R. Ganeriwal - Oh, I didn't see it when I ---

A: V. Mahon - Insul-8, don't remember ---

A: H. Fleige, BART - We only had three bids, and Kaiser happened to be the lowest bid. We didn't like engineering specifications. We had performance specifications. We could have wound up with the 150 pound rail, but due to the penalty we put on heavier rail, we didn't get any bids for 150 pound rail.

A: R. Lillard, Porter - In regards to the first question, I think what you were looking for in the BART slide was our TRANSDUCTOR™ section. We had two sections up there, the stainless capped rail and the dual extrusion or silicon head were in those slides. We did not bid on the initial BART quotation.

Q: R. Ganeriwal - No TRANSDUCTOR™ rail?

A: R. Lillard - We did not have TRANSDUCTOR™ in 1966 as you now see it. The legalities involved wouldn't allow us to bid, either.

A: J. Corl, Insul-8 - We bid, but we were number 2. We were not low bidder. Therefore, we didn't get the job. Cleveland Crane was third.

Q: Mr. Mahon - I notice that you fasten your third rail to the insulator. In a lot of places that use 150 pound rail it just rests on the insulator. With that lighter rail, can it be carried without being fastened to the insulators since it can be rather easily moved off the insulator? What does Insul-8 say about that?

A: J. Corl - Yes, we use a tape over the top of it (the insulator). We do not clamp the rail, but the rail really slides over the top of the insulator. We want that rail to slide.

Q: So if there is a derailment, you are also going to take the insulators with the contact rail?

A: V. Mahon - Right, but not every derailment we have had has taken the insulators with the rail.

Q: R. Swindell, CTA - We have derailments, too. With welded contact rail (which we don't have) do you ever have to replace the rail.

A: V. Mahon - Yes.

Q: R. Swindell - Do you get so badly damaged, that you have to replace a section?

A: V. Mahon - Yes. I wish that we had included that in our presentation. We have a special welding set-up to weld contact rail. We may not get to it and weld immediately, but we do whatever is necessary to restore service.

Q: R. Swindell - What do you do, just leave a gap until you can get back ---

A: V. Mahon - We either use a gap, or use what has been bent. We get back when we have time, put in new rail, and reweld.

Q: R. Swindell - We found in our experience that if we have a derailment, or an accident, the jointed contact rail bends at the joint. To get it back into service, we just take off the splice plates, put the rail back where it was, and put a new set of plates on it. That is one reason why we've stayed away from continuous welded rail. But I didn't have any experience with it and I didn't know whether you had any problems with it.

A: V. Mahon - In some of the incidents that we had, such as the truck collision with a train that was being moved to another yard, a lot of damage was done to our third rail. We couldn't use the damaged rail. We put a gap in and operated with four car trains to bridge the gap, and then came back later for final repairs.

Q: E. Rowe, MBTA - Mr. Mahon, it's very odd that both Boston and Chicago had tested your prototype third rail, and over a period of time we both arrived at the same conclusion, that it wore down in both of our systems. I have some of the samples in my office that show the amount of wear that we get over the period of testing. We are at a loss to understand this. Looking at your collector shoe assembly, as seen on the slides, it appears to be very similar to what we use, the cast iron type of shoe and assembly. Why are you not experiencing the wearing conditions that both Chicago and Boston face?

Q: V. Mahon - What's the pressure of your shoe on the rail?

A: E. Rowe - We have about 15 pounds pressure.

V. Mahon - We're running 13 pounds.

E. Rowe - I'm sorry, 15 to 20 pounds pressure.

Q: V. Mahon - Did this (the samples) come out of the subway?

A: R. Swindell - The rail wear in the subway is much less than in the open air.

V. Mahon - We have not noticed much difference in the wear that we've had on our aerial structures. We're surprised. We're happy with the surprise.

H. Fleige, BART - There is a difference. You talk about a life of 60 years. We actually require a life of 30 years, which is equivalent to 50 million shoe passes. At this time, we have seen about 2 million shoe passes, which is 4% of expected life. Our wear, as best we can measure, is between 8 and 16 mils. Extrapolating that to 50 million passes or 30 years, could mean a wear of 200 to 400 mils, and that makes the Kaiser rail a little marginal.

A. Kusko - I wonder whether part of the reason couldn't be the big buffer choke you have at the input to the propulsion system on the BART car, limiting the amount of arcing and current inrush that you get. As I recall, I've never seen arcing on any of your shoes. Maybe I just haven't seen them on ---

H. Fleige - We don't have a buffer choke.

A. Kusko - You have a choke. You come off your third rail collector assembly, go through a reactor, and have a capacitor bank and a chopper on the load side of the reactor. There is a large reactor on the line (input) side.

H. Fleige - That is a reactor between the two rectifier phases. We have 12 part rectifiers.

A. Kusko - No, I mean, on the car.

H. Fleige - I am familiar with the car. We do see a considerable amount of arcing on the end approaches on each section, but even there, there doesn't seem to be any excessive wear at this time.

V. Mahon - We did have the arcing, and the rust problem. We noticed a lot of pitting on the top of the rail, and that's why we wanted to get the rail smoothed and see if it would help us. That's when we went into the program to brush the entire system, to try to get rid of that arcing. As soon as we did that, the problem went away.

R. Swindell - You say you have had about 2 million passes on that rail, on the section that you showed us?

V. Mahon - Yes.

Q: E. Rowe - In all fairness to Kaiser, when we tested their section of rail, we tested everybody's rail in the same place, on the leaving end of the passenger station with the highest current draw, on the old roadbed, with chipped ties, wooden ties, and that rail wasn't set the way you have set yours.

A: H. Fleige - Perfect alignment of the rail was a big secret to getting good collection.

Q: E. Rowe - If you have a good contact, and enough square inches, you don't draw arcs, or melt the rail. Ninety-five percent of rail wear is electrical, not abrasion. I think we all agree on that. All the rails that we got were set in the worst conditions that we have, right down near the water, where we had all kinds of salt water spray and tough winters, and we wore the edge nearest the running rail off on the Kaiser rail. We wore the steel right down to the aluminum in roughly two years. I think that was due of course to the higher pressure created on a smaller area by the shoe. I don't know what Chicago's experience was, but I'm sure they don't have a perfect roadbed either.

R. Swindell - I don't think that the Kaiser rail wears any more than any other rail. I hope no one leaves here with that impression. I think all the rails wear about the same amount. So many shoe passes, you wear off so much of the steel. It's a matter of starting with enough steel to give you the number of years service that you think you are going to have. I don't think the type of rail makes much difference.

V. Mahon - That's why we mentioned the maintenance on the running rails. We recognized that if the rail starts tipping out on us, and we start losing cant in the running rail, we're going to have an effect on our third rail. Another thing we watch is the collector shoes on the cars. If we see cars with collector shoes that are running irregularly, we get back to the rolling stock and shop people and ask them to check the tolerances on the collector shoes because they will give us problems.

Q: E. Rowe - The MBTA used to have an area which is now torn down in Sullivan Square, that I'd take people to, to show contact rail wear. Where the train went around a rather tight curve, where the pressure would come off the shoe and the shoe would ride up, you could see arcs. In a four foot length, the rail head would go down from an inch and a quarter to half an inch and back up to an inch and a quarter, just from the action of the arcing from the train going around the corner.

V. Mahon - Let me tell you something else that happened to us. You know there's a direct relationship between wear on a composite rail and how you maintain your roadbed. We have had rail wear due to the number of trains we run, especially at Daly City where we have had to transpose the running rail. But the third rail there is still in very good shape. It has good surface and alignment. We should have brought the pictures we took of it here. We were concerned what was happening to the third rail because of running rail wear, but we didn't have much to be concerned about.

Q: Did you have positive on the third rail, or negative?

A: V. Mahon - Positive.

Q: Because that could make a difference.

A: At 600 volts it could make quite a difference. At 1000 volts your currents are lower and there are other factors, probably, that we didn't have.

Q: E. Rowe, MBTA - On the 85 pound contact rail that we use, we get very little arcing on the straight right-of-way. The maintenance that we perform is probably similar to that of Chicago. and it is very limited. There is not much maintenance required and we do not have a big maintenance budget.

V. Mahon - I want to point out one more thing that's important to us. With our light cars and the speeds we're running at, which were up to 80 mph, and we are now back to 70 mph, we can't stand much variation in the roadbed. We are committed to maintain that roadbed so we can run those high speeds. We will probably go back to 80 mph someday.

Q: I've got a question for Insul-8 on the stainless steel cap. The joint in the cap and the extra gap, I understand, is halfway between the rail joints?

Q: J. Corl - On the cap, with respect to the aluminum?

A: Yes.

J. Corl - On a 40 foot piece of rail, with two 20 foot stainless caps on it, we leave approximately 1/32 inch gap between the two caps.

Q: Is that dependent upon the area in which you are installing it. In other words, if that were put in, in the East, with colder and more extreme temperatures, would you change that?

A: J. Corl - No. We can if we want to, but it's already calculated for 20 below (°F).

Q: What is that gap?

A: J. Corl - It's really about 0.045 inches, a little over one-32nd of an inch. That only takes up the 20 feet, of course, on each side. You're only dealing with 20 feet of expansion and contraction at one time. That brings up another point. BART was quite fussy about that stainless cap, how it was attached, and all. We went through some tests on the rail to get the cap off. Now for a 2 foot piece of that rail, to pull that cap straight off took over 7,000 pounds. To push it the other way, or slide it, it took 11,000 pounds on a 1-foot length to move the cap.

V. Mahon - We spent about three hours with this, one day, because we were not convinced.

Q: L. Pinkney, WMATA - I'm not sure if this is a rumor or not, but I haven't had an opportunity to ask you before. I understand that when you had your (original) aluminum rail, there was some peeling off or separation of the aluminum from the steel, and there were a series of things that you did to correct that. Are you familiar with any thing of that nature?

A: V. Mahon - We never had any of that. The only separation we've had is what we've separated here on the samples. Other than that, we have never had any problems with separation.

A: H. Fleige - They were strictly rumors.

Q: R. Ganeriwal, DeLeuw Cather - We have been told there is almost a dollar a foot difference between composite rail and 150 pound rail. Where could we get some numbers on this? From what we have been able to find out, there is a substantial difference in cost between 150 pound rail and composite rail. It is almost $12 a foot difference, instead of $1 a foot.

A: H. Decker, TSC - The figures that I have seen for installed rail are far closer to $1 a foot than they are to $12 a foot. I think probably the best source of cost information is the manufacturers themselves. I certainly do not have an inventory of costs. The other thing you have to look at these days is, when were these costs incurred? Are they 1972 dollars or 1976 dollars? I would expect that what you'd want to do to get good information would be to get the prices for the steel from Bethlehem, and find out, from your own experience, what your installation costs would be for the cadwelding and installation. You can make due allowance for escalation of costs. I'm quite sure that both Porter and Insul-8 will gladly supply the cost of the material.

E. Rowe - We have a job that has been mentioned. We hadn't talked about it before our meeting, but we had the same experience. Before the Authority made its decision, we wanted our consultant engineer to tell us how much more it (composite) was going to cost per foot than 150 pound rail, and he came up with that dollar ($1) per foot. Of course, we're talking 1972 dollars, so what it is today is questionable, obviously.

Q: A. Wacker, LIRR - Part of the third rail system is the point where you attach the feeder cables to the third rail itself. Has anybody had any problems with a bolted connection versus a welded connection such as we use on the steel rail? Did you do any experimenting on that?

A: H. Fleige - We have bolted as well as welded connections, and we haven't experienced any problems with either one. For new construction, we should use welded connections. Welding requires an experienced welder, and we do have some people who can weld the rail itself. When it comes to welding aluminum plates to the aluminum rail, I don't know which to recommend. Bolting may be cheaper than welding. But both methods have performed quite well. Not a single failure has occurred with either method.

A: E. Rowe, MBTA - The MBTA has used both, and tomorrow when you go through the yard, you'll see the application of bolts. On our 85 pound rail, we have recently used cadwelding. We cadweld the 1,000 MCM cables right on to the base of the third rail. On the composite rail, we elected to go to a NEMA four bolt connector, onto an L-shaped tab which you will see. If you ask our maintenance people, they'll tell you that they like a bolted assembly better than a welded one, because in the event of a failure, or when we've got a maintenance headache, it's so much quicker and easier to get that cable off the third rail and make any change that is necessary than it is to make up a weld or cut off a cable.

A: R. Swindell, CTA - In our case, we lug the cables to a series of bonds. It comes with a 1,500 MCM cable and we put three 750 MCM bonds into lugs, and that is our connection and disconnection point. Then we bond and weld directly to the base of the rail on both the aluminum clad and the steel rails identically. We make no difference between the two, and we use arc welding. We use a steel head bond, and we arc weld right on the base of the rail. But we never bolt it alone.

A: A. Houston, Maryland Mass Transit - I'd just like to reemphasize this pricing because apparently there is a wide difference, as has already been pointed out here. I think when you price this comparison of a 150 pound steel rail versus a composite that it's got to be done on an apple-to-apple basis, or in other words, on a ready-to-run basis. We did this back in 1974, and used 1974 dollars. We came up with $120,400 per mile for 150 pound steel rail installed ready to run, and the composite rail with 85 pounds of steel, $124,000 per mile. Now that is a differential of $3600 per mile. At that time, with the dollar saving in the cost of the power used, it would have taken us about ten years to write off the differential. Doing it just recently, because of the large jump in power costs, it looks like we'll save about $1200 per mile per year, and we'll write the differential off in three years. You must place the emphasis on a ready-to-run basis, and then make your cost comparisons.

Q: R. Ganeriwal - My question wasn't about overall economics, but is the composite rail ---

Q: H. Decker, TSC - If I understand the comment correctly, you are comparing directly the cost of a steel rail against the cost of a composite rail, per se?

A: R. Ganeriwal - Yes.

H. Decker - Composite rail is going to run a lot higher than steel rail. But if you look at the installed cost, on a ready-to-run basis, as Mr. Houston has suggested, and which is in line with the system approach that I suggested this morning, then I think the costs are going to be very comparable. In fact, the cost analyses I have seen, on the basis of energy savings alone--and I don't care who's made them--have always shown that in a reasonable period of time, less than 15 years, the added cost of composite rail has always been offset by the savings in energy losses, and they have been based on energy costs which are lower than they are today. I am of the opinion at the moment that it is a kind of a toss-up situation on an installed basis.

Q: R. Ganeriwal - We in turn came up with the same conclusion. That is why I asked so many questions. If you don't eliminate a substation on a given route, then according to us, you can never fail with composite rail.

A: H. Decker - The analyses I have seen contradict that.

A. Houston - There are two separate problems here. One is substation location and the other is reduction in the running rail. The substation problem develops a two sided curve for cost effectiveness. You can have substations too close together and your capital cost will get out of hand so it is not cost effective. You also can have them too far apart in which case the consumption (losses) along the rail is too great. Regardless of what rail material you use, whether it is steel, gold, aluminum, or anything else, the problem is that about one-half to two-thirds of that loss is in the running rail, and there is nothing being done about it. So there are really two separate problems, even though they are related. As far as locating substations is concerned, the principal thing is to locate them where your greatest load density is going to be. When you plot cut a curve of the load distribution along the right of way, what strikes you quickly is the two great big envelopes of in-bound and out-bound accelerating trains coming out of the passenger stations. This gives you a key as to where the substations ought to go--as close as possible to the greatest density of current that you might have. There's an old rule of thumb in power distribution that says that in laying out an area, you place your supply as close to the center of gravity of the load as possible to reduce your losses and improve your regulation throughout the distribution. The same factor applies here except that we are stretched out in a linear distance rather than in an area. You have a parallel arrangement on the DC side, and you've got essentially the same problems that you would have in laying out an area distribution system. I think the thing you want to do is emphasize a reduction in I^2R loss. If you do that, you automatically improve your regulation. There are two things that can be done. One is properly locating the substations, and the other is reducing the rail resistance.

L. Pinkney, WMATA - I understand what you are saying. Since your heaviest current draw will be at the stations, effectively what you are saying is to locate the substations at the passenger stations.

A. Houston - It turns out that way, yes.

L. Pinkney - If you do that, I find it difficult to believe that you are going to recover the savings in energy costs for this reason: if you make a study of locating your substations according to your current distribution, and then make another study locating your substations according to voltage drop, I'm pretty sure there's a good possibility that you would come up with two different workable schemes. I think you'd have to look at which one is more economical.

A. Houston - This is exactly the situation that comes up in favor of judiciously placing additional substations. For example, under what we call our D96 study which was done five or six years ago, they had gone on a voltage drop basis, and they had located nine substations along a 13 mile right of way. It turned out that in a couple of locations, two passenger stations wound up between two substations. It seemed wrong to draw this large, 9,000 amperes on two accelerating trains several thousand feet down the right of way from the substation, when the load lasts anywhere from 10 to 20 seconds depending on the topography and whether you are going uphill or downhill. In re-evaluating this, we went from 9 to 12 substations, an increase of 3. Now you can also take advantage of the fact that you only have to open up that ground (to excavate) one time at a passenger station and do not have to remobilize for a substation excavation, elsewhere. You are merely extending your passenger station excavation, providing room area to put the electrical equipment in. You may put more substations in, but you shorten the distance between them, so that you have inherently decreased the resistance in proportion to the length of the rail, both the contact rail and the running rail, reducing the total losses. This in turn justified our adding three substations to the systems and we could write this increased cost off in 15 years.

