NCTRP

National Cooperative Transit Research and Development Program

RESEARCH RESULTS DIGEST

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These **Digests** are issued in the interest of providing an early awareness of the research results emanating from projects in the NCTRP. By making these results known as they are developed, it is hoped that the potential users of the research findings will be encouraged toward their early implementation in operating practices. Persons wanting to pursue the project subject matter in greater depth may do so through contact with the Cooperative Research Programs Staff, Transportation Research Board, 2101 Constitution Ave., N.W., Washington, D.C. 20418.

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Areas of Interest: 21 facilities design, 25 structures design and performance, 33 construction, 40 maintenance, 54 operations and traffic control (01 highway transportation, 02 public transit)

Electrolytic Corrosion In DC-Powered Transit Systems

An NCTRP Staff Digest of the essential findings from Project 48-1, "Corrosion Attributed to DC-Powered Transit Systems, Conducted by IIT Research Institute; Chicago, Illinois

THE PROBLEM AND ITS SOLUTION

Historically, DC-powered rail transit systems have been constructed and operated with little consideration for the control of stray earth currents. While their prevention is a major design factor in construction of new facilities, stray currents have caused unaccountable corrosion costs to operators of buried utilities and other metallic underground structures in the vicinity of older rail systems. The resulting structural damage to transit properties and neighboring facilities is a significant and persistent problem, increasing operating costs and shortening life. Stray currents contribute further problems by creating hazards of fire, explosion, and environmental pollution.

The objectives of this research were threefold: (1) to document and quantify the dimensions of the problem, (2) to develop practical recommendations for the transit industry, and (3) to design a research program that will provide cost-effective solutions.

FINDINGS

The project working plan called for completion of several tasks including a survey, a workshop, a bibliography, and a research action plan for the future. The findings of these tasks were presented in a series of reports, listed below (the asterisked reports are summarized in the following sections):

1. Literature Review Report*
2. Corrosion Workshop Plan
3. Workshop Report
4. Final Report
5. Survey Report
6. Engineering Practices Report*
7. Report on a Research Plan*
8. Brochure, "Corrosion from Stray Current -- A Significant Problem Associated with DC Systems"

The reports will not be published in the formal NCTRP series, but they are available upon written request to the NCTRP, Transportation Research Board, 2101 Constitution Avenue, N.W., Washington, D.C. 20418. Another source of information regarding the project findings is: "Attitudes and Practices: Direct Current Transit Systems and Stray Current Corrosion," S.T. McCarthy, M.J. Neatrour, L.M. Krause, J.J. English, and M.M. Abromavage, Transportation Research Record 1192, Transportation Research Board, Washington, D.C., 1988.

Literature Review Report

This report, consisting of 60 pages of main text and supported by five appendixes, documents the results of reviewing more than 500 publications available since the beginning of the twentieth century on the subject of electrolytic corrosion. One appendix shows a year-by-year chronology of papers and other publications on related topics; another lists three papers described as the best overview papers on transit-generated stray currents; a third (86 pages) provides a listing of the identified literature and a three-level subject index containing more than 100 separate topics.

The findings of the literature review are summarized in the following discussion:

- An examination of the content and history of publishing activity, between 1900 and 1985, pertaining to the problem of electrolytic corrosion of underground structures due to DC-transit system stray currents, determined that interest in the subject as a whole can be subdivided into several subareas: the identification of affected structures and the associated transit system stray current effects; the environmental parameters that affect either stray currents or corrosion directly; and the methods for and effects of the corrosion control problem. Of these, the subject of control is of most interest. The principal aspects of control were determined to be engineering practices, management concerns, and safety considerations.
- Regarding engineering practices, two major subdivisions are evident: practices designed to protect structures from the corrosive effects of stray currents, and mitigation practices designed to reduce the magnitude of stray currents generated by the transit system. This division is found in all phases of control through engineering practices; i.e., preconstruction planning, maintenance, and theory and research. It was found that engineering practices geared toward corrosion protection were more numerous in the literature than were practices geared toward stray current mitigation, except with regard to preconstruction planning practices.
- An examination of corrosion protection alone determined that drainage, especially direct and polarized drainage, is the practice most often referred to. References to cathodic protection systems are slightly less prevalent. There are relatively few discussions in the literature pertaining to the use of coatings, the chemical treatment of soil surrounding affected structures, or electrical connections between affected structures.
- An examination of stray current mitigation practices alone determined that the separation between substations, the grounding practices at those substations, the electrical isolation of portions of the transit facility, and the electrical continuity of the running rails as the negative return path are the practices most emphasized. Stray current mitigation through the control of leakage resistance received more attention in the literature than did the control of the return path resistance.

