CIVIL ENGINEERING PRACTICE

JOURNAL OF THE BOSTON SOCIETY OF CIVIL ENGINEERS SECTION/ASCE

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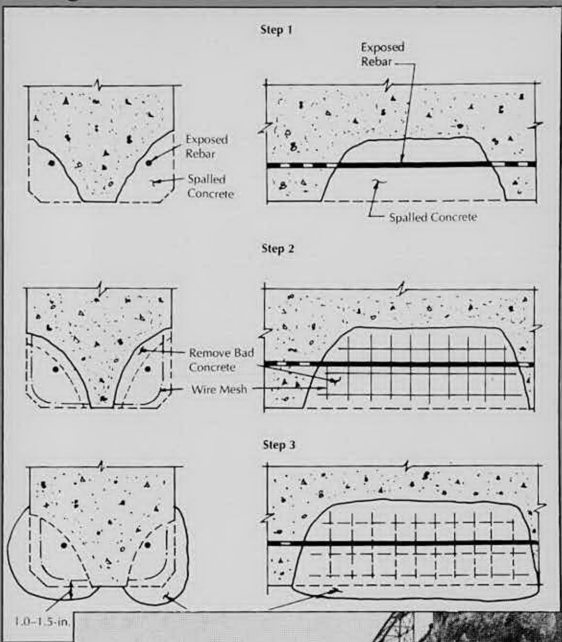
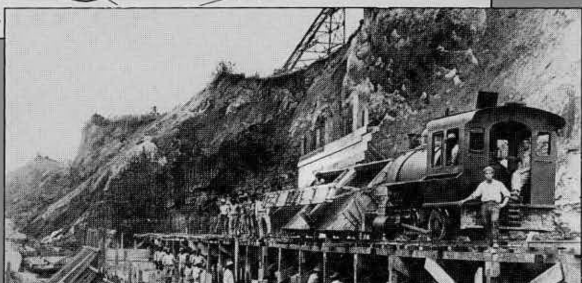
Bridge Rehabilitation





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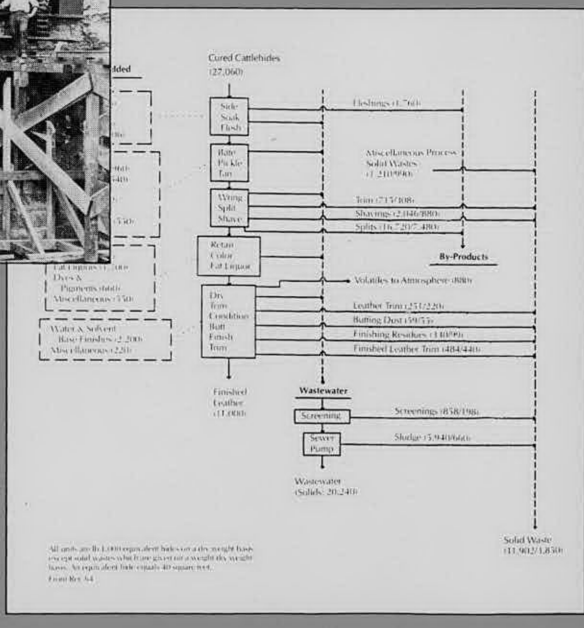

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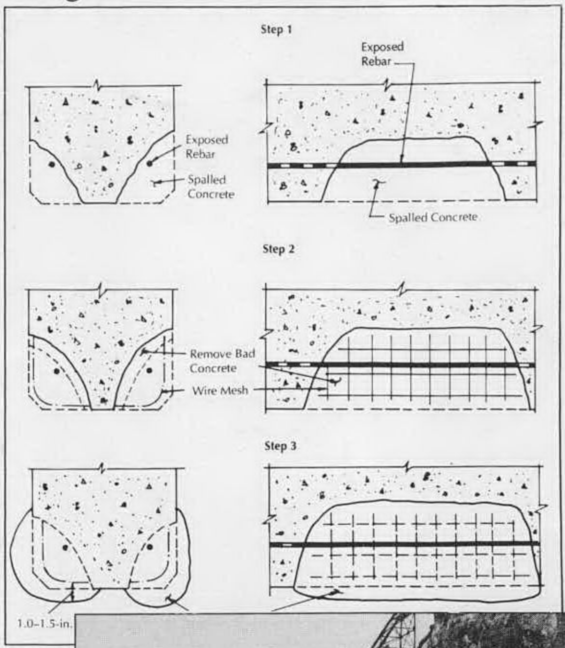