Q: H. Decker, TSC - You mentioned the two alternatives where you increased the number of substations by three. What was the total installed capacity of all substations with the two alternates? Were they the same?

A: A Houston - Basically they were three megawatt units or six total megawatts in the duplex system. Actually, the system would run on one 3 megawatt station. By increasing the number of stations, we went down from 3 to 2 1/2 megawatt units. Power is power, regardless of what you do with it. But if you break it up into smaller increments, obviously, you can reduce the size of the increments.

Q: E. Rowe, MBTA - Mr. Houston, did you say that it was a lesser amount of money to construct a traction substation at a passenger station?

A: A. Houston: In effect, yes because the bulk of the cost is in the passenger station itself. You're adding one more room to it.

E. Rowe - Our experience has indicated that it is more work to construct a traction substation than a passenger station, basically because you have greater concern for the aesthetics of the area, more than you would out in the right of way.

A. Houston - That's the difference between properties, perhaps. It turns out that in our aerial structures we can very handsomely put the substation at ground level underneath the structure, and no special dressing has to be done to the structure. Underground, who cares, it is covered up with dirt anyhow.

E. Rowe - We don't put them underground, but that's beside the point. This brings up one point that I would like to make. In no way do I expect this session or any session to come out with a set of hard and fast ground rules that are applicable to all properties. I think each property has to stop and consider all of the alternatives that are available to it, and pick the one that is most acceptable to it. Now if Maryland finds the best way is to put substations at the passenger stations, so be it. But I don't think that we're ever going to agree on a hard and fast set of rules, that this is the way the system's got to be.

R. Ganeriwal - I have seen some of these numbers associated with power and cost savings. I would like to say that many times people tend to take the worst case, which is the starting current surge, and calculate all the losses for that current. They do not realize that the surge is of very short duration, as Dr. Kusko mentioned this morning, such as 30,000 amps. for 20 seconds time. That might distort the picture quite a bit on the power cost data.

R. Swindell - If anyone took 30,000 amps and used that to calculate a year's load, they'd better come up with some pretty big dollar savings. Just to show you that we are not guilty of that, the $2500 that we saved in 1973 was based on the computer printout of what our load would be with our schedule, and what the currents and voltages actually are. If you don't do that, you're fooling yourself.

R. Ganeriwal - I have no problems with your numbers at all, but I've seen sometimes numbers which are in the hundreds of thousands of dollars for the cost savings, and I cannot believe it.

R. Swindell - You have to look at your overall schedule and what your acceleration and decleration is, what curves you've got, whether it is uphill or downhill, what the signals do to you, and so on.

E. Rowe - I think that when you are talking about cost data, it is odd to say you save $2,500 or $3,000 or $100,000. We are dealing with power costs of approximately ten million dollars a year, so if you save $2,500, it is really insignificant. Our selection of composite was not based on power savings, it was based upon the ability to space the substations a little farther apart.

J. Dyer - What Mr. Houston says about the voltage curves on normal trains, and I'll call them the old fashioned, cam controlled trains, is true. You get about a 20 second starting current surge. It is an altogether different picture when you get into chopper controlled trains. Choppers carry (draw) that maximum current for the full acceleration period. They start at a lower current and build up to a maximum current, so it (chopper) changes the picture there. There are a lot of variables, as you say, and each property has to make its own decision based on its own facts.

Q: H. Decker - I have a question that I think was addressed in a somewhat indirect fashion by the representatives of three properties that spoke. But I'd like to hear from the two suppliers, and I'm surprised the question hasn't come from the floor. In either the Porter rail or the Insul-8 rail, are any special appurtenances required, such as the insulators, or the chairs that support the rail, or the rail anchors and the end approaches? What kind of auxiliary hardware goes with it, and does this mean a property might have to stock two kinds of insulators if it has composite and plain steel rail?

J. Corl, Insul-8 - The insulators, for example, are different. The only difference between them is the cap on the porcelain insulator. The insulator is different for composite than it would be for a 150 lb rail because it does have shoulders over the top. Therefore, if there is 150 lb steel rail and composite rail on the same system, they would have to inventory. Now as far as the anchors go, I have never really dealt with the anchors on the 150 lb rail. We've always used Shield anchors. They are accepted all over, everyplace. The anchors are the same, for example, on the 115 lb rail as on 85. The end approaches would fit onto the same rail that you're using, either way they'd be the same. There have been discussions about transitions between one kind of rail and the other. As long as the head of both rails have the same contour, most properties do not worry about the transition, because there is a gap between sections of rail. You're not butting up two kinds of rails, in most instances.

R. Lillard, H.K. Porter - We have participated by supplying our composite rail in both Boston and Chicago. In Chicago, we supplied X thousand feet of TRANSDUCTOR™. We also supplied under the purchase order so many sections of the same plain steel rail that we used in our TRANSDUCTOR™ fabrication. The purpose of this was for their use on their own lines, in their yards, or for end approaches. On the MBTA, for Haymarket North we supplied the anchors, expansion joints, the end approaches, the insulators, and various appurtenances. In their case, they had 85 pound rail appurtenances in their system, so with the TRANSDUCTOR™ 85, there is no difference. In the same way on the CTA with 80 and 85 pound rail TRANSDUCTOR™, and 80 and 85 configurations there is no problem. The one point brought out on the insulators, is the rail base itself. Is the rail base 5 3/16 versus 5, or 2 3/4 inches? That is the only difference.

INSPECTION TRIP HAYMARKET NORTH EXTENSION

INSPECTION TRIP

Haymarket North Extension, MBTA
September 15, 1977

One the morning of September 15, 1977, approximately 50 people were taken by MBTA bus to the Wellington yards of the MBTA's Haymarket North Extension, which was built with composite third rail on main line track and 85 pound ASCE third rail in the yards and service tracks.

Outside the repair shops, representatives of H.K. Porter Company, Inc. and Huck Manufacturing Company demonstrated the joining of composite rail by the use of Huck bolts. Following a quick tour of the new Wellington Repair Shop, the group assembled at the junction of the main line tracks and the lead track to the yards. This location provided the opportunity of inspecting, under actual service conditions, the following:

Composite third rail in main line track.
Joints in composite third rail.
Joints between composite third rail and end approaches.
Cable connections to composite third rail.
Cable connections to running rail.
Cable connections to 85 lb third rail.
Anchors on composite third rail.

The group then visited the newest MBTA substation at Oak Grove and returned to Transportation Systems Center for lunch and the afternoon round table discussion.

The following photographs show some of the inspection trip activities.


HUCK

ROUND TABLE DISCUSSION
SEPTEMBER 15, 1977

Harold D. Decker
Moderator

ROUND TABLE DISCUSSION
Thursday Afternoon, September 15, 1977

Moderator: Harold D. Decker, Project Engineer
Transportation Systems Center

Following the field inspection trip, participants in the seminar reconvened at the Transportation Systems Center for a Round Table Discussion of problems concerned with the design, installation, maintenance and operation of the various types of third rail materials that have been used by transit and commuter rail systems. The discussion provided a forum in which any participant could ask questions concerning the installation, maintenance, operation and economics of composite rail, and receive answers from other participants who had first hand experience with composite rail, or who were manufacturers of it. It was hoped that this approach would result in the dissemination of accurate and comprehensive information concerning the advantages and disadvantages of composite third rail relative to the older, conventional steel third rail.

The material contained in this section was transcribed from the tape recordings made during the discussions. The speakers have been identified to the extent practicable. The transcripts were edited only to the extent necessary to remove redundancies, repetition, and extraneous remarks. In a few instances, the recording was unintelligible; in these instances, the word "unclear" appears in parentheses. In two instances where the tape was unintelligible and the material was considered important, the point in doubt was resolved by telephone conversation with the speaker. In some cases, clarifying words have been added, and are noted by enclosing them in parentheses. The material presented is considered to be a reasonably accurate, but necessarily imperfect, record of the discussions.

ROUND TABLE DISCUSSION SEPTEMBER 15, 1977

Discussion of Engineering, Economic, Installation, Operating And Maintenance Aspects on the Use of Composite Third Rail.

J. Webb, DMJM - Perhaps Joe Dyer can answer this. In your specifications you had a 500 hour salt spray test. What did you use for acceptance or rejection on that test?

J. Dyer, LDP - I don't remember. It was a long time ago.

J. Spiringer, H.K. Porter - I think I can answer that. We took resistance readings before and after the salt spray test. We charted the locations so we could take readings from exact locations prior to and after the test.

J. Webb - You took your readings. What constituted an acceptance?

J. Spiringer - There was nothing in the specifications saying that it had to meet such and such, within a certain percentage. What they wanted to find out is how much the resistance would change. During the two tests the resistance change was nominal and it was accepted.

D. Newman, NYCTA - You spoke yesterday of life cycle costing, and the indications from both Boston and Chicago were that the installation costs of 150 pound rail and the composite rail were relatively the same within 3 to 5 percent. The power saving, if you weren't going to eliminate substations, was also not significant. It seems that the significant factor might be the maintenance cost over the 50 or 60 year expected life. Has Chicago or Boston done any projections of maintenance cost differences?

R. Swindell, CTA - I really don't feel that there's going to be any differences in the maintenance costs between the two types of rail. The base rail is the same in both cases. If you were talking our system, for instance, we say our 144 pound rail will last a hundred years. We say the 60 to 80 pound will last about 60 years. Now if you want to say in that 40 year interim there is a difference, that may be. But over a period of 60 years, there will not be any difference, in my opinion, in the maintenance cost of one versus the maintenance cost of the other.

J. Dyer - One of the important factors, to us, on composite rail, is the high currents which you see back at the circuit breaker (under fault conditions). We've had problems on the system with the breakers not opening because there is not enough current through some of our longer sections to make the breaker trip (under a fault).

With the composite rail, with the extra 3,000,000 circular mils of copper equivalent or a 6,000,000 circular mil rail, we get half the resistance of the steel rail and that is enough to increase the current to take the circuits out. We had a problem at South Station where we had a fire. The breakers did not open 9500 feet away. We calculated we had only 1500 amps there. If we had had composite rail in there, instead of 85 pound rail, the breakers would have opened.

D. Newman - That's comparing to 85 pound rail, but comparing to 150 pound rail ---?

J. Dyer - We had 150 pound rail just short of that point. We have been changing the 85 pound rail out. This was the 85 pound rail that had been there since 1907. We were in the process of changing to 150 pound rail to agree with the South Shore Extension. We were having shoe wear difficulties. Some was on the 85 pound rail with a 12 inch radius head. The shoes were all wearing to the smaller curve. When they sat on a 150 pound rail, with 24 inch radius they were sitting on the two outside edges. We were bearing on two spots 1/8 inch wide; our current density was way up and we were having rooster tails behind the train. We knew we had to change the whole line out, but the money ran out 500 feet short of South Station and we hadn't changed the contact rail at that time.

If we had had a composite rail, a high-conductive rail in there, the circuit breakers would have tripped and we would not have had the serious problems we did.

H. Decker, TSC - I would like to add one comment, Mr. Newman. I believe the comparisons of costs were done in early 1973. At that particular time, we hadn't been faced with the rapid escalation of energy costs, and the rapid escalation of prices. Some of the analyses I have seen that are recent, and use current figures for both types of rail and for energy, show that there is a significant savings in the energy because energy cost has gone up at a much faster rate than the cost of materials.

R. Swindell - I want to bring out the point that on our initial installation we were trying to do some different things with the existing property. We had two substations on the branch that are approximately 3 miles apart. They were situated in such a location that for low-density loads, the old 4,000 series cars with trolley poles, we could operate. But to allow us to increase our service, to increase the number of trains, and use newer trains which use a higher amount of current, we had to make some kind of a change, and that is the reason we went to third rail. With substations 3 miles apart, we had the option of spending $580,000 to put in 144 pound rail, and possibly end up putting in another substation for a million dollars. You can put in aluminum clad rail at $604,000 and not put in that substation. In our case, it was very borderline. Now to get back to the point about short circuit capacity. With 144 pound rail on a stretch like that, I would not advise anybody to put in substations three miles apart. We had only 200 amps more of short circuit current than we would have had for full load. You just cannot distinguish between full loads and short circuit under those conditions. You've got to get those breakers open. It is really more important to be able to open a breaker with third rail than it is with overhead trolley wires because I think you're more likely to have problems. This is some of the rationale that we used.

H. Fleige, BART - I would like to point out that all these functional arrangements did not apply to BART. BART specified a rail of 0.002 ohms per 1000 feet. This rail could have been steel or composite, and the only difference in BART would have been the installation cost because of the higher weight of steel. We would not have had any savings in energy because once the resistance is specified, the losses are fixed. The only benefit you get from composite rail is light weight. For new installations, once the design is fixed and the substations have been spaced, it doesn't matter whether you get steel or composite rail, you gain only in the weight for installation purposes.

R. Swindell - But then you penalized for weight. It did make a difference to you? You didn't want 400 pound rails?

H. Fleige - That's right. We thought for repairs and maintenance that a lighter weight was more desireable. It didn't give us any other benefits.

A. Houston - But obviously you thought the lighter weight was enough benefit that you penalized for extra weight so it does make a difference to you.

H. Fleige - Yes, that is correct.

R. Ganeriwal - One area of general concern that has not been raised here is the so-called stray voltages. Transit systems that are being designed, or are like BART, have their running rails insulated from ground. The stray voltages which appear from running rail to ground will go up if you space the substations farther apart. I would like to ask this question of BART. With -- (unclear) --- located, do you use composite rail and space the substations farther apart, and if so how do you handle the stray voltages?

H. Fleige - Well, you're right. The longer the distance between substations, the higher the potential difference between the running rail and ground. I think that that problem has to be solved differently than by spacing the substations closer. I think that it would be very uneconomical to do that. If there is a possibility of spacing substations farther apart, I don't think we should be discouraged by the fact that it also raises the stray voltage between running rail and ground. That problem has to be dealt with differently.

J. Webb - That does concern us, how you do it. Does BART have a solution to their problem yet?

H. Fleige - No, not really. We do have a problem, but it isn't serious , and there are several methods that can be used. It depends on whether you worry about the maintenance people getting slight shocks, or the patrons standing on the platform. We do not have a single complaint up to this time from a patron experiencing a shock. But we foresee this as a possibility, particularly since we have gone to diode grounding which raises that voltage more than it is now. We are considering, if it becomes a problem, coating the platform edges and insulating them, and maybe coating the cars, with an epoxy coating.

A. Houston - The outside of the car bodies?

H. Fleige - Yes, the outside of the car bodies. On our train destination sign we do flash the message once in a while, "Do not touch the train", for that reason.

------ There was a report that BART read about 200 volts to ground on a platform. Is that true?

H. Fleige - To the best of my knowledge, we have measured the (voltage) spike with the diodes in operation, and we found 150 volt spikes of very short duration.

R. Ganeriwal - That is exactly what my concern has been. You may save some money on your substations, but maybe the solution to the problem (of exposure to shock) would cost more than what you save on your substations.

A. Houston - That is one of the advantages of spacing your substations closer together. You reduce your stray current and you reduce the potential to ground, one is related to the other.

H. Fleige - We reduce the voltage problem. The voltage drop is a function of the length.

A. Houston - Exactly. If you decrease your substation spacing, you reduce the I-R drop along the running rail, which is the passive circuit that is supplying the necessary voltage to create stray current. You accomplish both things; you reduce your stray current, you reduce the voltage on the rail.

H. Fleige - Another method is used in Munich: whenever the voltage reaches a certain point, the running rail will be temporarily solidly grounded at that point.

------ But that also costs money.

H. Fleige - We do not feel we have a serious problem even though out substations are two miles apart.

R. Ganeriwal - That's the point I was trying to bring up. For every site with composite rail, it doesn't mean that there are only cost benefits. There are other problems associated with composite rail ---.

R. Swindell - At any place on your system, theoretically, the voltage on the running rail can be exactly half of what your potential output from the substation is if you happen to have a short circuit at that particular location. It's got to go that high. As far as stray currents are concerned, you're talking about getting 5, 10, or 15 volts, which is extremely high, on your running rail. Most of the systems nowadays that are being designed with ATC and ATO have the running rail insulated from ground, so you don't have the problems that we used to have with stray currents getting into the utilities and causing electrolysis problems. One good way to keep from getting shocked on your platform is to not put anything within 6 to 8 feet of the train that is grounded. These are things that you can consider in design of the station itself. As far as their spikes of 150 volts is concerned, you can have substations next to each other and get transient spikes that can be quite high. On the DC positive circuit it can be as high as 1800 volts, on a 600 volt system. I don't think you can protect yourself against all of these spikes.

E. Rowe - Chicago and Boston are using substations spacings that are kind of long. But I believe that regardless of what the spacing of the substations is, you can still have this problem. Even in our newer systems, the Haymarket North Extension, where we use rubber tie pads - and I consider those running rails insulated from ground - there is nothing that precludes some drainage or leakage through the tie and into the ballast. We're not without our electrolysis problems. I think it is due to the age of our system and the fact that we have a tremendous amount of street car operations with rails right in the asphalt pavement. There is nothing whatsoever that can be done that I know of, within the realm of practicability to insulate those running rails. As far as the spacing of the substations goes, I agree with what Ron Swindell concludes. The effect would be on electrolysis in any system. It's something that we as transit operators have to accept as maybe the best effort to diminish electrolysis.
I don't think we'll ever get rid of it.