- As indicated earlier, the nonengineering aspects of corrosion control are management and safety. Literature dealing with management emphasized the training and education of concerned individuals and organizations, regulation and standards, and the coordination of affected organizations and the transit agency. Discussion relative to safety considerations was limited. Recent literature concerned with safety has concentrated on electrical shock hazards.
- Additional research needs resulting from the foregoing findings can be divided into four broad categories. The first involves the review of present knowledge concerning: electrolytic corrosion of transit facilities, electrolytic corrosion affecting reinforced concrete structures, efficiency of various techniques of draining stray current from affected systems, relative benefits of installing new or additional mitigation facilities to an existing transit system, and sources of shock hazards and techniques for eliminating them. The second category of research needs centers on quantification of the effects of substation separation and ground, and the effects that isolating portions of the transit system will have on the control of stray currents. The third category suggests the development of devices, specifically diode drainage or grounding devices and automatic monitoring systems, to improve corrosion control techniques. The final category of research needs involves the development of prediction and analysis tools in the form of experimental facilities and computer modeling for use by the corrosion engineer.

Engineering Practices Report

On-site surveys at five transit properties, a mail survey that generated responses, and a workshop survey, in addition to the literature review, provided the resources for compilation of the "Engineering Practices Report". This report addresses transit agency practices and those of other systems affected by electrolytic corrosion. It identifies techniques of corrosion detection, measurement, protection and mitigation; it describes their implementation; and it assesses their applicability and success rate. The report also compares the techniques and provides recommendations based on the comparisons.

The findings are summarized as follows:

- Direct drainage is not recommended for use in protecting an affected system from stray current corrosion because unidirectional current flow from structure to negative bus cannot be guaranteed. Therefore, this method can be detrimental to the drained system and to neighboring structures as well.
- Diode drainage is preferred over direct drainage, but its use is limited to grounded transit systems with drainage currents typically less than 200 A and an adequate structure to negative bus potential to overcome the 0.7 V needed for the diode to conduct.
- Reverse current switches are recommended when a diode does not provide the necessary drainage characteristics. However, because the switches are mechanical devices, they have a tendency to malfunction.
- Utility interconnections have the same problems as direct drainage. The user must be aware that each interconnection changes the electrical network and, thereby, can increase or redistribute the stray current. In order to keep track of all interconnections, an up-to-date listing should be maintained, with the cooperation of all parties involved.
- Impressed current rectifiers are generally not used in stray current areas because they must be adjusted to compensate for the worst case

stray current. This can result in overprotection, causing additional electrolytic corrosion.

- Constant potential rectifiers eliminate the overprotection problem of impressed current rectifiers, but they must overcome the bias of the structure in order to control the worst case stray current.
- Isolating devices interrupt the continuity of the current path, but have high maintenance requirements that may not be cost effective. Because current can also jump across the devices through the earth, this method generally should be used in conjunction with another protection method.
- Protective coatings that are professionally chosen and applied can be effective in reducing stray current corrosion, but to be completely effective they generally need to be used in conjunction with another protection method. The use of noncorrosive materials is extremely effective when installing a new underground structure.
- Frequent substation placement is effective in reducing stray current, but is not cost effective for existing systems. The use of this method is proposed for new transit systems.
- Bonded rails improve the rail return conductivity, but have a tendency to break. Welded rails are suggested as the best form of bonding because they ensure a continuous negative return circuit and require less maintenance than any other method of bonding.
- Cross bonds are effective in reducing stray current, but are limited to areas that do not use the running rails as a signaling system. Where the running rails are used as a signaling system, impedance bonds can be used with caution.
- Voltage equalization can be used to control stray currents at the traction substation by controlling voltage between track sections.
- Ballast that is kept off the rails, clean and dry, can reduce stray current. A further means of stray current reduction is to use less ballast so that it only goes about halfway up the tie. This gap between the ballast and rail will create a greater resistance gap, and in this way decrease the stray current. If, after attaining the gap, cleaning the ballast, and eliminating water intrusion into the ballast, a problem still exists, a special ballast (e.g., low conductivity granite) could be used as an alternative to reduce the stray current.
- Diode grounding can be used as an effective means of stray current mitigation as long as the track system is properly maintained so as to avoid additional leakage current and inadvertent grounds.
- An insulated negative feeder system can reduce the potential gradients on the track, but it will not necessarily reduce the potential difference between the tracks and the affected system.
- Electrical isolation of maintenance/storage yards can greatly reduce stray current in the vicinity of these yards. Isolation should be considered in the design and operation of a transit system.
- One final thought, of utmost importance, that is brought out in all literature and all of the surveys performed: *for any protection or mitigation technique to be effective, it must be continually inspected and maintained.*

Research Action Plan

"Report on a Research Plan" details the development of recommendations for a research program to meet the needs of the transit community relative to the issue of stray currents. A program of 20 projects is proposed, grouped under six subject categories, costing a total of approximately $5 million (1986 dollars) and requiring less than 7 years to complete.