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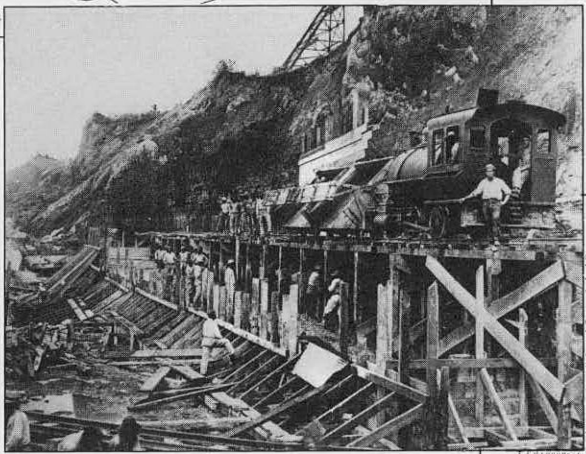

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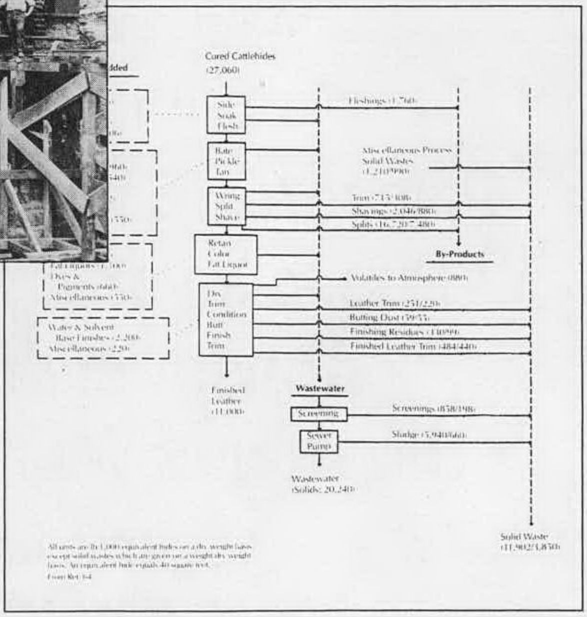

Leather Industry Wastes

CIVIL ENGINEERING
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Civil Engineering Practice
Boston Society of Civil Engineers Section/ASCE
The Engineering Center
One Walnut St.
Boston, MA 02108

Phone: (617) 227-5551
Fax: (617) 227-6783

CIVIL ENGINEERING PRACTICE™

JOURNAL OF THE BOSTON SOCIETY OF CIVIL ENGINEERS SECTION/ASCE

Bridge Rehabilitation

Given the country's aging infrastructure, bridge rehabilitation provides an economical and environmentally sound solution to a massive national problem.

FRANK STAHL

Our shrinking resources have begun to drastically affect how we live. For example, recycling has stopped being just a fashionable battle cry of environmentalists. Nowadays, the recycling of common household materials such as glass bottles, metal cans and newspapers is becoming mandatory in many parts of the country. The rehabilitation of our bridges, for whatever reason, is but another aspect of recycling or preservation of existing and scarce infrastructure resources.

In the past, when a bridge was severely damaged or had outlived its functional usefulness, it was abandoned and replaced with a new structure at the same or adjacent location. Today, such action is very rare, notwithstanding such prominent projects in New England as the replacement of the Charter Oak Bridge in Hartford, Connecticut, and the proposed replacement of the Boston Central Artery. Instead, it has now become standard practice to make every effort to rehabilitate rather than replace bridge structures.

Reasons for Rehabilitation

There are many reasons why rehabilitation or replacement of a structure becomes necessary — no structure has an infinite lifespan. Chief among these reasons are structural damage, structural inadequacies and functional inadequacies.