J. Dyer - One of the things we did do, though, and we started it way back in Boston elevated railway with manual substations and a lot of streetcar operations, was to provide electrolytic switches in the basement of every substation. These switches were available to all the utilities. The gas and electric companies, and Western Union at one time, would bring their own cables into the basement of the substation and connect (the sheaths) to the electrolytic switch. That switch was open when the substation was down and closed when the first machine went on the line. That collected into a metallic path all the stray current that got into the utilities system. We still do that at new substations. We provide five automatic contactors, not circuit breakers, in the basement of each substation. These are available to utilities. They supply the cable and we provide the labor to install it. The contactors are automatically interlocked with the station so when the station goes off the line, they open, and when the first machine goes on, they close. These collect the stray currents from the cables. We have used these for many years, and we have found it very effective. We collect up to 3 or 4,000 amperes at a time. So you should provide a path for the stray currents to get back on. I think that we all know that one ampere will take 15 to 20 pounds of steel a year off a steel pipe. It will take up to 75 pounds of lead off a lead sheath or pipe, so it's a real problem when we're talking about thousands of amperes. We are talking about 3,000 times 75 pounds of lead leaving the cable. It has always been a design standard of ours to provide a path for the current to get back to the substation.

H. Fleige - I don't know whether that technique requires clarification, but we are dealing with two problems, the stray current and the potential from the running rail to ground. Now to fight stray currents, we usually increase the potential from the running rail to ground. So whatever you do to alleviate one, you worsen the other one.

R. Ganeriwal - If you bring the stray currents back it will increase the stray voltage problem?

A. Houston - I can't buy that. If you don't have a voltage drop on that running rail, you're not going to have stray currents. For example, some properties use a fourth rail to return the current. They have no stray current problems, because the return rail is insulated. Here you effectively are grounded. Did you tell me sometime back that you measured about 9 ohms to ground in the running rail when it is wet, and about 15 when it is dry? This is less resistance than the 25 ohms maximum permitted by the National Electric Code. So effectively you are grounded, even though for communication purposes you may be substantially ungrounded. But it is the leakage current that goes from one point of the running rail to another point of the running rail, or to another point of the structure and returns back, or to a pipeline and returns back, that causes electrolysis problems. If you get rid of or reduce the stray voltage, you're going to reduce the effects of the stray currents.

------ The leakage current is such that it creates serious problems on other people's property. It has nothing to do with the dangerous voltage which exists between the running rail and ground. In fact, we mentioned that if you have a fourth conductor, that conductor or negative return is hot with respect to ground. The reason you don't have to worry about it is that nobody touches it. If the trains are sitting on the running rail and the public touches the trains, a poor conductor is................

A. Houston - With a good conductor and good insulation, you've got a high voltage and should be able to read it with a volt meter that is sensitive enough. You probably have some voltage to ground. But there isn't sufficient current flow over a human body to be noticed. You've got the insulation on the other side that completes the circuit. You have two choices: either you completely insulate, or you completely ground, if you want to protect the individual.

H. Fleige - Right. But if you completely ground, you have a very high stray current. If you put the whole running rail in dirt, in ground, you have a very high stray current problem. You have no problem of dangerous voltage.

A. Houston - Exactly.

H. Fleige - And if you insulate completely, you do not have any stray current problems, but you have a very high voltage to ground and a dangerous voltage.

A. Houston - The point is, if you reduce the voltage along the rail, you reduce the stray current effect, even though you may be solidly grounded.

H. Fleige - The only current which produces the dangerous voltage to ground is the normal return current, not the stray current.

A. Houston - If you've got a parallel path, it comes off the running rail that produces the stray current. The stray current finds its way back by another path to the negative bus. You can't get away from that. And the potential that causes that is the potential on your running rail.

H. Fleige - That's right.

R. Ganeriwal - The only way to solve both problems is by having a running rail that has no resistance.

A. Houston - Exactly. That goes to the other extreme.

A. Wacker - But an insulated running rail is not low resistance.

R. Ganeriwal - If the substation is floating, you do not have that IR drop in the running rail.

A. Houston - Well, that's another side of things.

R. Ganeriwal - My question to BART was, if they had experienced high voltages. If new properties space their substations out and use composite rail, they're going to have the same problem and maybe much more. What's the solution to it?

H. Fleige - I don't believe that the answer is putting substations closer together.

R. Ganeriwal - You don't have a solution to ---

R. Swindell - Do you have a problem with it? Have you had people get shocked?

H. Fleige - No.

R. Swindell - We've never had people get shocked.

H. Fleige - Your running rail is not insulated, is it?

R. Swindell - Certainly it is.

H. Fleige - In what way?

R. Swindell - All the running rails are insulated from each other. You cannot operate an ATC or an ATO system ---

H. Fleige - You have a concrete ---

R. Swindell - A wooden tie.

H. Fleige - Do you have any concrete structures?

R. Swindell - Yes, we have one stretch of concrete structure, and those rails are insulated. The ballast itself is an insulator. I do not know of the ATC or ATO system that you can operate with grounded rails, because you short out the signal system.

R. Ganeriwal - What voltages have you measured between running rails and ground?

R. Swindell - I've seen five or six volts on elevated stations between an earth ground and the running rail. To my knowledge, we have never had anybody receive a shock by touching the train and/or the platform itself. We normally try to keep any grounded steel six feet away from the trains. But you can't put in a system and operate automatic train control if you've got grounded rail.

A. Houston - About two years ago we went up to PATCO and we instrumented and measured in a tunnel and out on the surface right-of-way, near Westmont station, which had no substation, and at Townsdale and Collinwood stations, which did have substations. We measured the voltage to ground, and we had the telephone company up there. Their control engineer told us they had lead sheath cables that ran about 500 feet off the center of the right-of-way and paralleled it for 10 miles. We used that as a ground reference, and we made the other connections for instrumentation to the running rail. We checked the cars and the trains and their schedules, and we ran over 24 hour tests. There was definitely an association between the current being drawn in that ring and returning through that running rail, and the voltage spikes that were showing up on the charts. During the two-train acceleration out of Westmont, we got about a 105 volt peak. Normally it ran between 30 to 40 volts; when there were no trains, there was no voltage to ground. So there's definitely an association between the current in the return rail and the voltage which you can expect to ground from the return rail. This can be predicted pretty much by the condition of the track and the current in the track. The resistance on that measured 0.04 ohms per mile. Over the entire 10 mile length, we had 4/10ths of an ohm total. That's damn near grounded.

R. Swindell - I think there's no question that if you've got R and you've got I, you've got E. I think we might face up to a fact which no one will dispute, that if you get things too far apart, you can raise that potential. I've seen a work train sitting on a track, and I've seen that train with a cable on it, lifting a grounded load off the platform and the cable burned in half. There was no high voltage, but there was high current. Although the voltage between the two was relatively low, you pulled a lot of current with very little voltage because you've got a good connection to ground somewhere. The voltage potential may have been only 6 or 7 volts.

H. Fleige - But these are the only complaints that we have had. The maintenance people and the track people bridging the running rails with some metal part that was grounded, see a lot of - sparking and a few low voltages to ground.

A. Houston - Another point I'd like to make. At Haddonfield, those substations were two miles apart. The ones in the tunnel section on the Philadelphia side were approximately a mile apart. There was just about half the voltage recorded in the tunnel, about 20 to 25 volts, where we had a 30 to 40 volt range outside, with the exception of the peaks that reached 105 volts. That was about midway between the two substations and we had two trains accelerating at the same time out of the station without the substation.

R. Swindell - Maybe the answer is to make sure that your negative return system is as good as your positive system.

A. Houston - On our elevated sections --- (unclear) --- we had somewhere between 15 to 20 million circular mils in the negative return, and that reduces the problem considerably.

H. Fleige - I don't think you can control everything, such as a telephone conductor, for stray currents and stray voltages.

A. Houston - It is a question of how much you want to tolerate economically. That's probably the answer to your question.

A Wacker - Does Chicago supplement the return rail by cables or other rails?

R. Swindell - A lot of times you do a calculation on what your negative return losses are. You figure that you have one rail that is so many circular mils and is bringing out your positive, and you have two rails that are taking back your negative. Generally, that's not the case. Generally, your schedule is such on your operations, that you have four rails taking back the negative. It's not one third rail out, the two running rails taking back the negative. It's one third rail out and maybe four return rails back, because you are running a double track railroad. You may have four, you may have three return rails, effectively, depending upon what your schedule is. If we've got four return rails - and on the north side we've got eight return rails - we have more ampacity on the negative than we've got on any one section of positive, because all running rails are cross bonded together. You really don't just figure your two return rails and one third rail; you have to figure all four return rails and look at your schedule and determine its effect. Maybe you have no trains going out and three trains going in, and two rails are completely unloaded. They are cross bonded together, and take some of the negative return current back. You've got to look at the whole system. Generally we figure that we've got four million circular mils in the negative return because we've got four rails.

--- If someone wishes, can he use a composite rail turned on its side as a guard rail?

R. Swindell - We're not for guard rail. We have one location where our negative system is very poor, and we are considering the possibility of putting in about 7,000 feet of aluminum clad rail, laying on its side to keep any of the trains from hitting it. And, as you would a guard rail, you use that as part of the negative return. Right now, the negative return comes out of the yard, goes down some street car tracks, comes to a bridge, goes up on a pole line, back down to the street, on to the street car tracks, into an underground cable, into our elevated section. What we'd like to do is get rid of all that risk. We've got some problems with it being in the street. First of all, it's completely inadequate, and secondly, contractors are always putting in a new sewer line and they are going to hit your negative, and the system stops. So we'd like to get on our own right-of-way. A much cheaper way than putting cable in would be to put some kind of rail in and lay it down. To get the capacity we want, without putting in two rails, we have been considering the possibility of putting in 7,000 feet of aluminum-clad rail which will get us from the yard to our elevated section, and then we would bond to the elevated structure.

J. Webb - You would just by-pass all that in the street?

R. Swindell - We would take it out. The utilities are after us in Chicago, primarily because we don't use our street car tracks any more, and it really works in reverse of what it used to. In fact, we are in the process now of installing negative contactors in the bridge feed sector in the cables that come from the streetcar rail, which we have to maintain because the city uses the 600 volts DC and we supply the power. What we're doing is, putting these contactors in so that except when they're actually using the bridge, those negatives are broken.

J. Webb - When they operate the bridge you close the contactors?

R. Swindell - Yes, they have to call us., and we close them and they can operate the bridge. I suspect there's enough ground in the city of Chicago so they could operate every bridge they've got without us closing the contactors.

D. Newman - How often do you cross-bond your rails in Chicago?

R. Swindell - With our weegee bonds I think we cross-bond about every 2,000 feet. It depends on the speed, and location on the system, the signal blocks. For the four rails, I think it's about every 2,000 feet.

D. Newman - Do you have areas of single rail track circuits?

R. Swindell - On the Congress St. route we do, we have the old conventional block signal.

D. Newman - How often do you cross-bond there?

R. Swindell - I can't answer, I don't know. We do have a second negative rail there, very similar to a guard rail. It runs down the track, so we do effectively have two tracks - two rails for each track for negative return.

J. Dyer - We run separate lengths of PVC covered copper cables on the single rail track circuits to supplement the system.

D. Newman - Do you cross-bond also?

D. Dyer - At some places we have three million circular mils of bare copper lying in the ballast. At some other places, like the Highland branch with single-rail track circuit, we couldn't run a copper conductor down the full length of the rails because we would short the signal system out, but in every other block we put in a million circular mil cable, all the way down. That helped us. We have had no voltage problem there. I think the real answer is to make the negative side of the system as good as the positive side. People have known for many years the current will get back, and it will. If you can bring it back on the negative side, it may cost you money, but it is the answer.

R. Swindell - One of the biggest problems that arises to cause problems is the bonding. If you have a bond which fails, that shows up in electrolysis and elsewhere, I'm not sure what the effect of welded rail is, as we don't have much of it. I suppose you could have a bad joint. If that shows up, one way to get rid of the poor joint electrically would be to bond it, and to make sure that all those bonds are in good condition. Joint bars in the running rail are not sufficient. The joint has to be bonded. The effects will show in several places. It will show up in your signal system and it will definitely show up in the current you are carrying back, what percentage of the DC you're putting out on your positive cables as compared to what you're bringing back on the running rails. If you have half a dozen joints in a section of track that are bad, you're just not going to get all that current back on the running rails, you're going to lose 30, 40 or even 50% of it back into the utilities, and they'll soon be complaining to you. You've got to keep that negative system up to snuff.

H. Decker - I think we very pointedly brought out the fact that we have to keep our running rail return quite low in resistance, and the better the third rail is made, the worse that problem becomes. I'd like to toss out a suggestion for the manufacturers who are here, that maybe it's time to take a look at something good and cheap and simple that they might do to help the transit industry. Perhaps it's something that they ought to give a little bit of thought to. I don't know whether this is within APTA's province or not, but I think it's a serious problem. Certainly the running rail return is becoming of increasing concern as the resistance in the contact rail goes down.

J. Dyer - I've heard various figures during this conference, on the installation costs of composite rail. Ron Swindell said he figured on installing 40 sections a night, and 80 went in eventually. I think we had 60 installed at one point. How are the cost figures that have been mentioned here been arrived at? Back in 1972 there wasn't that much experience with installation practices and costs, how many men are required on a crew, how many sections can be installed in a night. I think something like that should be updated using up-to-date figures before we go throwing them around.

H. Decker - Absolutely. I don't know where the earlier information came from for the Huck Bolted rail. There was a lot of experience in the past with the welded rail, and I think those cost figures are probably quite legitimate. But on the Huck bolted rail, I'm in total agreement with you. I do not know where some of those old cost figures were derived from. I do feel on the basis of the installations that have been made to date, you can come up with some really valid costs. I guess dollar figures are not the right way to look at them. But labor hours are. How many joints per shift per man, or per crew, that would be installed, is the best criterion. Wages always go up, material costs go up. So if we know we can do 60, 40, or 30 joints per day at least we have a pretty good handle on what the joining costs of the types of composite rail are.

R. Lillard - Initially we got into this with the composite versus the welded rail. As you pointed out, the welded rail has been around for a while, so the numbers that we use for comparison are pretty factual. The numbers for the installation of composite rail are in the initial stages. When we started working with CTA and MBTA the numbers were basically H.K. Porter numbers, as far as labor was concerned. We talked to track personnel at both sites, and took a round, fat number, Are you talking about 10 sections a shift, or are you talking about a hundred? That's how we arrived at the numbers that we started with initially, just for comparison's sake, in discussions with transit authorities. We were considering this not only for revenue systems, but for new systems without Porter rail. And the point is very valid, even more now than before, since we do have the background of two rather new transit system installations. We derived other benefits from these, and it's no longer Jim Spiringer or Dick Lillard saying that you could make a joint in three minutes. We are the supplier. Now we have operating-properties experience to use. We went through a rather long, disheartening series of discussions with an authority in the southeast portion of the United States. We quoted numbers of the same conservative values and of course, they said it is not so. We showed improved cost savings and performance. We have a thick volume in which we put valid numbers. We're right now going back and updating it.

J. Webb - I think there has to be a difference in dollar cost between new construction and systems in revenue service because with new construction you've got a right-of-way that you can use all day long at straight time. With systems in revenue service, you're going to work on weekends and possibly spend time and a half or double time for labor.

R. Lillard - We had both situations. CTA was operating, and the MBTA's Haymarket North was a new installation that had a clean right-of-way. I very firmly believe that our numbers were, in fact, conservative, but they were very realistic, whether people believed them or not.

G. Grant - One of the big questions System X protested was the time it took to do a weld vs a Huck bolted joint. We even gave in on that point. From personally talking to the people that have done this type of a job, I'd say that it takes an hour and a half to weld a joint, and we conceded to half an hour, because that's what they said they could do. Even playing that game, the dollar savings for the length they were talking about was considerable, up in the area of a quarter of a million. Later they turned around and conceded that our figures were low, after they had made us use the half hour for the welded joint.

R. Lillard - The numbers that were brought to light yesterday indicated a cost difference of composite rail versus welded steel rail of basically a dollar a foot. Some questions came up with regard to these numbers, and that there was more than a dollar a foot difference. I am sure they were looking at the all steel rail at so much a foot, versus composite rail at so much a foot, whereas a dollar a foot difference results when you get all of the tangibles together, and you start trading back and forth. This is important.

H. Decker - The costs should be compared, as Mr. Houston mentioned yesterday, on a ready-to-run basis.

A. Houston - If nothing else, that's one of the most important facts that you must consider-the ready to run basis for cost comparisons.

H. Fleige - I do not want to knock the bolted joint. But you people talk so much about the welded joint and we prefer welded joints, I would like to see this put in the proper perspective. How much does one mile of bolted third rail cost, including the installation, the insulators and the third rail itself? Do you have any figures available on a per mile basis?

R. Lillard - We have costs on previous programs which we furnished both to the CTA and to the MBTA. We have given budgentary numbers, some a few months ago and some a few weeks ago. Right now, you must look at current day costs. I can give a cost today, per mile, composite, on our design.