The overall objective is the development of engineering design and cost analysis handbooks. To that end, the program stresses: (1) improvements in transit system technology that will reduce the generation of stray currents responsible for corrosion problems, and (2) more effective means for controlling unavoidable corrosion effects. Advances in engineering applications for monitoring and measuring corrosion rates and for developing contemporary predictive capabilities are also included in the program, as are research projects in public safety, occupational safety, and management practices.

Figure 1 shows the subject categories, specific projects, and the proposed timetable for the research program.

APPLICATIONS

The surveys conducted by the research team showed that managers lack information on stray current effects and its control. In response to this information gap, an 8-page, two-color brochure entitled "Corrosion from Stray Current -- A Significant Problem Associated with DC Systems," was prepared and was provided to several operators of DC transit systems. Intended for utilities and transit agencies, management, transit system designers, transit and utility corrosion specialists, the brochure emphasizes methods of control and, particularly, points out the value of area committees to coordinate control measures. Because of the favorable response to the brochure, it is reproduced in its entirety as a concluding section in this digest.

The research plan provides a ready-made program to address the issues identified in this project. Although the costs of corrosion are difficult to assess, it has been estimated that the cost to the U.S. industry of dealing with the stray current corrosion problem, each year, is on the order of $500,000,000. While the currents come from a variety of sources, as stated in the brochure, "most of it is produced by DC railways." The 5 million dollar recommended research program, which represents a tiny fraction of one year's total cost to society from this problem, thus offers the potential of significant benefits if it is undertaken and its results can be successfully implemented.