Structural Damages. The most obvious reason for rehabilitation or replacement is damage to a structure caused by the forces of nature or man. For example, the Niagara arch bridge, built in 1898 at the site of an early Roebling suspension bridge, was completely destroyed by ice flow in 1938 and was replaced by the present structure. Probably the most famous bridge failure was the collapse of the Tacoma Narrows Bridge in heavy winds on November 7, 1940. This bridge was completely rebuilt, utilizing only the foundation and portions of the approach viaducts of the original structure. San Francisco's Golden Gate Bridge suffered considerable damage to its stiffening trusses and lateral wind system during a severe storm in December 1951. Subsequently, in addition to the necessary repairs, the bridge was rehabilitated in 1954 by the addition of a lower lateral bracing system.

In addition to windstorms and floods, earthquakes can inflict considerable damage to bridges as was dramatically attested to recently by the damage to the San Francisco Bay Bridge and the Oakland Viaduct during the Loma Prieta earthquake on October 17, 1989. In addition, the 1971 San Fernando, California, earthquake caused serious damage to nearly 70 highway bridges. Seven of these bridges either collapsed or were sufficiently damaged to warrant their replacement. Earthquakes occur more frequently than is generally realized, constituting a serious problem in many parts of this country and throughout the world.

Bridges are often key targets in armed conflicts. Hundreds of bridges were severely damaged or destroyed in Europe during World War II. Many had to be completely replaced, but just as many were built and rehabilitated using existing foundations and substructures, as well as portions of the superstructure. The historic Chain Bridge across the Danube in Budapest and the sixteenth-century Ponte a Santa Trinità in Florence were two such bridges that were rehabilitated. More recently, the unique cable-stiffened San Marcos suspension bridge built across the Lempa River in 1953 and the Cuscatlan Suspension Bridge on the Pan American Highway built in the 1940s were casualties of the fighting in El Salvador.

Not infrequently, the loss of, or damage to, a bridge results from accidents such as a ship or truck colliding with a bridge superstructure, a ship colliding with bridge foundations, or an overheight truck colliding with truss portal bracing.

A more recent phenomenon is the sudden failure of individual bridge components, or even entire bridges, due to a local fracture initiated at a metallurgical defect produced during the fabrication of the detail or in the steel fabrication process itself.

Damages to bridge structures caused by erosion and corrosion are much more widespread, but far more subtle in their effects. Recent notable examples of the effects of longtime deterioration are the collapse of the Schoharie Creek Bridge on the New York Thruway that was caused by scouring erosion and the undermining of a pier foundation, and the collapse of the Mianus River Bridge on the Connecticut Turnpike that was caused by corrosion build-up in the pin-and-hanger assembly. In addition, New York's East River bridges, in particular the Williamsburg Bridge, have suffered extensive corrosion damage that was caused not so much by old age as lack of proper maintenance.

The lack of proper maintenance, or "deferred" maintenance, is a chronic problem that affects both steel and concrete bridges, and the concrete components of steel bridges. The long-standing habit of unrestricted use of de-icing salts and other chemicals is taking a heavy toll on bridges. Bridge deck repairs and replacement have become a routine cause of traffic delays not only in this country but also in Europe.

Structural Inadequacies. Structural inadequacies result from changes in design codes or traffic loads that have occurred since the original design. Many major bridges in this country were constructed in the nineteenth century or early in this century. The Benjamin Franklin, George Washington, Triborough and Golden Gate Bridges were built in the 1920s and 1930s. Hundreds of smaller bridges were built during the Works Progress Administration (WPA) days of the Roosevelt Administration. There was a tremendous increase in automobile and truck traffic shortly after World War II that brought about the creation of a national highway network. This evolution has been accompanied by improved design theories, a better understanding of the strength of materials and the discovery of new materials. Allowable stresses in current codes vary substantially from those used in the original designs of these structures. In addition, entirely new concepts such as fatigue and earthquake parameters must now be taken into account in evaluating structure safety.

Similarly, vehicle loads have increased dramatically since the turn of the century. The only reason that such structures as the Brooklyn Bridge, Williamsburg Bridge and Eads Bridge — all of which were designed prior to the advent of the automobile — can still serve traffic is that they were designed to carry railroad traffic in addition to horse-drawn vehicles.

Functional Inadequacies. Functional inadequacies also result from code or usage changes that have occurred since the structure was originally designed. However, code changes generally result directly from usage changes. Some older bridges were built for a mixture of railroad traffic and horse-drawn carriages. In the early twentieth century, relatively light and slow-moving automobiles started to compete with horse-drawn vehicles. Soon thereafter, the automobile took over the road and after World

War II motorized vehicle dimensions, speed and traffic density began to seriously affect design code requirements. Prior to World War II, a lane width of 9 feet sufficed; a 10-foot lane was considered the norm and there were few other geometric or safety requirements.