H. Fleige - Very round figures, very round figures.

R. Lillard - The way the materials are fluctuating right now ---

H. Fleige - I am trying to make a point. It is fifty thousand dollars or a hundred thousand dollars?

R. Lillard - Per mile?

H. Fleige - Yes, per mile. Just a round figure, any round figure. Plus or minus 50%. Including insulators, parts, cover board.

R. Lillard - A good round, barnyard number, about $150,000 a mile.

H. Fleige - How much?

R. Lillard - $157,000.

H. Fleige - $157,000 per mile? We have 60 foot long rail sections. How many joints are we taking about in a mile?

R. Lillard - That's 60 into 5280.

H. Fleige - How much?

R. Lillard - A hundred, roughly.

H. Fleige - So we save, and this is my estimate, let's say, half an hour, bolted versus welded joints.

W. Miller - Well, I have one question before you get into that ---

H. Fleige - I just want to get it in perspective, I don't want to favor one side or the other one, under false pretenses.

W. Miller - No, what I would like to do is get it back to the apples to apples basis. When you talk about doing full welds you have to weld steel, and you have to weld aluminum. How many welds are you talking about in that one joint, doing it your way?

H. Fleige - We can make the welds in an hour very easily. But I have a suspicion that even in material costs for a bolted joint, the material costs at least as much as the expert costs for the welded joint. Also, there is very little material cost for a welded joint.

W. Miller - That's unreasonable. Don't tell me there are no material costs in a welding shop.

H. Fleige - But nothing compared to the bolts and splice plates. We found out that they are quite expensive. It think we paid about $8. for a splice plate and bolts.

W. Miller - For fish plates or aluminum splice bars?

H. Fleige - Aluminum splice plates.
--- I think if you check, this was a very low cost and the man in supply really didn't know what he was supplying.

H. Fleige - After 20 years, can you still get aluminum splice plates? You can always make a weld.

W. Miller - The cadweld kit itself for 150 pound rails cost about $35.

H. Fleige - I'm not talking about 150 pound rail welds. I'm talking about composite rail welds.

W. Miller - What you're trying to ask is what is the comparative cost of welding composite conductors such as you have, against the same cost for using a splice joint. If I understand you correctly you are saying that you can get this in lengths that are greater than 39 feet?

H. Fleige - We do have 60 foot sections.

W. Miller - Alright, but those 60 foot sections have to be put together, so the question I come back to so you compare apples to apples is that no matter how you do the thing, you have to make a certain number of welds to make a finished length. Now how many welds do you have to make to come up with a realistic cost for comparison? I don't know your process, but I assume that you have to weld the steel, and you have to cut your aluminum back to weld that steel so you don't ---

H. Fleige - It's a very simple operation. You grind the edges of the steel. It may take a little bit more time, but we are hearing that it takes two or three minutes for putting the bolt in, grabbing the tool and doing the job; It does not take a thousand other things into account. Particularly during repairs, you have to pre-drill the rails very accurately, and this is not simple.

W. Miller - I don't think I quite understand the ---

H. Fleige - This is what I mean. I'm looking at it from a maintenance point of view. We have to see the whole picture.

W. Miller - We are trying to put it on an apple to apple basis. It's nine munutes to drill that hole if you have to do this in an adverse situation to put in a section. Now, assume you have to drill four holes. You get a splice joint in and we'll assume you can't take advantage of the Huck bolt, where you can knock it out; you have to literally go back and drill the four holes. That's 18 minutes.

H. Fleige - It might cost $175 out of a mile, so what does a half hour saving mean over all?

W. Miller - Well, that's 18 minutes, plus three minutes to put the joint in, or 21 minutes. How long did it take you to make that weld? You have two joints now, you have two welds to make, so that's two hours. Or, if you have two crews going, you're talking about twice the number of men you otherwise need to do that operation. I'm trying not to be argumentative, but to put the figures and the situations we run in to on an apples to apples basis and you can push away the ---

H. Fleige - That is right, put it on an apples to apples basis. The overall costs, the three minutes, is very very ---

---------------- Let's work it out. Use an hour for a gang. How many do you have in a gang, five men? So that's five hours times 100 joints. That's five hundred hours.

R. Swindell - Gentlemen, I don't know if any of you have ever been to a derailment. It probably takes three hours or so to get the train back on the tracks, or two hours, depending on what the situation is. Believe me, you can drill a lot of holes while you're sitting there waiting for a utility to come out and get your train on the track, and nobody cares about the time for a joint. The only difference that I can see between a welded joint and a jointed piece of rail, steel rail welded compared to our composite or bolted rail, is the fact that if you do have a derailment, the chances are that you are not going to damage the rail with a jointed rail, because the joint will bend. Now we've had more derailments than we care to admit. In the 18 years I've been there, we have had to replace exactly one piece of rail because of a derailment. We go out there and look at the situation, and the only thing we do is replace the joint.

J. Dyer - We've had the same experience. The only rail we had to replace was one that got burned pretty badly.

R. Ganeriwal - In other words, the bolted joint acts like a break-away point.

J. Dyer - That's exactly right.

H. Fleige - But the accident has to happen at a joint.

J. Dyer - No, it doesn't. You can knock down 800 feet of (third) rail but it bends at the joints.

H. Fleige - This is very interesting. In other words, you actually look at the bolted joint as a break-away point, just like we run out pick-up shoes where we have a sharp break-away point. This has never been mentioned as one of the benefits of a bolted joint, that the rail breaks at a joint. That's definitely something to think about.

H. Decker - Perhaps we're beginning to lose perspective here. We're worrying about what it costs to make a welded joint in place of a bolted joint when we're trying to replace a piece of third rail after a derailment. My comment is basically, who really cares? If it cost $1,000 for one and $500 for the others, who cares? I think what we should be looking at are the capital costs of new construction and replacement or upgrading with both types of rail. I think that's where we ought to be looking, as opposed to the emergency repairs or replacements.

W. Miller - I don't really think we can come up with an answer to your question, because New York City Transit, for instance, uses a tip-over type insulator. Long Island uses another method, MBTA has their own, etc. They all do it for a purpose, so when you try to come up with a cost figure such as you're asking for, it all depends on what you're using. One figure doesn't fit everybody. It is not of serious concern until you get down to the point of starting to lay out your system and find what you are going to need, etcetera, and then you can take that total figure and come up with cost per mile.

A. Houston - Dick, do you have figures on new construction capital costs, ready to run, of 150 pound and composite rail?

R. Lillard - We've drawn some budgeting numbers, and they have to be updated, primarily, on the rail cost.

E. Rowe - I'll give you a typical figure, and I figure it cost us $110,000 a mile to put in Haymarket North. That includes everything, in place, ready to run.

J. Dyer - Fiberglass insulators were used, and they are a lot cheaper than porcelain.

E. Rowe - No they weren't, not when we got them.

---- Does any one have a price for 150 pound rail?

A. Houston - That's what I was going to ask, what would their price have been if you were going to 150 pound welded?

E. Rowe - I don't know, but I can find out what it cost us to put the South Shore line in. There is about five years difference in time.

H. Fleige - Does that include coverboard?

E. Rowe - We do not use coverboard.

H. Decker - One thing I would like to see is an estimate of their relative costs on some time basis. Ed, you said you had 110K per mile on Haymarket North installed, ready to run, with the Porter composite rail. Do you have corresponsing costs, or can you get them, for the South Shore extension with the 150 pound rail and cadweld joints?

E. Rowe - I'll get that, I don't have them.

H. Decker - I'd like to try and put those figures, if you agree, into the minutes of the meeting, as well as cost figures that have been experienced by one property. Ron, if you have anything of that nature, I would appreciate it too. It may be hard to come by. (See page 216 - TABLE A-1)

R. Swindell - It is, because on our system, when we do a job like this, we generally include the duct lines, the cables, the getaways to and from the substation, and that confuses the issue because it is dependent on how far you're running to the substation, and so on.

E. Rowe - We have a break-down. I should be able to get it for the South Shore line.

H. Decker - We're looking for a relative estimate on the order of magnitude of maybe plus or minus 10%, or so. We're not looking for it down to five decimal places.

E. Rowe - I'd like to go back and address the maintenance question. We experienced a derailment last might. On all the derailments that I've been involved in with our composite rail, and there have been five or six of them, the composite third rail does exactly what Ron said. The rail itself does not bend and you don't have to replace the rail. In the unlikely event that a derailment does bend a piece of rail, our experience has been to knock out the Huck bolts, get another 39 foot piece of predrilled rail and whatever else is needed and put that rail back in a hurry. The easiest thing that we have to do in a derailment is to put that third rail back.

H. Decker - Mr. Fleige, if I understood my short conversation with Mr. Mahon correctly, you do have a welding machine on BART for making welds on the composite rail. Is it possible to get a description of that welding machine?

H. Fleige - Yes, we will send pictures and a description of it. (See page 199 - APPENDIX B)

H. Decker - If I could get a picture and a description of the welder, I would like to include it in the proceedings of this conference, as an addendum to the minutes.

R. Swindell - Mr. Fleige, how do you weld your composite rails? Do you cadweld, or is it all done by one machine at one time?

H. Fleige - No, no it is a hand-welding process. It is not really an automatic machine.

R. Swindell - Is it an arc weld?

H. Fleige - It is a metal arc on the steel and on the aluminum. First we weld the steel, then ---

R. Swindell - You weld across the top of the head?

H. Fleige - Right.

R. Swindell - And then you have to grind that down?

H. Fleige - You grind it down. That operation takes 3 or 4 minutes with a hand grinder.

R. Swindell - How many men do you have in a crew when you weld the rail?

H. Fleige - Four men could do the job. Since it is usually done at night there are always some extra men standing around in case something unexpected happens.

R. Swindell - Can you do that hot?

H. Fleige - Oh, no. We don't touch that rail when it is hot.

E. Rowe - I'd like to add something. We found some loose bolts yesterday, and I went back and got the superintendent on the phone, and asked for an emergency crew. They came over and used a ratchet wrench on the hot rail. We do not deenergize the rail.

J. Dyer - We use a ratchet wrench with insulation on the handle.

H. Fleige - First, we have a little item of voltage; and second, our union just wouldn't hook up the rail live.

W. Miller - The composite rail is used in both Boston and Chicago. Is the rail worked hot, under emergency conditions, or in case of a burnout?

R. Swindell - We do almost all out work hot.

W. Miller - On the composite also?

R. Swindell - On anything. We rarely take the bar off. Rarely will Transportation allow us to.

W. Miller - That's our situation with the New York City Transit Authority, with a 150 pound contact rail, plus the other variations that we have.

J. Dyer - We stop service a 1:30 in the morning, so if it is possible and does not require overtime, we use night crews --- (unclear)

H. Fleige - The same is true on BART. We do not even run on Saturdays, we do not run at night or on weekends. So we have ample time to deenergize the rail and do the maintenance required.

R. Swindell - We found that under traffic in the daytime, we can put in 10 or 12 pieces of third rail, be it 144 pound steel or aluminum. We use fewer men if it's aluminum that we do if it's a heavier rail, since we need less to pick it up. But in changing rail under traffic, you've got to take out the chairs, put in your change in size of rail, and put in more chairs.

We've also found out that at night, on a single track, we can put in about 10 or 12 pieces of third rail. The reason is that it is much more difficult to work at night, particularly on the elevated section. You can put up artificial lighting until you think you have sunshine, but the shadows are still different than they are in the daytime. It is extremely dangerous to walk, and dangerous to touch anything. We found that we can do 10 or 12 pieces in the daytime under traffic, or we can do 10 or 12 pieces at night, at time and a half or double time, with a single track. Also, the men work about half as efficiently at night as they do in the daytime. In the subway, whether it is night or day doesn't matter.

E. Rowe - We can put in about six hours a night, but we only get four work hours. Ron, how many actual work hours are you getting at night?

R. Swindell - It depends on what line we're on and where we're at. I'd say about six, but we only get four or five in the daytime. In the daytime, we don't get eight hours work. We are not allowed on the railroad until 9:00 to 9;30 AM, and we've got to be off before 3:30 or 4:00 PM. One of the advantages of the Huck bolt is that when you're off the line at 3:30, that railroad is ready to run. We can Huck bolt those joints and walk away.

from them. We don't have to go back and put in a bond, a single bond on a regular 144 pound rail. Two days later we go back and put the other bond on. It just takes too much time.

J. Dyer - On the last job we did with 150 pound rails in place of the 85 on the Cambridge-Dorchester line, the track crew was way ahead of the welders. They were placing rail on the insulators. Well, we bought some things called Dorset connectors. They're big bronze clamps that are clamped on each side of a 150 pound rail joint, and we ran cables for jumpers between them. That was satisfactory for a temporary connection until the welders caught up with them.

H. Fleige - Have you ever welded your composite rail (on MBTA)?

J. Dyer - No. I was talking about 150 pound steel rail.

H. Fleige - But you never welded your composite rail?

J. Dyer - No. We had done some test sections ---

E. Rowe - I welded your rail with a heliarc welder, a metallic arc - inert gas welder. I did five sections. It takes about an hour to make a weld. It is a good way of welding rail. When we did this job the authority left the specifications as wide open as possible, for many reasons. We wanted to stimulate competition and not have anyone knocked out of the bidding processes. We permitted the bidder to bid with a welded joint, with a huck-bolted joint, or with a bolted joint. However, if you bid with a welded joint, you had to supply all the welding materials because the installation was not a part of the contract.

W. Miller - On a derailment, what did you (MBTA, CTA, BART) find about replacement of insulators?

J. Dyer - The last derailment that I remember was a big derailment, with 900 feet or rail down. We broke about half the insulators and had to replace them. They were fibergalss insulators. They break easily on a derailment, and sometimes you get fumes coming from them.

G. Grant - For the sake of discussion, so we can clear up a point, which insulator are you talking about here, the one we saw today or ---

J. Dyer - The fiberglass insulator, that is, two piece with an epoxy joint, the one we use for a standard insulator.

E. Rowe - The one you saw today, George.

J. Dyer - No no, not the one like that.

E. Rowe - We don't know yet what happens to those insulators (on Haymarket North) in a derailment.

---- Do these break because of a bolt that's loose? Do they break at the bolts, the holes?

J. Dyer - Some of them break at the bolt holes, some of them break at other points. It depends on where they are hit. The time that this rail came off, the motor fell off the car and subjected things to a pretty serious stress. It would have broken porcelain or anything else. It tore up 800 feet of track, pulled up all the ties, and we just put the third rail back on when we put the insulators back in place. The rail was okay.

R. Swindell - Our insulators are primarily the tip over type. They will support some force to the side, but very little. At 10 o'clock one night, I got a call that there was 2500 feet of third rail down on our Dan Ryan extension, and at 4:30 the next morning, we had all 2500 feet of it back up for morning operations. We only had three broken procelain insulators. I believe that was because they are tippable. We do allow them to tip over, rather than break. What happened at the extension was that a shoe broke off the train, got on the inside of the rail, and just laid it over. It wasn't a derailment.

---- These are porcelain insulators?

R. Swindell - Yes they're porcelain.

A. Wacker - Since you are talking about insulators that brings up a point. Clearly what I hear is that the Porter rail is the solution technically, but economically it is very undersupplied, and it may not be true.

---- Beg your pardon?

A. Wacker - If you're the only bidder there'll be no competition, and that price could be sky high. What we save on energy, a few watts here and there ---

H. Decker - Yesterday we had Jim Corl represent Insul-8, and I might add that in the audience, representatives from Kaiser, and Cleveland Crane were ---

A. Wacker - But in the discussions, they were all rules out.

H. Decker - Oh no, they weren't. They weren't ruled out for the discussion period, they were ruled out only for the presentation period because they were not present suppliers.

A. Wacker - No, during the discussion it was pointed out the different types of rail did not actually meet the specifications. The Porter rail is the one that really stands out.

R. Swindell - We tested Kaiser, we tested Cleveland Crane, we tested Insul-8, we tested Porter. The only fault that we found with any of the rails was the size of the head. That doesn't mean the Kaiser's rails are no good; I feel they need a bigger head on it. It doesn't mean the Insul-8 was no good. In fact, I think when we had our first bid opening for aluminum clad rail ---

F. Nichols, Kaiser - When we went to all of the trouble of putting on a bigger head which was welded to the I-beam, you still had worries about the contact between the aluminum and steel.

R. Swindell - I really don't think Kaiser Aluminum was serious about the application of that larger head to that steel rail. First of all, it made the rail extremely top heavy, and unstable. Secondly, I think the expense that they went to, to weld on a bigger head would have prohibited them from bidding. Kaiser Aluminum did bid on our job. They were not low bid unfortunately, and they bid the same general design of putting the aluminum on, except on 80 pound steel rails, as I recall. We did receive bids from Insul-8. Cleveland Crane did not bid, H.K. Porter bid, and a company called Brighton Construction Co. bid. To get what you want is a matter of writing an adequate specification. If there's enough quantity to interest suppliers, you will get bidders. We rejected the samples because of the type of wear we had, and the wearing material.

J. Dyer - We did the same thing (on MBTA). We were told about the process by which they manufactured the rails that are now being used by BART. If you had a heavy head on one side (of the steel) and the base on the other, you would end up with a big circle, with the curve toward the lesser mass. They couldn't manufacture that configuration.

A. Wacker - It would seem to me the way to do this, the way BART did it, regardless of specification, would be to allow the supplier complete freedom.