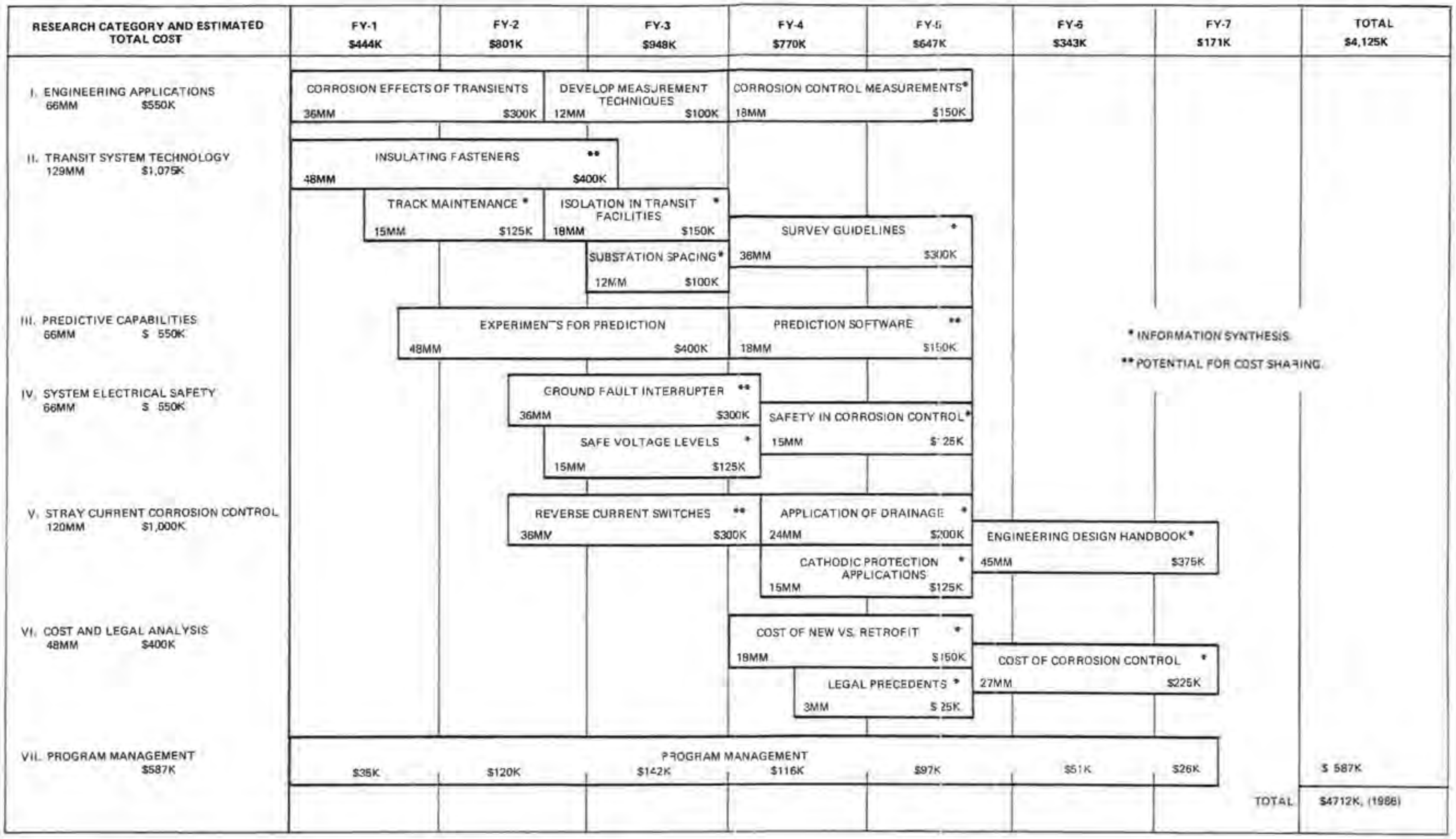

FIGURE 1 **Proposed research program (and estimated cost in 1986 dollars based on $100,000/man year) for stray current corrosion from DC powered transit systems.**

CORROSION FROM STRAY CURRENT
A Significant Problem Associated with DC Systems

CORROSION FROM STRAY CURRENT
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Under NCTRP Project 48-1

THE PROBLEM

Each year, U.S. industry spends more than $10 billion to deal with corrosion. Five percent of this cost, an estimate of The National Association of Corrosion Engineers, Battelle Institute, and the U.S. Department of Commerce, is attributed to stray current–electrical current that strays from its intended path. Although stray current is produced by many operations that use DC current, such as welding, DC-powered bridges, and underground mining where DC vehicles are used, most of it is produced by DC railways.

Stray current can create significant, and sometimes major, problems for anyone that relies on conducting metallic structures located belowground.

- Stray current contributes to the corrosion of belowground metallic structures, thereby decreasing their lifetime and increasing operating costs.
- By contributing to the corrosion of belowground metallic structures, stray current also contributes to the creation of explosion and fire hazards and environmental pollution.

The severity of the problem varies from place to place, and frequent monitoring is necessary just to maintain the status quo.

The direct flow electrical current used by DC railways is supposed to travel along the rails, but, as illustrated in Figure 1, some of the current may stray from this intended path. This stray current will pass into the earth and to nearby conducting metallic structures such as utility pipelines, cables, belowground storage vessels, and reinforced concrete, which provide low-resistance alternative return paths. The stray current then travels along these structures and through the earth, from one belowground conducting structure to another, until it returns to its source of power, the DC power substation.

As stray current leaves one metallic conductor to pass into moisture-containing earth en route to another conductor, it removes a portion of the conducting metallic surface. In time, the metallic surface deteriorates or corrodes. This deterioration or corrosion causes failure or degrades performance.

Figure 1. — STRAY DC CURRENT FOLLOWING EASIEST ROUTE OF RETURN AND CREATING AREAS OF CORROSION.

AFFECTED PARTIES AND STRUCTURES

Stray current does not distinguish between a belowground structure that belongs to the gas company and one that carries a municipal water supply. It does not differentiate between the rails from which it strays and the telephone cable it leaves en route to a substation. It is impartial and will contribute to the corrosion of any structure when the conditions are suitable for electrochemical reactions.

The parties and structures most frequently affected by stray current are:

- Transit companies/agencies
  - Rails
  - Stations and platforms
  - Electric cables
  - Communication and signaling cables
  - Tunnel structures
- Utilities
  - Gas pipelines
  - Water pipes
  - Telephone cables and related hardware
  - Electric cables and grounds

- Liquid product (e.g., oil) pipelines
- Storage vessels (e.g., gas, oil and chemical storage tanks)
- Reinforced concrete structures (e.g., bridges, highways, buildings)
- Other belowground metallic structures.

CONTROL OF THE CORROSION PROBLEM

Corrosion caused by stray currents from DC railways can be controlled if all affected parties join in a multifaceted approach:

- Transit companies can reduce corrosion-causing stray currents by applying *stray current reduction techniques* to the railway.
- Affected parties can protect belowground structures against corrosion by using *protection techniques*.
- All affected parties can use *comprehensive maintenance techniques*.
- The design of new systems and modernization/ extension of old systems can include *precautions* to minimize conditions that create stray current.