Today, a lane width of 12 feet is standard, with 13-foot lanes desired for truck lanes. Functional design requirements include minimum dimensions to side or overhead obstruction; cross slope, superelevation and sight distance specifications; and curb and centermall traffic barrier standards. In determining the design plan for the rehabilitation of a structure, all such requirements must be carefully considered, since the Federal Highway Administration (FHWA) rarely provides funding for structures with substandard features.

Rehabilitation vs. Replacement

Not infrequently, the merits of rehabilitating a structure must be weighed against those of complete replacement. Factors that have to be considered in such an evaluation fall into four basic categories:

- Economic
- Environmental
- Historic
- Political

Economic considerations cover construction costs (including design, construction management and financing costs), traffic maintenance costs during rehabilitation, the cost of temporary repairs to keep a structure serviceable until the replacement structure is completed, and land acquisition and business and private relocation costs. A thorough economic evaluation should be based not on a first-cost basis comparison but on a reasonable life-cycle basis that includes one or more rehabilitation cycles and maintenance costs. In addition, the costs on businesses in the area affected by traffic detouring, the costs of moving businesses and residents from land acquired for new construction as well as the costs of removing tax-producing property should also enter into this equation.

Environmental factors, most of which have a large cost component, affect the quality of life in the area in a way that cannot be completely evaluated in monetary terms. Typically, they include the air-pollution and other effects of backed-up traffic on detour roads, or exposure to lead paint during rehabilitation. For a replacement structure, especially if on a new alignment, the effects of the loss of business establishments, churchs, schools or other public facilities on the remainder of the neighborhood, as well as the removal of homes on nearby schools and churches or on the ethnic composition of the area, must be evaluated somehow.

Older bridge structures must be given some consideration with regard to their historic significance. In some instances, bridges have been made historical landmarks and are, thus, protected by laws that make it difficult or impossible to change features, or replace parts, even if it is necessary for safety's sake. Other structures are eligible for landmark status and, consequently, responsible authorities are reluctant to permit alterations that would endanger this status. A replacement bridge on a new site might impinge on nearby historic structures. Or, the rehabilitation design might not "fit in" with nearby historic structures.

Political considerations include all of the above factors since all public actions fall into the sphere of politics, especially in an election year. No matter how detached and professionally the arguments are presented, occasionally the political process will take over and force decisions to be made not so much based on the facts presented, but on what satisfies a vociferous segment of the population. Engineers are challenged to persuasively recommend the best solution based on engineering, economic and environmental considerations.

Design Approach to Rehabilitation

Bridge rehabilitation is normally preceded by a thorough inspection and structural rating. Detailed instructions and regulations for these operations are now available. However, when the need for engineering inspections was first recognized, engineers had to develop their own program, criteria and test procedures. Probably one of the earliest such efforts was the inspection of the Brooklyn Bridge, performed from 1943 to 1945 by a Board of Consulting Engineers that had assistance from a team of engineers from the New York City Department of Public Works. Their report, "Technical Survey of the Brooklyn Bridge," remains an appropriate model for all engineers engaged in this type of work.[1]

The Golden Gate Bridge was the subject of an in-depth inspection from 1967 to 1968. The work included removing various materials such as cable wires and several suspender ropes for testing. While standard ASTM test methods and material specifications intended for new materials were employed, testing methods and acceptance criteria had to be established for materials that had been in service for more than thirty years. Much path-breaking work was accomplished by the inspecting engineers who worked in collaboration with the steel industry in developing the methods and criteria.

The collapse in 1967 of the Point Pleasant Bridge (Silver Bridge) across the Ohio River in West Virginia with the loss of 46 lives provided the catalyst for a national policy on bridge inspection. As a result, the first national specification, the *Manual for Maintenance Inspection of Bridges,* was issued by American Association of State Highway and Transportation Officials (AASHTO) in 1970.[2] This specification replaced the many different, and mostly nonmandatory, specifications and guidelines for bridge maintenance and inspection in use by various highway authorities.