E. Rowe - That's how the MBTA did it. Our bids were very similar to CTA's, as I recall. The MBTA did not tell the manufacturer how he had to put that composite third rail together. We told them that they could either bolt it (the aluminum) on, or they could Huck bolt it, or they could extrude it around, or they could cast it in molten fashion. We allowed them to either have welded joints or bolted joints, or we allowed them to have Huck bolted joints. The specification was very wide open. H.K. Porter bid on the third rail, Insul-8 Corp. bid, and so did Kaiser Aluminum. There were three responsive and responsible bidders to our advertisement. There was no proprietary product involved. H.K. Porter bid the lowest price and they got the job. Had one of the two other manufacturers had the low price, they would have gotten the job.

R. Swindell - We feel the same way in Chicago. Had Insul-8 been low, Insul-8 would have had their rail in Chicago.

J. Corl - They were very competitive bids, less than 4 percent apart.

R. Swindell - They were very close.

A. Wacker - I want to avoid a repetition of the problem which happened to us when we started using the Porter insulator. When we started with a special design for our purpose, we were given an estimated price of $13 per insulator and we even bought 1000 units at that price. Then we put them in our specifications for some of our grade crossing eliminations. When the contractor went out to buy these units which were offered to us and sold to us at $13 per insulator, his price would have been $32. If that is going to happen with rail, once you have it specified and tied down, you wind up with a very expensive system.

H. Decker - One question I would ask is, are you comparing the prices on the same basis, of insulator to insulator or insulator to installed insulator?

A. Wacker - Yes, material only.

H. Decker - That is one thing we've got to be awfully careful of.

J. Corl - Are you talking about buying ten thousand and then buying five?

A. Wacker - No, I'm talking about buying a thousand which we bought at $13. and a contractor buying 2,000 at $32.

J. Corl - How many years later?

A. Wacker - Two years later. We went back to the porcelain insulator. The thing is that once you specify a certain rail system because you like it, because the Huck bolt is fast and easy to install and lighter to handle, once you tie yourself down in that fashion, you have no control over the price.

H. Decker - I think you do have a degree of control in the price if you do exactly what Ed Rowe said. You use a performance specification which allows as wide a performance margin as you can get and accept.

---- I'd like to just observe one thing that touches on the discussion and just draw it out. How many suppliers are there available on 150 pound rail?

(Several - One)

---- There is less competition on 150 pound rail by far, than there is on composite rail.

R. Swindell - One our 144 pound rails, we own the rolls and the only place they could be rolled was Bethlehem Steel. I would venture to say that the gentlemen here from Huck bolt would be delighted to sell Huck bolts to Insul-8, to Kaiser Aluminum, to H.K. Porter, to anybody. The Huck bolt idea is not proprietary, there is no patent on it whatsoever. I think you as an operating property have to decide what you want your rail to look like, basically, what you want it to be. If you could give me a piece of rail that was only so big around and would carry all of the current that I need and have all the voltage - I'd turn it down, because first of all, in my opinion, it is not physically strong enough to stand up. Somewhere within your own operating experience and background, you have to decide what you want that rail to look like. The only thing that we told the manufacturer is that we wanted aluminum on both sides of some standard 80 pound rail. As a matter of fact, there was some question of our first specification which everybody bid on. We're even loosening that up a little bit, changing some of the terminology to make sure that all of the interested manufacturers can bid on it.

E. Rowe - I'd like to add something to that. Our experience shows that we have got to go to UMTA for pre-bid reviews, and they're tough. If you are specifying a proprietary product they will not let you issue those bids. I don't care whether it is a nail or something worth 10¢ or worth ten million dollars.

J. Dyer - If I can get two pieces of rail at the same price and one carries twice the current, I am very happy to take the one with greater ampacity.

A. Wacker - The thing is, are you going to get them at the price you want in the bidding. You have to go out for bids, you have to design, and you go through all the details of how you want to have it perform and how you make connections to the rail, and so on. You can't leave it open. You have to lay out the system. But before you lay it out, before you specify, you want to make sure that the system works technically. From what I've heard, it seems to work very well, technically. If we now specify this rail, and we get a tremendous price, we have a problem. We have a technically working system now.

R. Swindell - What you are worried about is this: If you design for an aluminum side rail of any kind, and you've compared that with some kind of steel rail, and you have decided to use a composite rail instead of steel, you want to make sure that you buy it for somewhere near what you thought it was going to cost. Is that right?

A. Wacker - Yes.

R. Swindell - The only way I think you can insure that is to keep your specification open to some degree so that all of the interested manufacturers can bid. If you pin it down to one manufacturer, you're in trouble.

A. Wacker - You mainly have to be sure that you get two bids for two types of rail.

R. Swindell - If you decide that you need the aluminum, and you design your system to that, then you really need it. If you don't need the aluminum, don't buy it. Don't put a composite rail in the yard. For instance, if you decide that you're going to design your system in such a way that you don't need composite rail, then don't use it. I think that's the answer to that. If you design it one way with four substations and see what that cost is going to be with aluminum, or another way with five substations and steel, and see what the cost is, you're talking about overall costs for the whole project.

A. Wacker - The technical aspect is only one problem of design. We always have to consider cost, too. Let's say you compare direct burial and a duct system for cables. Now there's many advantages and disadvantages of one against the other, and nobody has said that the direct burial system is cheaper. If you don't go out on a bid like that of (unclear), you may wind up paying the same price as if you had a duct system with manholes and get a direct burial system.

H. Decker - I think we're getting into a field which is a little bit astray of the main purpose of this seminar, and that is how to assure ourselves a good contract, or a good contract specification for bidding purposes. I think it becomes a question of just plain common sense. You do want to go out with a series of alternatives. At the time you go out on procurement, you may want to take two different approaches. But it seems to me that in buying thrid rail, you can certainly specify a current carrying capacity in terms of equivalent copper circular mils, or something of that nature. You can specify that either steel or a combination of steel and aluminum can be used, and you don't really care how the aluminum and steel are held together as long as they don't come apart. You can state that it should have a certain overall head width and head radius, rail height and so on. I think we can cover those pretty well and still leave the manufacturers a wide field to maneuver in.

R. Swindell - Let me say one more thing about that. When you prepare a specification and lay out a job or purchase order, you must have in your mind an idea of what you think the price will be. If you think that the price is going to come in at $15 a foot for third rail, and it comes in at $25 a foot, I suggest you throw out the whole bid, and startover. You should try to find out where did I go wrong, what am I doing wrong? I think that's your alternative. Then you can look at this man over here and ask why he didn't bid your job. Then you go back, and start over again, see where you're standing, and re-evaluate the situation.

I think that's what you almost have to do.

You should have some kind of general idea of what the cost is going to be at the time you advertise for bid. Most of us do. We don't go to the manufacturer and say, "How much are you going to quote me per foot," but you say, "What is it going to cost?" He must have an idea.

If his price comes in double what you think it should cost, don't panic; start all over again.

J. Dyer - This isn't pecular to the rail business. It is common to all ways and all phases of this business. Circuit breakers, transformers, rectifiers, cabling, you never know how high or how soft or how hard that price is going to be until the bids come in. It is part of the bidding process.

A. Wacker - I don't want to get involved in a head program like you did. My problems are different. I would really like to specify a system that works. If you tried a system and it works, I want to specify that system. I don't want to wind up paying high prices just because I specified something.

R. Swindell - We are in the process of getting ready to purchase a rather large quantity of rails, something in the neighborhood of 300,000 feet. I don't know exactly where it stands, because I'm not in engineering anymore and handling that part of it, but I know that we have gone over our specifications and we have assurances that the speficiations are good for at least two of the manufacturers. Now at one time I heard Kaiser Aluminum didn't want to go back in the business for less than a million feet of rail to be purchased. There's no way you can get them to bid on our quantity of rail. I think you do the best with what is available. We specified 80 pound or 74 pound steel rail since we couldn't be sure of getting 80 pound rail because we couldn't get anyone to roll it. Whether we can now or not, I don't know. We had some things in these specifications that we felt to be a little proprietary. We took them out of the specifications. It is a matter of writing a specification around what you generally feel you want, so that more than one manufacturer can bid on it. If you get yourself trapped into buying from one manufacturer, you may or may not have problems depending upon his reliability and reputation as a sole manufacturer.

F. Nichols, Kaiser Aluminum - I'm from Kaiser. I think when you had reference to that million feet you may have been talking to some of our marketing people, with reference to the cast rail.

R. Swindell - Yes.

F. Nichols - We would be, I'm sure, interested in supplying a bolted rail.

R. Swindell - Oh, you would? Well, you'll have to drop in to Chicago, and -

F. Nichols - I think somebody from our company should contact you.

R. Swindell - Well, now, there's three separate manufacturers who are going to bid on our specification to make what we think is an acceptable product for us. I'm sure they're going to be competitive.

E. Schmid - The point is, even though you have the Porter rail in there now, you are not specifying that rail ---

R. Swindell - Absolutely not.

E. Schmid - You are satisfied with what is available on the market by these three manufacturers?

R. Swindell - Right, I haven't seen what Kaiser would make, but if they meet our specifications we're satisfied. Now our only problem with Kaiser was with the thickness of the head, and they can do it with this other piece now. I really think they were serious about it at that time. The rail was thick on the top, and quite high, with a bottom flange which we thougt just wouldn't be safe.

E. Schmid - A good design for a mushroom!

R. Swindell - I think you got it right, yes!

A. Houston - And if it is cost effective, then you'd be satisfied with the system. It's about the best you can do.

R. Swindell - I might add, too, that we have never asked the rail manufacturers to buy such things as chairs, anchors, and appurtenances to the rail. We buy the rail, the splices, the bolts, and other items separately. We don't go into the full system procurement through the rail manufacturer.

E. Schmid - I might add for the sake of discussion, that I know nobody else that has done that yet, either.

E. Rowe - No, we bid the job the same way that Chicago did. We bid rail, the joint bars, the end approaches, and the terminal pad assemblies as a package, but not the anchors or the insulators.

E. Schmid - For the sake of answering your question, those items were actually bid separately to the contractor. He took the competitive bid. It just so happened that we sold them to him. The items were on a competitive bid with him, and he went to Brand X, Y and Z, and got them that way. In other words, they were bought separately on a competitive bid basis. We were fortunate in that instance.

H. Decker - For my own purpose, I'd like to address the gentlemen from New York. Do you have any feel for how much new contact rail you might be in the market for, in the next several years? A crystal-ball type guess?

W. Miller - No. I would guess no more than 45 miles of new route, say 100 miles, possibly of contact rail. That does not include the capital replacement program, eliminating a 75 pound Carnegie section that we've had in since 1911 or 1917.

H. Decker - Is that included in the estimate?

W. Miller - No, it's not. That brings up an interesting question, and that's why I asked about the maintenance costs. We're at a point now where we are, over the next several years, ready to go out and replace that 75 pound contact rail, and our thinking all along was naturally to match the rest of our system with 150 pound steel rail. Now I just wonder if there are any advantages, since the substation spacing is going to remain the same, to put in some 100,000 feet of composite rail, for some savings in I^2R losses and some better voltage to your trains. But now we have a stores problem; we have another item on the property to be maintained. This is something you want to weigh, and see if there is any real advantage over the long run to putting in, in a system like ours, 100,000 feet of composite rail, if there is no real capital advantage.

R. Swindell - Again you have to look at your entire system, I think if you need it, use it. If you don't need it, don't buy it, because you're paying a premium for it. If it's going to do you some good, in your entire system, buy it.

W. Miller - The question is, are you paying a premium for it? If you are talking about now, estimates are running within 5 to 10% of each other. Is it possible that steel prices are rising and a couple of years from now, composite might be cheaper?

R. Swindell - Yes, that may very well be. Steel prices are going up.

A. Houston - You can pay for it in the savings in I^2R losses.

R. Swindell - It may very well be that in the near future, you'll be able to buy a 75 or an 80 pound composite rail cheaper than you can buy a 150 pound steel rail. I don't know. I would say probably not, because the price of aluminum is probably going up at about the same rate as the price for steel. I've got a feeling that a stand-off is going to be there. You're paying for the manufacturing cost of putting the rail together, whatever that may be.

---- The ratio of the steel to the labor to the aluminum that you put into it is the factor. If there's a small amount of steel and lots of aluminum, you can carry more current. So that a piece of rail installed would be probably less costly that 150 pound rail (for equal ampacity).

R. Swindell - Do you have paralleling cable, at all, on this particular route?

W. Miller - No, I don't believe we do.

R. Swindell - And your substations are how far apart?

W. Miller - Well, I think the way the IND was laid out, you could close down every other substation and run full service. They were needed for redundancy.

E. Rowe - We were criticized because I think you can shut down every other substation on Haymarket North and run full service. We were criticized for our substations and they are a little more than a mile apart.

J. Dyer - The project manager said, "Why did you build them if you don't need them?"

E. Rowe - That's right.

J. Dyer - We needed them for maintenance purposes. What if every other one shut down if we didn't have redundancy?

R. Swindell - There's a lot or redundancy in transportation and power systems. How much is it worth to move people reliably? In fact, I was a little surprised, Ed, when you told us today that your rectifier out there was only rated 60% of what you needed to ---

J. Dyer - Not the rectifier - the system. The power system carries 60% of the load with one machine out, but Ed knows that.

E. Rowe - I said it would take 100 percent, remember?

J. Dyer - Yes, at least.

R. Swindell - Ours is designed so that we can lose one unit out of any substation without any effect. If it's a two unit substation it's obviously doubled in capacity. It's a three unit substation two-thirds of the units are needed, and so on.

E. Rowe - Of course, Ron, those figures are based on six car trains at 90 seconds leadway.

H. Decker - Are we out of questions? I though that the trip out to Haymarket North would have triggered some more.

W. Miller - The question of whether to put protection board on our contact rail is interesting. We have protection board all over our system except for some isolated sections and yards. I know the MBTA doesn't have it any place. Chicago has no protection boards.

J. Dyer - We have maybe 20 work cars that can't clear a protection board. The battery boxes under the cars would foul the protection board. We considered it, but unless we get all our work cars with proper clearance, we can't put it in. We even tried with a section that could be thrown back to let the work cars pass, but that is pretty expensive. We agree for safety. You even have it in your tunnels, I know, so you are not using it for icing protection, you are using it for safety. You use a two by ten board on a bracket hanging over the contact rail. We believe in safety but we have not had any fatalities. We did have one of our iron workers fall across the rail and get burned, but not electrocuted. We really have had no bad incidents, other than the fact that vandals throw shopping carts off a bridge, and they pushed a Volkswagen down onto the right of way. It's fantastic, some of the things they throw across the third rail. Two or three times in a day, we'll have an outage, and the breakers will lock out because of metal on the third rail. It would be an advantage there, I think. The train might run into the obstacle and carry it along. Then you would have the section out. If we could have done it, we would have done it many years ago. We have had directives to look into it.

R. Swindell - We have basically the same problem. Not only do we have a paddle-type shoe, we also have an over-riding shoe which hangs directly over the top of the third rail, with its mechanism. This really prohibits us from putting anything over the top. For us to put in a cover board and be able to clear our equipment, not just our work cars but our actual train equipment in revenue service we would have to move the third rail approximately 8 inches farther out. We have an untold number of bridges where we could not move the third rail. Besides, we would probably have to put in a second third rail system while we were revamping this one, and we'd have to widen those bridges.

J. Dyer - Do you have ice scrapers?

R. Swindell - Yes, we have ice scrapers.

J. Dyer - You can't use an ice scraper which drops down vertically at a 100 pound force on the top of the rail if you have cover board. Now, you don't have ice scrapers in New York evidently.

W. Miller - We do not have ice scrapers. We had repositioned contact rail on our Third Avenue El and some of our elevated structures going up into the Bronx. It was originally a two, 75 pound third rail system designed for the old hanging shoes, and they had ice scrapers and leaf scrubbers. In the late 50's we went to a program to upgrade the system with 150 pound (steel) contact rail, put out into the IND position which accommodates the more modern shoe that we use and allows the installation of protection board. We do not use ice scrapers.

J. Dyer - We used ice scrapers until a few years ago. Then they started to cause short circuits and were taken off.

E. Rowe - Then they were put back on again -

---- Of course, our service is so frequent, ice doesn't get a chance to build up. (laughter)

R. Swindell - The question of cover board is brought up periodically. Again it's a matter of equipment. I have reservations in my own mind as to whether cover board would cause more trouble for us from a maintenance standpoint than it would do us good. He says no one has ever been electrocuted. We, to my knowledge, have never had any blood either. But this is because most employees really know what they're doing. When we work on the elevated structure, if we have the third rail on the outside of the structure and if it has a cover board over it and we have to handle a bad order train and want to get to the shoe, I don't know how we would do it, or how we would get to it and free it, or even be able to see that there was a problem. I can see, from a maintenance standpoint problem that it might be more difficult for us. I don't have any experience, but suppose you get a bunch of wet papers wedged in under the cover board and a train comes along, would it knock the shoes off? I don't know the answer.

H. Fleige (BART) - We have cover board on every one of our third rails.

J. Dyer - How much snow and ice do you get?

H. Fleige - It was dictated to us by the Public Utilities Commission. They have a great interest in cover board for safety. Personally I feel we do not need it everywhere, particularly in the subway, for the reason that we cannot do any maintenance while things are running in the subway. With the cover board and a two and a half to three foot walkway, there just isn't any room. We do not allow any person in our subways doing clean-up work during revenue service. I tried it myself once, hanging off the grab rail, and I was scared. I was glad when the train finally had passed and I could sneak out of there. I don't think we need cover board when we work with the power off. The same applies to most of our aerial structures. We cannot perform any maintenance during revenue service. We could turn the power off. For the time being, we're stuck with it until the PUC relaxes and allows us to remove it.