Examples of some of these techniques are shown in Figure 2.

Stray Current Reduction Techniques

Older transit systems, which constitute the majority of existing systems, were often constructed without adequate concern or knowledge about corrosion-causing stray current. As a result, rails carrying current back to power substations are often undersized for modern power requirements. Bonding of rail joints is inadequate; cleaning of track beds difficult. Rails lie intimately in contact with earth. Grounded passenger stations and support structures are electrically connected to the rails. Stray currents generated by these systems are massive and the affected parties, including transit agencies, have been forced to spend large sums of money on corrosion-related problems.

Figure 2. — EXAMPLES OF STRAY CURRENT REDUCTION TECHNIQUES: A — BURIED COPPER CABLE TO REINFORCE RETURN OF CURRENT THROUGH RAIL; B — INSULATED PIPE JOINTS; C — DRAIN WIRE TO NEAREST POWER SUBSTATION; D — INSULATED RAIL FASTENERS; E — INSULATING JACKETS; F — INSULATING SHIELD; G — INCREASED NUMBER OF POWER SUBSTATIONS.

It is only recently that stray current reduction techniques have been actively pursued. Older transit systems, as well as municipal underground utility systems, are being upgraded using various techniques and practices, among them:

- Comprehensive maintenance programs have been instituted.
- The current load supplied by substations is altered in response to circumstances instead of remaining constant.

Protection Techniques

With time, the old DC railways have undergone so many changes that, today, the exact nature of their electrical systems may be unknown. Although these systems often generate significant stray current, it is not practical to update them. Instead, various techniques are being used to protect below-ground structures:

- Joints of conducting metallic pipes are insulated to help protect them from corrosion by breaking up pipeline continuity.

- Cables are protected with insulated jackets over metal shields and are insulated where they enter buildings.

- Drainage devices are installed to provide an alternate path for stray current. These can be as simple as a wire that connects the belowground structure to a substation or as complicated as a device that can eliminate corrosion-promoting fluctuations in current flow.

Comprehensive Maintenance

Corrosion control programs can only be as effective as the maintenance programs of both the transit agency and the other affected parties. Their success also depends on interaction between system designers and operations engineers to ensure coordination activities. A successful maintenance program is based on the following principles:

- Regular inspection of track beds, rail bonds, tunnel structures, and drainage bonds can often identify potential problems at a time when they can be solved with mininum effort.

- Routine surveys for stray current between belowground structures and earth, between one belowground structure and another, and between a belowground structure and the source of stray current can provide useful information.

- Measurement of currents between drainage bonds and related structures can be an indication of the effectiveness of the bonds.

- Maintaining voltage equalization at substations reduces the possibility of stray current.

- Keeping ballast clean, dry, and off the rails can further reduce stray current.

Precautions for New Systems or for Modernizing/ Extending Old Systems

The concern about stray current control has influenced the design of DC railways. The planning of new DC railway systems and modernization or extension of old systems now includes precautions to reduce stray current:

- Closely spaced substations

- Insulating rail fasteners

- Rails that are insulated from stations and other structures

- Almost complete isolation of entire systems from nearby belowground structures, eliminating the need for drainage wires

- Comprehensive maintenance programs from the outset.

Research, with input from all affected parties, continues to seek and explore methods that will eliminate many sources of stray current.

AREA CORROSION COORDINATION COMMITTEES

Area corrosion coordination committees have been established in most large metropolitan areas, as illustrated in Figure 3 on page 8, and in many other regions where municipalities and private interests have very substantial investments in pipes, cables, and other belowground structures. Members of these committees represent the transit and utility industries and other affected parties.

The participation of all affected parties in these committees can eliminate unnecessary expenditures for all:

- Participants can identify potential problems and work together to seek ways to solve them.

- All affected parties can benefit from cost savings that result from cooperatively sponsored research, responsible design, thorough maintenance, and implementation of innovative ideas.

- Cooperation among participants can provide a way to avoid very costly after-the-fact litigation.

- Cooperative corrosion control and prevention is, undoubtedly, less costly than corrosion-dictated repairs.

For information about the corrosion coordination committee in your area contact:

The National Association
of Corrosion Engineers
1440 South Creek Drive
Houston, Texas 77084
(713) 492-0535

Figure 3. SELECTED CITIES WITH DC POWERED TRANSIT SYSTEMS.

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