W. Miller - In the New York subway we are sometimes confronted with ten rails across which could be very confusing if you didn't have cover board.

H. Fleige - We have two tracks.

R. Swindell - I would say that if we in Chicago, with the philosophy we have, we're starting from scratch to build a railroad, we would have trouble with the problem of cover board. I don't think there's any question about that, just from a safety standpoint.

E. Schmid - Cover board will not prevent ice-ups.

A. Wacker - As a matter of fact, it helps you to have it. If you want to get the ice off the third rail, you wait until a beautiful sun comes out. That sun will melt the ice fast. If you have protection board over it, the rail will be in shade.

E. Schmid - You had some problems a few years ago.

H. Decker - I like to ask Mr. Wacker one question. On the Long Island, is your entire system equipped with cover board?

A. Wacker - Yes. It is a plain board, which is open on both sides.

H. Decker - Two by eight, essentially the same as New York City uses?

A. Wacker - Yes.

W. Miller - I'll ask both Joe and Eddie a question, that may be of interest to them since they went through an icing test. Did you find any difference in the ice build-up situation between an 85 pound rail and a 150 pound rail due to conditions of head radius, and that kind of thing?

J. Dyer - We've had more trouble on the South Shore Line since it's been in than on other lines. It is our first experience with 150 pound rail. Up to that time we always used 85 pound rails. Whether it was the way the storms came up during those years or not, or the location of the railroad, I can't say. The larger mass seems to accumulate more ice. It doesn't take much ice to stop you. An eighth of an inch of ice on top of the rail will stop you. Part of that problem, I think, was our own doing. We mix 150 and 85 pound rails. With the shoe worn to a curve it broke the film on the outside of the rail, allowing the ice to build up on top of the rail. I don't think it's a problem that everyone has. A new railroad would use all the same size rail.

W. Miller - Ice clings to the 150 pound more than it does to the (unclear) 85 pound. We ran tests with 150 pound, and one section we coated with some graphite. We were able to keep ice off the graphited section.

J. Dyer - We found very little difference in the snow melting tests we've gone through between melting the ice on 150 pound and 85 pound rails in either time or watts per foot. The (test) program saved us a lot of money, I think. Ed, what were you using, 50 watts?

E. Rowe Fifty watts per foot.

J. Dyer - We were using 50 watts per foot on the MI cable on that little job that they just put out. Ed, do you still use the same railroad (heater) at (unclear) the switch points?

E. Rowe - Right.

R. Swindell - How often are you heating the rail? How many feet do you heat?

E. Rowe - What we do, is to heat the rail so that we never allow both shoes on a car to be on an unheated section.

R. Swindell - Does this mean every other rail?

E. Rowe - We heat a 50 foot section and then skip 50 feet and heat the next 50 feet, and so on.

J. Dyer - We heat the rail in the stations, going out of the stations and coming into the stations.

E. Rowe - Right. Where the train has momentum, we don't heat at all. On level transportation track, there is no heat there at all. Once the train starts moving, the ice scrapers will take care of the situation.

R. Swindell - We're doing the same kind of testing, except that we are only putting electric heat on the rail on hills.

E. Rowe - We do it on inclines, going up the hill, but not coming down.

R. Swindell - Right, but we're not even going to test anything on the level.

W. Miller - (unclear) Do you have any reverse driving operations?

E. Rowe - No, not at this time, we don't.

W. Miller - In New York, we're putting it in at the stations on the exposed courses of our system, and on inclines, especially on critical portions of our system first, and then hopefully on all inclines. We are also putting it in on some pieces of level tangent track, supposedly non-maintenance type track, like the Rockaways across the flats and Jamaica Bay, where we have all kinds of problems.

R. Swindell - How many watts per foot are you using?

W. Miller - Dennis just asked me that and I'll be damned if I can remember!

R. Swindell - You're using 50, and I think we're using 50.

J. Dyer - We are using 50 (watts per foot) as a result of a test that we ran at the Army Environmental Laboratories in Natick. We used a heater and Variac on various 20 foot sections of rail. We sprayed them at different temperatures, and we found that about 26°F with a light spray was the worst condition. We set the Variac, figured the current, figured the power, and concluded that with 50 watts per foot you would melt ice. After a 20 minute period and no heat on, you would have a quarter inch of ice. If you kept the power (heat) on, ice never formed on the rail. Forty of fifty years ago, we were heating rail on the North Station incline, for instance, with third rail track heaters. In normal practice, you put the heater under the head of the rail, at 200 watts per foot, which is what we had always used. It was with the heaters we had, Singer or GE Calrod in sheaths, and we just put in heaters all the way up to keep that rail heated. But we were using 200 watts a foot. We didn't care since we were generating our own power with a low incremental cost. Now we're going out on to an area where we buy power and that is going to cost us a lot of money in demand charges. If we used this power over a half hour period, we set a new demand at that particular station. It isn't as bad as I thought it would be; I figured about 10,000 kilowatts of heat for the whole railroad. Ed tells me it's only 12,500 a year including demand for the whole line on the Haymarket North. I was figuring heating the whole length of it, and not just heating sections. At 50 watts a foot, we can heat any rail, whether 150 pound or composite rail with a groove in it that will accept the heater cable and the clips. We're not going to do that in Haymarket North, we're going to leave the rail there, and we're going to mill a slot out, I think, a half an inch deep.

R. Swindell - Our tests indicated that we would go to about thirty watts per foot. We're not concerned about melting a quarter inch of ice. We're really concerned about keeping the ice from forming. We run service all night long, and if we can keep the ice mushy, we can break it up (with the shoes). I think our approach is a little different than yours.

E. Rowe - Our criteria if I recall, was that we had to melt ice that had already formed. We do not run these heaters all the time. We only put them on when we have ice forming. The criterion that the authority established was that we had to melt ice that was already there and hard. It wasn't just keeping the rail clear. The other thing was that, as I recall, we had safety factors at 50 watts per foot. We might have been able to get away with 40 watts per foot but we went a little high so we would guarantee ourselves that we would never have a shut down.

J. Dyer - Before we shut down, we want to be able to melt the ice off the rail.

H. Fleige - Needless to say, we don't have that problem, but we do have the opposite problem. We actually do have problems with the sun. We had to put sun shields on all our multiplex boxes, because the electronics start to act up when the box gets too hot and we had to keep the solar heat out of the boxes.

W. Miller - Are those boxes vented?

H. Fleige - No, they are not vented.

W. Miller - Did they have any fans in them?

H. Fleige - They have a little drainage hole in the bottom, no real ventilation.

W. Miller - You have no provision for heat dissipation?

H. Fleige - Not as such. It gets very hot on the Concord line and on the Fremont line. Because of the heat build-up, we had to put a sun shield like a little tent structure over the boxes.

J. Dyer - I don't know if anybody noticed out there today, but that was the reason the back of the boxes were vented-for heat dissipation.

W. Miller - I don't think you want a vent in there, you don't want moisture in there.

J. Dyer - It doesn't really matter if a small amount of moisture gets in.

H. Fleige - Yes, that's right, We have an ungrounded box, mounted on wood posts with no grounds inside, which is a requirement of the union, as their linemen won't work in boxes that are grounded. We have 600 volt positive and a fiber glass box mounted on 2 by 10 planks that are lagged onto the wood frame. But that's only the 600 volt boxes. Our signal and telephone boxes are similar to yours. We don't want to vent them too much because in moist weather we would get bad humidity conditions in there.

E. Rowe - The (600 volt) switch boxes had to be vented in order to meet the ANSI tests. That's when we went to Chicago, and did all the heat testing. They had to be vented to meet the test requirements.

\- Pause -

H. Decker - Are there some questions that are still plaguing someone? (Pause) As I sense it, then, we are probably run down for this particular meeting. I hope that this meeting has been a source of information to all the people who have attended. I know I have learned a lot from this seminar with you people. I certainly enjoyed the opportunity of getting out the seeing

Haymarket North running. I hope that those of you who may have questions that are not covered at this meeting will address them to me. If there are things in addition to those that have been mentioned here at the meeting that you'd like to see included in the Proceedings as an appendix or an addendum please let me know; I'll try to get them in.

G. Butler, UMTA - I'd just like to say on behalf of UMTA, that we're very pleased at the turn-out, and that you people who came here took time away from your busy schedules to sit down across the table and have open discussions on this matter. As with Hal, I too learned a great deal about what is going on, and again, thank you very much.

H. Decker - Are there any other comments? The meeting, then, stands adjourned. I thank you all for coming, I'm glad to have met you all, and I hope to be in touch in the future.

APPENDIX A

THIRD RAIL - DEICING PROBLEMS

Joseph Dyer

THIRD RAIL - DEICING PROBLEMS

PRESENTED TO

AMERICAN PUBLIC TRANSIT ASSOCIATION
RAPID TRANSIT CONFERENCE

WASHINGTON, MARCH 31, TO APRIL 4, 1975

BY

Joseph P. Dyer
General Superintendent of
Power and Signals
Mass. Bay Transportation
Authority

APPENDIX A

Third Rail - Deicing Problems

The problem of third rail de-icing was not discussed in detail at the seminar. Several persons present requested that information pertinent to the problem be made available. This paper on "Third Rail - Deicing Problems" is therefore included as an appendix. The paper was originally presented at a meeting of the American Public Transit Association's Rapid Transit Conference held in Washington, DC, March 31 to April 4, 1975.

Permission to reprint the paper has been graciously granted by APTA and MBTA.

THIRD RAIL - DEICING PROBLEMS

The first installation of third rail heaters on the MBTA was in 1957 on the North Station incline of the Orange Line. The system was devised by George Ellard, then Signal Engineer, and Chromalox Electric Heating Engineers. Tubular type heaters at 200 watts per foot were developed. One end of the element was welded to the sheath. The heaters picked up their energy directly from the third rail. These heaters functioned successfully. In the same year, the same type of third rail heaters were installed on curves on the Orange Line Elevated structure at Sullivan Square.

In 1961, 200 w/ft third rail heaters were installed on the Red Line (Dorchester Extension) on the Long 500 ft. radius curve between Savin Hill and Fields Corner and also on the Old Savin Hill Flyover.

These early installations worked satisfactorily. They derived their power from MBTA generating facilities and because of their limited nature, had no significant impact on the traction power system.

In the winter of 1972 - 1973, icing conditions caused trains to be stalled on the South Shore Line, particularly on the new Savin Hill Flyover. Problems of third rail icing were aggravated by the new 150# third rail and the removal of third rail ice scrapers from Red Line cars, after a fire in the Dorchester Tunnel in January of 1973.

A decision was made by the authority to install third rail heaters on the West Boston Bridge, the Savin Hill Flyover and on the Anderson Bridge. Two hundred watt per foot third rail heaters were ordered and were installed by the Signals and Communications Division forces on the West Boston Bridge in the late fall of 1973. A contractor installed the third rail heaters on the Savin Hill Flyover and Anderson Bridge in the winter of 1973 - 1974.

The West Boston Bridge installation added 316.2 KW demand. This was supplied by existing MBTA generating capacity at a low incremental cost.

The Savin Hill Flyover and the Anderson Bridge third rail heater installations added 449.5 KW to the demand. Savin Hill Flyover receives power from Columbia substation and Tenean substation; Anderson Bridge receives power from Tenean substation and North Quincy substation.

Power for Columbia and Tenean substations is supplied by Boston Edison. Power for North Quincy substation is supplied by Mass Electric-New England Power.

Turning on these heaters for as little time as 15 minutes will affect the demand charges imposed by these utility companies for a period of months.

The Signals and Communications Division in February of 1974 commenced testing heating of both composite aluminum clad third rail and 150# steel rail in Charlestown Yard to determine an optimum watts per foot heating requirement for each type of rail.

This testing was continued by the Signals and Communications Division on the Anderson Bridge in cooperation with the installation contractor.

The Operations Directorate was greatly concerned over the interruptions of service caused by the storms of December 16, 1973, January 11 and February 17, 1974. The third rail on the South Shore Line was iced over extensively. This resulted in a massive disruption of service.

The Signals and Communications Division was asked to prepare a plan showing the requirement for third rail heating on the South Shore Line at locations where trains had been stopped due to icing conditions. A field survey was made in cooperation with the Transportation Department. After consultation with the Operations Directorate, a third rail heater plan was prepared for the South Shore Line and for the new South Bay Maintenance Center, including the connecting track. It was determined that third rail heating would be required on 42,991 feet of track.

In previous installations, it was found that heaters need only be installed on approximately 50% of the third rail in a heated section, that is 50 to 60 feet of heated rail with gaps of unheated rail or approximately the same length.

This assured that a married pair would have at least one collector shoe of each car in a heated section of third rail. One car of a married pair has the compressor, the other car has the generator both of which draw current independently.

At the most critical areas, such as inclines, leaving stations, at interlockings, three calrod type heaters will be grouped to provide a 53 foot heated section of third rail with a gap of 47 feet.

At less critical areas, where trains have picked up momentum, the gaps will be 117 feet to assure that the first and last collector shoe of a married pair will be in heated third rail. Where grades are favorable, there will be unheated areas.

This will reduce the requirements to 22,383 feet of heated rail. At 200 watts per foot, this would require 4,477 kilowatts of power.

Substation capacities on the South Shore Line and the South Bay Maintenance Center are sufficient to handle this additional load. However, since power for these substations is furnished by private utilities, the demand factor would be tremendous. To reduce the demand factor, it was obvious that the lowest possible watts per foot which would do the third rail deicing job properly must be determined.

Testing of third rail heaters by the Signal and Communications Division at Charlestown Yard continued into March. Various watts per foot were obtained by placing combinations of 350 watts per foot, 600 V.D.C. switch snow melters of different lengths and total wattage in series. The wind velocity was measured and water sprayed onto the third rail during tests. Freezing rain conditions, however, could not be duplicated.

Some favorable data was obtained which indicated that the optimum wattage required for deicing third rail would be less than 90 watts per foot. Further testing was required, however. Meanwhile, the days were getting warmer and the Signals and Communications Division sought a refrigerated facility such as a meat storage plant where controlled freezing temperatures could be obtained.

The Signals and Communications Division was unable to find private refrigeration facilities available in the Boston area. They learned that the U.S. Army had a climate test laboratory at Natick, Mass., under the jurisdiction of the Material Test Command. This facility has complete environment control capabilities, including temperature, wind velocity and precipitation.

The Natick facility was inspected on March 8, 1974, by the Operations Directorate, Signals and Communications Division and Planning and Construction Directorate personnel. The lab people were most cooperative. They listened to our problem, discussed how their facilities could be used, when and how long they would be available and introduced us to their legal people to initiate making the facilities available to the MBTA.

During the period of March 25 through May 5, the Signals and Communications Division of the MBTA conducted third rail deicing tests at the Army Material Command, Natick, Massachusetts. The environmental chamber facilities in the Climatic Research Laboratory were utilized by the MBTA to simulate various weather conditions which are present during ice storms.

The purpose of the tests was to determine the minimum wattage required to keep conductor rails free of ice during ice storms. Using the lowest feasible wattage, determined by the tests, a substantial reduction in wattage below the 200 watts per foot presently used would mean a considerable savings to the MBTA. It was determined that tests be made using 50, 70, 80 and 90 watts per foot.

The arctic wind tunnel in the Climatic Research Laboratory has a test area of 15 x 60 feet. Temperatures within the tunnel can be regulated and maintained in the range of minus 70°F to plus 70°F ± 1°F. Two banks of refrigeration coils, located at one end of the wind tunnel out of the test area, cool or reheat the chamber as required.

Humidity within the wind tunnel can be regulated from 18% to 90% relative humidity (dewpoint ± 1°) between temperatures of 10°F to 70° F.

Wind speed of 2 to 40 mph can be provided and controlled using two fans located in an outside portion of the wind tunnel.

Water spray can be induced into the wind tunnel at a maximum rate of 10 gallons per minute, equivalent to 4 inches of rain per hour. Water spray can vary from a fine mist to a heavy droplet form, governed by the nozzle used. The rate of flow of the water spray is regulated by valves located outside the wind tunnel. Water temperature can be controllable between 90°F and 35°F, in an area of 15 x 20 feet.

Three (3), 20 foot sections of conductor rail were placed within the artic wind tunnel. These included one section of 150# rail (Fig. 1) which is now in use on the South Shore, one section of 85# rail (Fig. 2) and one section of aluminum clad "Com-Tran 85#" rail (Fig. 3), supplied by H.K. Porter, Inc. is being installed on the Haymarket North Project. "Com-Tran" conductor rail consists of 85# steel rail with two aluminum conductor extrusion bars fastened to the web of the rail with 5/8 inch Huck bolts approximately every 18 inches. The MBTA had the top of one aluminum bar milled at East Boston Bethlehem Ship Yard to accept a 5/8 inch diameter tubular type heater.

Each rail was placed on five, 4 foot pieces of 4 inch X 4 inch pine located at the end of the arctic wind tunnel, under the tunnel's water spray system. Each rail was located to receive the full benefit of the water spray.

The heaters used during this test were tubular type 5/8 inch diameter, double lead heater units which are now used for switch snow melters on the MBTA system. The overall length of each heater is 18 feet with an 18 inch cold section at each end. These heaters are rated at 350 watt per foot at 600 volts. With an active heater length of 15 feet, this gives a total wattage of 5,250 total watts at 600 volts. Mounted on a 20 foot length of rail, this left 2 feet-6 inches of unheated rail on each end.

One heater was installed on the 150# rail with clips designed by the Signals and Communications Division. These clips are now being used on the South Shore Line. One heater was installed on the "Com-Tran" 85# rail utilizing the groove which had been milled into one of the aluminum conductor extrusions. The heater was

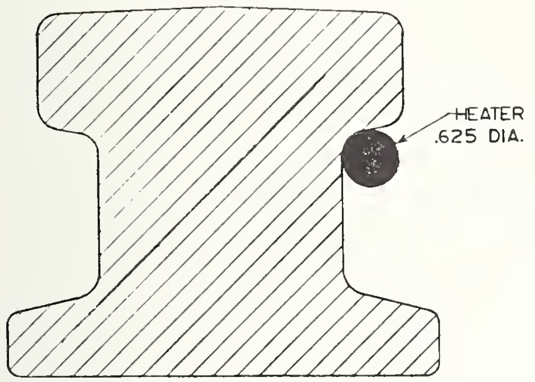


FIGURE 1 150# RAIL WITH CALROD HEATER

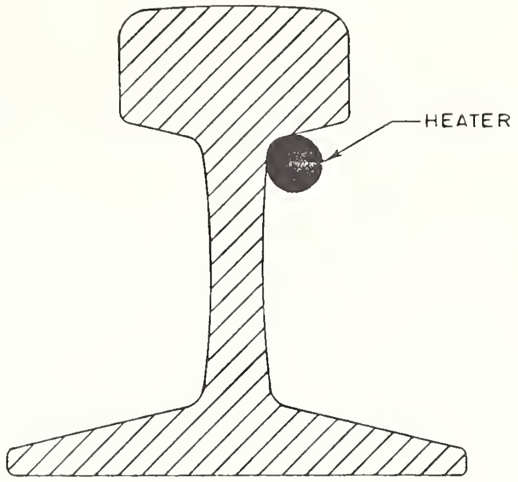


FIGURE 2 85# RAIL WITH CALROD HEATER

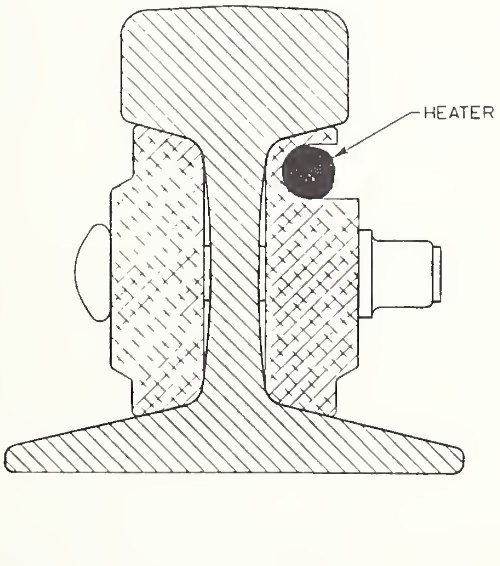


FIGURE 3 COM-TRAN 85# RAIL WITH CALROD HEATER

inserted into this groove and held fast with five, 3 inch "C" clamps since no formal method of affixing had been developed at this time. "C" clamps were also used to attach a heater to the 85# rail.

Each rail had 2 feet-6 inches unheated sections at each end of the rail. These cold sections would show any ice build-up which would occur during any of the tests. This would give a comparison to any ice build-up which might occur on the heated portion of the rail.

Since the heaters which were available were of a fixed wattage at 600 volts, D.C., a means of varying the wattage output of these heaters had to be devised to obtain the watts per foot desired for the tests. The Climatic Research Laboratory provided a 60 HZ, 460 volt, 20 amp, single phase, two wire fusible disconnect as a power source. The MBTA purchased a 460 Volt Variac which could be varied from 0 to 540 volts and deliver 10 amperes. With an ammeter connected in series and a voltmeter across the heater, the Variac was adjusted to achieve the various wattages desired.

Typical climatic conditions encountered during and preceding ice storms were recreated throughout the testing period. These test conditions were based on data furnished by the U.S. Weather Bureau and by Northeast Weather Services. Personnel from Northeast Weather Services visited the test site during the first part of the testing period. They were briefed on the capabilities of the arctic wind tunnel and also the procedures being used during testing. All the conditions required to perform the necessary tests were within the capabilities of the arctic wind tunnel.

Instrumentation used in the recording of data was supplied by the Climatic Research Laboratory. This consisted of an anemometer, a digital electronic counter which was used in conjunction with the anemometer, ten thermocouples of various lengths and a strip chart recorder.

The anemometer was placed in the same location as the rails and in the center between two rails. Height of cups was approximately 4 feet from the floor. It was noted that any other location would not give an accurate wind speed indication due to variations in wind speed caused by eddy currents within the tunnel. The wind speed is read from the digital counter which displays a numerical reading every second which is converted into miles per hour. An accuracy of 0.1 mph is obtained. The anemometer remains in the tunnel and the counter is on throughout each test. Wind speed is recorded each time a temperature recording is made.

Nine of the ten thermocouples were placed on the rails in order to record temperature changes. The remaining thermocouple was placed in the vicinity of the rails in order to monitor ambient temperature. Thermocouple locations were recorded at the top of each data sheet. Each thermocouple was placed on the rail and then covered with Duxseal (a flexible mastic). The Duxseal held the theromocouple in place and also protected it from moisture and heavy ice formations. Temperature variations are picked up at the rail by the thermocouple and transmitted to the strip chart recorder where the reading is printed out. A reading is printed from the same thermocouple every 40 seconds. This cycle remains constant through each test. At predetermined intervals, data is then transferred from this chart and recorded. All observations made during a test and any changes in climatic conditions were recorded.

During the last few days of testing at the Army Natick Laboratory the Nelson Electric Company made available to the Signals and Communications Division a sample of their mineral insulated heating cable. This MI cable was designed for 460 volt operation of 80 watts per foot. The cable had an outside diameter of 5/16 inches and a total heated length of 24 feet. Tests were made with the MI cable installed in the groove of the "Com-Tran" 85# rail - the MI cable was first tested at 60 watts per foot. The cable was affixed to the rail using "C" clamps at 18 inch intervals.

Voltage was applied to obtain 60 watts per foot. Extreme bowing of the MI cable occurred when it started to warm up. This condition was so extreme that the only portions of the MI cable left in contact with the rail were those directly under the "C" clamps.

Before any further testing could be done, it was apparent that a means of containing the MI cable had to be developed. A 10 foot section of 1/2 inch Electro Metalic Tubing was split in half and the MI cable was placed on the rail under the Electro Metalic Tubing. The Electro Metalic Tubing was held fast with "C" clamps. The tests were then resumed.

The 60 watts per foot test was repeated and then a test was done using 50 watts per foot. The MI cable was then removed from the "Com-Tran" 85# and placed on the 150# rail under the 1/2 inch EMT. Tests were then run using 50 and 60 watts per foot. The results of these tests indicated that the MI cable with the EMT cover was more effective than the tubular type heaters at the same wattages.

The MI cable has a smaller outside diameter than the tubular heating units. It developed a higher sheath temperature than the tubular heater at the same watts per foot. The higher sheath temperature plus the EMT cover made more heat available to the rail.

It was found that even at the lowest wattage tested (50 watts per foot), the surface temperature of the head of all three test conductor rails could be increased and maintained above 33°F even at very low ambient temperatures and extreme simulated weather conditions. Higher wattages, of course, increased the rail temperatures at a greater rate and higher peak temperature was achieved than with the lesser wattages.

Fifty watts per foot supplied enough heat to keep the rails free of ice. It was considered advisable, however, to use a higher watts-per-foot rating to achieve a high enough rail temperature to melt ice already formed and to keep the transit system in operation no matter what ambient conditions may occur.

Seventy watts per foot has been determined by the Signals and Communications Division to be the minimum rating required to insure deicing of the third rail under all conditions.

From the data available as a result of the tests, it has been determined that a wattage far below the 200 watts per foot of heater can be used to keep the third rail free of ice. Extensive testing has proven that 70 watts per foot is the maximum needed.

Throughout the testing period we were able to observe the effects of varying weather conditions on the three sections of test rail and their heaters. The following is a descriptive report of the various observations made:

Thermal conductivities vary widely with the composition of the material which is being heated. The "Com-Tran" 85# rail absorbed and also lost its heat at a faster rate than the 150# and 85# sections of third rail. Two factors entered into this. The first being physical size - "Com-Tran" 85# and the 85# rail have approximately one-half the steel mass of the 150# third rail. The second factor involves the aluminum inserts which are placed in the web on both sides of the "Com-Tran" 85# rail. Being aluminum, their heat conductivity is far greater than that of steel. They absorb heat faster than steel; they also dissipate heat faster than steel. The aluminum bar acts as a heat sink and readily transfers heat to the 85# steel rail member.

The groove which was milled into the aluminum insert on one side of the test "Com-Tran" rail increased the surface area contact with the sheath of the heating unit thereby increasing its efficiency. Without this groove approximately 75% of the heater's sheath surface area would be exposed to free air. This would mean that only 25% of the heating capability of the heating unit would be utilized. Higher wattages would, therefore, be required to de-ice the rail. The groove also facilitates the mounting of the heater to the rail, and acts as a partial shield for the heating element reducing the cooling effect of wind and rain on the sheath of the heating unit.

MBTA Engineers in a discussion on March 15, 1974, with H.K. Porter engineering personnel discussed providing a recess in the aluminum bar of the "Com-Tran" 85# rail for insertion of heaters. Representatives of H.K. Porter later witnessed a portion of the test at the Natick Laboratory. The MBTA Engineers recommended that H.K. Porter extrude aluminum bars with provision for a shield as well as a recess for installing a tubular heater. Recommendations were also made for suitable clamps to hold the shield and heater in the recess.

It is important to note here that the melting point and the freezing point of water are significant temperature levels because they are the transition points between different structural arrangements of the molecules within the water. At these transition points water is either being transformed from a liquid to a solid or vice-versa.

While the water is freezing, its temperature remains the same although it is losing heat. At first, the temperature of the water will drop steadily until it reaches 0°C (32°F). When this has occurred, ice will begin to form. Although heat is steadily being removed from the water as it turns to ice, its temperature will remain at 0°C (32°F) until all of it has frozen solid. After complete freezing has taken place, further cooling will bring the temperature of the ice below 0°F (32°F).

When one gram (.03527 ounces) of ice at 0°C melts, it absorbs 80 calories of heat. When the resulting gram of water at 0°C freezes again, it releases these 80 calories of heat to its surroundings. Note that melting and freezing occur at the same temperature. In melting, the substance in solid form absorbs heat. In freezing, the substance in liquid form gives off heat. Since ice has a melting point under normal atmospheric conditions of 0°C (32°F), it follows that if the temperature of the conductor rail can be increased to a minimum of 33°F and held at that temperature, ice formation would be eliminated.

As long as climatic conditions remain stable, the rail temperatures will reach a maximum temperature level for a given wattage and very little deviation from this maximum will take place. Changing such things as wind speed, ambient temperature and the introduction of moisture to the surface of a heated rail will affect the temperature of the rail. Increasing the wind speed will cause the temperature of the rail to fall. As the wind speed increases, radiation of heat from the rail will increase - the effect being a greater rate of heat loss. The cooling effect of high winds will affect ice formation especially at exposed locations such as bridges and large open areas. Conditions of this type exist on the MBTA; these locations are where the worst icing conditions occur.

Reduction of the ambient temperature increases heat radiation by the rails; the colder the ambient temperature, the greater the radiation. On the other hand, the colder the rail is at the onset of application of heat, the faster the heat is conducted by the rails from the heating unit.

The colder the rail, the faster it changes temperature when heat is applied. The peak temperature is determined by the watts per foot which governs the amount of heat applied. The rate of heat rise will decrease as the rail temperature approaches its peak.

An interesting observation was made relative to the water spray which was introduced into the test area. As water at 36°F fell on the test rails which had been preheated beforehand, the initial effect was to cause the temperature in the heated portion of the rail to drop and the temperature in the nonheated portion to rise.

The ambient temperature may range from 28°F to 34°F during an ice storm. Rain falling on the rail will cause ice to form when the rail temperature is below freezing and the ambient temperature is in the 28°F to 34°F range. If the rail temperature is increased to 33°F with rain falling, ice will not form even with ambient temperature below freezing.

When a large diameter tubular heater is mounted on the rail, a considerable portion of its surface area is exposed to the weather. This leaves a large area of the sheath exposed to the cooling effect of wind and rain, dissipating a portion of the heat through radiation and conduction. This reduces the amount of heat available for transfer by thermal conductivity from the heater's sheath to the rail. This plus the fact that only a limited portion of the sheath is actually in contact with the rail reduces the heating efficiency of the heating element. Therefore, a test was run using the non-slotted side of the "Com-Tran" 85# conductor rail with a heater enclosed in a Lexan cover. Results of the test indicate that a cover which shields the sheath of the heater from the elements increases the heater's efficiency. Unfortunately, the cover which was used for the test was a half section cut from a 3/4 inch Lexan tube and did not afford an adequate shield. Rain water came into contact with the heater's sheath, thereby cooling it. Even with the inadequate cover, a somewhat higher temperature was recorded compared with temperature recordings taken previously with an uncovered heater at the same wattage. With a more efficient cover, lower wattages could be used for deicing conductor rail.

The results of the limited tests with the Mineral Insulated Heater cable were impressive. However, the cable was designed for operation at 460 volts, A.C. No experience with the use of MI cable with D.C. voltages of 600 and above was available. Because of the magnitude of the third rail heating installation contemplated by the MBTA, it was determined that time proven tubular type heaters would be used.

Because of the favorable results obtained at the Army Laboratory, it was agreed that MI heater cable be tested under actual operating conditions. The Nelson Electric Company supplied two 53 foot test lengths of MI cable designed for operation of 50 watts per foot at 600 volts. The test heaters were installed at Wollaston Station on the South Shore Line in September of 1974.

One length of MI cable was installed on 150# conductor rail in the pit area leaving the station, southbound. The second length was installed 47 feet south on a slight upgrade. The heaters were encased in a split section of 1/2 inch EMT and attached to the rail with MBTA designed clips spaced 18 inches apart.

The MI cable heaters were energized continuously at 600 volts, D.C. for a period of six months to determine their ability to withstand this voltage. No problem has developed yet.

The distribution of heat through the rail has been uniform. During a light rain, the whole of the heated portion of the rail is dry. No ice or snow accumulated on the heated rail.

For further tests, the MI heater cables were turned off prior to a storm in which a mixture of snow and freezing rain fell. The heaters were turned on after a 1/2 inch accumulation built up on the conductor rail and cut off traction power. Within 15 minutes the 50 watts per foot MI cable melted the ice accumulation and dried the entire section of rail.

The MBTA's decision about the type heater to specify and the watts per foot required had to be made nine months before the MI heater cable results were in. The decision was made to use 1/2 inch diameter tubular type heaters designed for operation at 70 watts per foot.

The preliminary third rail heater location plan for the South Shore Line and South Bay which was prepared by the Signals and Communications Division was reviewed by the Operations Directorate. The plan was then revised to incorporate the required changes.

In May 1974, after more detailed engineering was performed, the Signals and Communications Division prepared requisitions for the major components required. This included 1,490 - 1225 watt heaters (70 watts per foot), 19,370 clips for attaching heaters to the rail, 31 contactor cases for remote control of the heaters, 23,000 feet of 19 conductor control cable and 160,000 feet of 1,000 volt feeder cable.

UMTA funding was sought for the project. The request was finalized November 25, 1974; UMTA concurrence was granted on December 9, 1974.

APPENDIX B

WELDING COMPOSITE RAIL ON BART

APPENDIX B

Welding Composite Rail On Bart

Several questions were raised during the seminar concerning the welding techniques used by BART to weld their composite (aluminum-steel) third rail. Subsequent to the seminar, Mr. H. Fleige of BART supplied the information which is included in this appendix. Receipt of this material, and permission to use it, are gratefully acknowledged.

BART does not use any special equipment in welding its composite third rail. It uses a gasoline powered 400 ampere d-c welder mounted on a road/rail vehicle. The welder is suitable for welding the steel portion of the rail by direct current using metal electrodes, and for welding the aluminum portion of the rail using a metal-inert-gas (MIG) gun with a one pound spool aluminum electrode. The illustrations in this appendix comprise a pictorial, step-by step description of the process used.

The time required to make one weld, including joint preparation (grinding), is approximately one hour. As noted during the seminar, BART prefers to use welded joints in their third rail. BART recognizes the fact that a bolted third rail provides a "break away" point that could prevent damage to the rail itself in the event of derailment or accident, but believes that this advantage is not important in its operations since its derailments are infrequent.

FIGURE 1 FRONT VIEW - 400 AMPERE DC WELDER

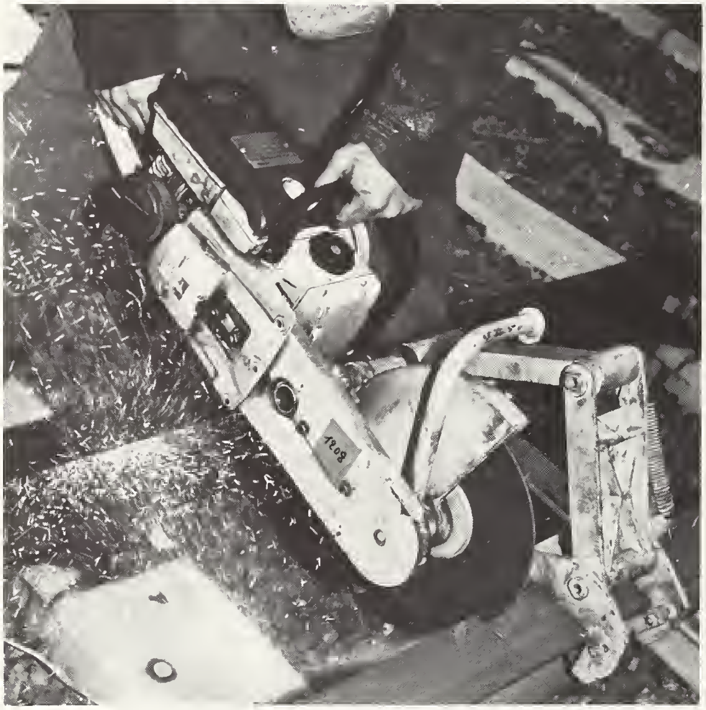


FIGURE 2 GASOLINE POWERED SAW AND JIG CUTTING CONTACT RAIL

FIGURE 3 APPLYING WAX TO DISC GRINDER TO PREVENT CLOGGING OF DISC BY ALUMINUM

FIGURE 4 GRINDING RAIL ENDS PRIOR TO WELDING

FIGURE 5 RAIL END PREPARED FOR WELDING

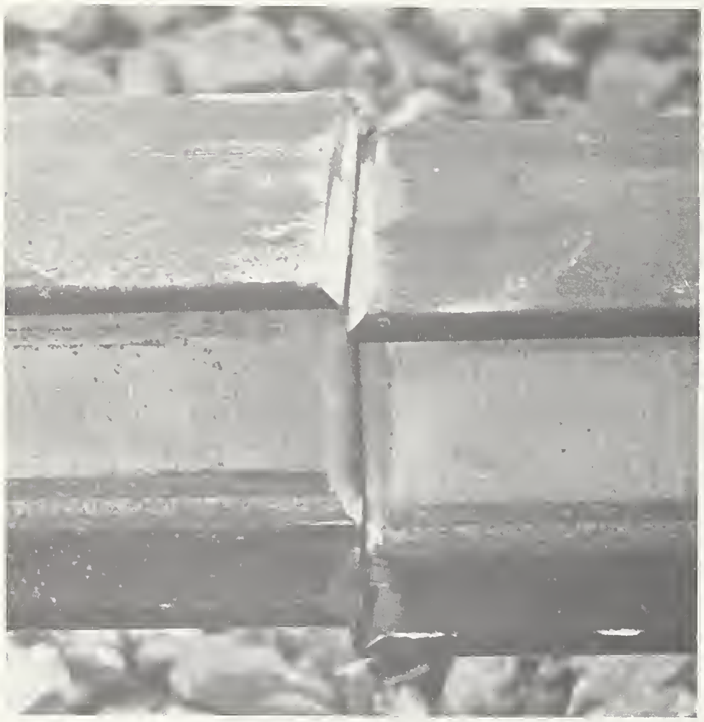


FIGURE 6 UNALIGNED ENDS OF THIRD RAIL

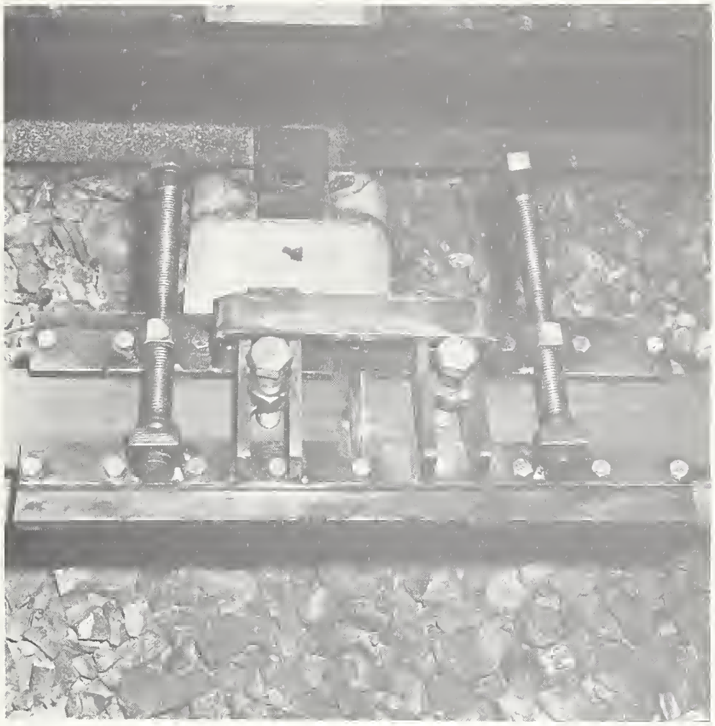


FIGURE 7 THIRD RAIL AND ALIGNMENT JIG

FIGURE 8 WELDING STEEL PORTION OF COMPOSITE RAIL

FIGURE 9 GRINDING STEEL SURFACE SMOOTH ON TOP OF RAIL

FIGURE 10 PREHEATING ALUMINUM AND TESTING FOR PROPER TEMPERATURE BEFORE WELDING

FIGURE 11 WELDING ALUMINUM PORTION OF COMPOSITE RAIL WITH MIG GUN

FIGURE 12 COMPLETED WELD

APPENDIX C

MAINTENANCE OF RAILS ON BART

APPENDIX C

Maintenance Of Rails On Bart

In his presentation on "BART Experience with Composite Rail", Mr. Mahon stated that trouble-free operation with their composite third rail was due, at least in part, to the maintenance of the proper geometric relationship of the third rail relative to the running rails, and to the meticulous maintenance procedures employed by BART on its roadbed. These maintenance procedures were described in an article, "Speno Grinding Keeps BART Commuters Riding In Comfort", which appeared in the Spring 1977 issue of "Trans/Action", published by the Trans Union Corporation of Lincolnshire, Illinois. The article is reprinted here with the kind permission of the Trans Union Corporation, and presents BART's maintenance procedures in greater detail.

San Francisco's Bay Area Rapid Transit (BART) train speeds up to 80 mph, giving commuters a luxury-like ride. A Speno rail-grinding train helps make track smoother, safer.

SPENO GRINDING KEEPS BART COMMUTERS RIDING IN COMFORT

Since its September 1972 opening, San Francisco Bay Area Rapid Transit (BART) system has been giving its patrons a smooth ride between urban and suburban areas. After all, as the most advanced rapid transit in the world and the first new U.S. rail system to be completed in 60 years, this was what they expected.

But to Vincent Mahon, director of BART's power and way maintenance department, their comfort is not something that just happened. It is the result of careful planning and continuous work.

"We paid close attention to maintenance requirements from the first day we started designing the system," explains Mahon. *"A very important contributor to our smooth ride and long rail and tie life is our own Speno rail grinding train."*

The grinding train, designed and assembled by Speno Rail Services, a Trans Union Corporation affiliate, is little brother to six larger trains which grind rail for most major railroads in the U.S. and Canada.

Today it is keeping BART track in mint condition, lessening the wheel's impact on the rail and ties, and reducing noise and vibration both inside and outside the trains.

Where, Why to Grind

BART's first use of the grinding train was to remove the scale that all rails contain when delivered from the mill. Mill scale was considered especially critical with BART. Removal of mill scale from running surface of rail contributes to reduction of wheel slippage during braking and acceleration of trains

BART's Vincent Mahon (right) and R. F. Daron discuss rail-grinding operation in front of Speno train, as BART train speeds by in background. The grinding train works weekends, when other trains are idle.

Sparks fly from beneath BART's Speno train as it grinds rail to provide the utmost in rider comfort and safety. Rails were first ground before BART service started, to remove mill scale that could have caused car-control problems.

BART's Superintendent of Track and Structures W. P. Lagle, rides in back of speeding train, listening and feeling for irregular track conditions. The total system consists of 142 miles of track which he must monitor.

operating over new rail. Removal of the scale is also particularly important in the area of train protection where the design calls for the wheels and axle to act as an electrical shunt, thereby signaling a buffer zone for following trains. It was therefore imperative that rail coating be minimized so that signal systems and Central Control's ability to identify trains would not be hampered. All 142 miles of BART's 71 miles of double track were ground prior to use, to take off .003 inch of scale and create a smooth metal surface.

Once the full 71 route miles were opened, the grinding train began its standard maintenance runs to keep the rails clean and smooth. Every weekend, when BART is closed down, the Speno train moves into position and starts grinding at one or two miles per hour with its 24 grinding wheels.

All track doesn't get the same treatment. Although most rails are ground every 14 to 20 months, station areas are ground every 12 months due to corrugations developed by acceleration and deceleration of trains.

Rail differences also call for different grinding operations. Two passes of the grinding train is all that's needed for the straight sections of the normal 119-lb. rails, but curves, with 4½- to 8¼-in. superelevation — the height difference between outside and inside rails on a curve — require up to as many as 20 passes. In some areas the rails are special, flame-hardened steel, which call for four to five passes to remove only .002 in.

Besides corrugations and normal corrosion, the grinding train must remove wheel burns caused by train braking and accelerations. If left on the surface, these wheel burns can lead to internal thermal fissures which will cause rail failures.

An Integrated Design

During the construction period of BART, a number of track surface maintenance ideas were considered and rejected by Mahon and his group. One in particular that looked good was to use belt grinding. But tests showed that it would not give the production rates called for by the BART schedule. That is when Speno Rail Services was asked to design and build the grinding train with its 10-in. grinding wheels that spin at 3500 rpm.

The planners also used this opportunity to integrate the design by having Speno coordinate its efforts with the manufacturer of the 50-ton Plymouth locomotive. This 33,000-lb. tractive-effort diesel/hydraulic unit was designed with another interesting feature — it can be hooked in tandem with a similar unit, so that when BART goes to seven-day service, another locomotive and grinding unit can be easily attached to double the train's capacity.

The present train has four grinding cars, a control car, a generator car, water car and the locomotive. The water is used to keep down dust when grinding inside the subway stations. The whole train requires only three operators — two on the grinder and one in the locomotive.

The grinding train is part of a total package which stresses rider comfort and safety. Except for those on the sharpest curves, the rails are all continuous-welded to eliminate as many joints as possible. The rails are held in tension, to allow for excellent rail alignment (plus or minus one-fourth in.) to support the cyclical loading as trains pass over them. To establish and maintain the tension, the rails were installed and welded at 70 deg. F or above ambient temperatures and were pulled together as they were welded.

BART track gauge is 66-in. — the standard gauge is only 56½-in. — to give its lighter BART cars the stability they need on aerial sections where wind conditions exist. This design also facilitates movements of trains through subway construction. This wide stance provides better passenger seating than is normally found on most rapid transit trains.

A full 12 inches of ballast "gives" enough so that wheel impact, which can hit like a gigantic hammer, does not damage the concrete ties. BART has not experienced a single tie failure since opening operations.

To say the grinding train is successful would be an understatement. *"Our Daly City line has carried over 234 million gross tons of traffic with not one case of rail shelling,"* says Mahon. *"That adds up to over 102,000 train movements at speeds up to 80 miles per hour, with trains passing by every six minutes from 6:00 a.m. until 8:00 p.m. every weekday, and every 20 minutes from 8:00 p.m. to midnight. Traffic-wise, we're a very busy railroad."*

Technicians at underground BART control system monitor all train movements, identified on wall-mounted console. The Speno grinding train was used to remove mill scale from track, to assure proper electrical contact needed for this display.

APPENDIX D

RELATIVE COSTS OF COMPOSITE AND STEEL THIRD RAIL INSTALLATIONS

APPENDIX D

Relative Costs Of Composite And Steel Third Rail Installations

Accurate and recent data on the relative costs of composite and steel third rail installations is not readily available. Information contained in the following paragraphs is offered as a guideline for any transit property considering a third rail installation. This data must not be used as a subtitute for a detailed cost estimate prepared for each specific route in which current and projected rates are used for labor, materials and interest. In addition, for a full life cycle cost analysis, projected costs should be used for operation and maintenance, energy losses, and scrap or salvage value of material (and cost of removal) at the end of the useful life of the installation.

The cost estimates presented here were completed in late 1974 by a transit property for a new line. They provide a direct comparison between a complete third rail installation of Bethlehem 150 lb. NMC contact rail, and one employing an H.K. Porter TRANSDUCTOR^{TM} 85-2 compsite rail. (The composite comprised 85 lb. ASCE steel rail and extruded aluminum side plates in the web area of the rail). For the steel rail, cadwelded butt joints were assumed. For the composite rail, joints were assumed to be made with extruded aluminum splice bars and Huck bolts. Appurtenances (insulators, anchors, etc.) were assumed to be identical for both types of rail and were not considered in detail. The cost figures are presented in Table D-1, and represent costs per mile.

The table shows that the composite rail installation cost was higher by $3,600 per mile ($0.68 per foot), or about 3 percent, than the steel rail installation cost.

In this instance, with the costs of electrical energy taken as $0.036 per KWHR and for the expected traffic volume on the route, the costs of energy (I^2R) losses in the composite rail were estimated to be $1256 per mile per year less than the cost of losses in the steel rail. Hence, the increased cost of the composite rail would be recovered in slightly less than three years. A present value analysis prepared by this system over them the 50 year expected life of the rail showed a penalty against the steel rail of over $25,000 per mile due to the higher I^2R losses in the steel rail, which is considerably in excess of the incremental cost of $3600 per mile for the composite rail.

It should be noted this analysis did not consider any possible savings that might have resulted from a reduction in total substation capacity, but was based entirely upon installed costs and reduced energy losses in the contact rail.

TABLE D-1

RELATIVE COSTS OF STEEL AND
COMPOSITE THIRD RAIL INSTALLATIONS

	COST PER MILE	
	150 lb. STEEL RAIL	COMPOSITE PORTER 85-2 TRANSDUCTOR™
1. Contact Rail		
(a) Material	$36,600.00	$63,400.00
(b) Labor	60,000.00	60,000.00
2. Butt Joints		
(a) Material	$ 4,000.00	Included in 1 (a)
(b) Labor	14,800.00	500
3. Expansion Joints		
(a) Material	1,600.00	Included in 1 (a)
(b) Labor	3,400.00	100
4. Subtotals		
(a) Materials	42,200.00	63,400.00
(b) Labor	78,200.00	60,600.00
5. Totals	$120,400.00	$124,000.00
	($22.80/ft.)	($23.50/ft)

APPENDIX E

COMPOSITE THIRD RAIL SEMINAR ATTENDEES

APPENDIX E

Composite Third Rail Seminar Attendees

American Public Transit Association
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H. Fleige, Electrical Engineer
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Chief Electrical Engineer
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Glassport, PA 15045

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Day & Zimmerman, Inc.
John E. Kennedy, V.P. Consulting Services, Div.
Harry Klein, Sr., Electrical Engineer
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Philadelphia, PA 19103

DeLeuw, Cather and Company
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William E. Abbott, Sales Engineers
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A.J. Spiringer, Sales Manager
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Lucius Pinkney, Jr., Senior Electical Engineer
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Massachusetts Bay Transit Authority
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Transportation Systems Center
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Shield Electric Company
Edson Schmid, President
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Lexington, MA 02173

Transportation Systems Center
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B. Bosserman
R.W. Booker
R. Thibodeau
G. Neat
J. Bowe
C. Spenny
L. Zorio
R. Robichaud

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Dr. Alexander Kusko, President
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Needham Heights, MA 02194

APPENDIX F

ELECTRIFIED TRANSIT PROPERTIES

APPENDIX F

Electrified Transit Properties

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Asst. Gen. Manager of Design and Construction

Metropolitan Atlanta Rapid Transit Authority
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Atlanta, Georgia 30308
Assit. Gen. Manager Transit, Mr. William D. Alexander

Honolulu Department of Transportation Services
Mass Transit Division
650 South King Street
Honolulu, Hawaii 96813
Manager Dir. Mr. Richard K. Sharpless

Massachusetts Bay Transportation Authority
45 High Streeet
Boston, MA 02110
Chmn, Mr. Robert R. Kiley

Transport of New Jersey
180 Boyden Ave.
Maplewood, New Jersey 07040
Chmn. Pres., Mr. John J. Gilhooley

Long Island Rail Road
Jamaica Station
Jamaica, New York 11435
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Metropolitan Transportation Authority
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New York, NY 10019
Dir. Trans. Res. & Engr., Mr. Arthur G. Raabe

New York City Transit Authority
370 Jay St.
Brooklyn, New York
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Niagara Frontier Transportation Authority
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Buffalo, New York 14203
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Staten Island Rapid Transit Operating Authority
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Tri-County Metropolitan Transportation District
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Chmn. & General Manager, Mr. Lawrence Hanigan

Toronto Transit Commission
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