Code Requirements

The *Manual for Maintenance Inspection of Bridges* is now in its fourth edition and has become a standard reference for the engineering profession. The manual covers two basic topics:

- Inspection
- Capacity rating

Procedures for correcting deficiencies have been specifically excluded from the manual since they must be addressed on an individual basis.

Inspection. Specifications for inspection fall into three basic categories:

- Personnel qualifications
- Frequency of inspection
- Inspection procedures

The manual requires that the individual in charge of inspection operations be a registered professional engineer or have a minimum of ten years' experience in bridge inspection in a responsible capacity and have completed a comprehensive training course based on the United States Department of Transportation's "Bridge Inspector's Training Manual."[3] For a bridge inspection team operating under the general supervision of a professional engineer, the manual requires that the team leader have a minimum of five years of responsible experience and have completed the training course.

Lately, these minimum requirements have been superseded by many agencies that now require that each individual inspection team be headed by a registered professional engineer and that each team have an assistant team leader with a bachelor's degree in engineering or equivalent experience. In addition, the assignment of an independent quality control engineer who is not part of the inspection team is now frequently required. This quality control engineer must be a professional engineer.

The manual specifies that each bridge must be inspected at regular intervals that do not exceed two years. Interim inspections are required for any bridge with known deficiencies or in questionable condition. A stretch-out of inspection schedules, or having initial biennial inspections performed by maintenance personnel rather than an engineering team, are acceptable provisions for new structures.

Inspections should be conducted in a systematic and organized fashion. The manual presents a comprehensive general listing of the items that require inspection from foundations to superstructure and railings. This listing must be modified or supplemented to conform to the actual condition of the structure. The project manager and the chief inspector should visit the site at the beginning of an inspection project to perform a reconnaissance examination that would be used to determine the schedule, type and experience of personnel needed, means and equipment for access and whether any special tools are required. Drawings and past inspection records that are needed to prepare sketches and forms for use by the inspectors should be requested.

Necessary preparations should be completed in the office before the start of field operations. Since inspectors frequently have to work in exposed areas, from scaffolds and in inclement weather, any unnecessary movement to record inspection data will not only delay the project but also may affect the safety of the operation. The use of voice-recording devices is sometimes helpful, especially if the equipment is not hand-held and there are sufficient resources to transcribe the recordings afterwards.

Rating. A check of the load capacity or rating of the structure is normally an integral part of any inspection assignment. This effort requires careful evaluation of many conflicting factors in an effort to extend the useful life of the structure and to safeguard the public. The more questionable the condition and capacity of a bridge, the more detailed an analysis will be required. Not only the physical condition of the bridge as determined by the inspection, but the governing laws and legal requirements of the local jurisdiction, the degree to which bridge load restrictions can be enforced and the interest of the public in obtaining the maximum safe utilization of the facility must be considered.

Ratings must be performed for the "as-built" and "as-is" condition of the structure. The as-built calculation is based on the original design dimensions and member sizes, including any later modifications, but using current design load requirements. For older structures, sufficient field checking must be done to assure that the plans are truly representative of the structure's current status. If no plans are available, sufficient field measurements must be taken to permit an adequate as-built analysis. This as-built design check normally need be performed only for the initial bridge inspection and should be available as a reference for any subsequent inspection and rating.

The design check of the structure in the as-is condition is based on the results of the current field inspection — *i.e.,* considering member sizes reduced by corrosion and wear, members damaged by accidents, and other defects affecting the capacity of the structure unless such defects are scheduled for immediate repair.

Each bridge must normally be rated for two load conditions. The first, or upper, load level determines the absolute maximum permissible safe load level to which the structure may be subjected and is referred to as *operating rating.* The second, or lower, load level determines the permissible load level at which the structure can be safely utilized for an indefinite period of time. This level is called the *inventory rating.* Either the load factor or the working stress method can be employed to determine these ratings.

The manual permits a certain degree of independent judgement in such areas as allowable unit working stresses and assumed loading conditions. The engineer may want to modify the allowable material stresses based on judgements of its quality — as is most commonly done in the case of timber structures — or based on actual tests such as concrete cores. A reduced or increased load impact factor may be assumed based on road alignment, traffic speed and pavement condition. It may also be advisable to use a higher safety factor for a bridge carrying a large volume of traffic as compared to a structure carrying only light traffic.

Reports. The preparation of an all-inclusive report is one of the most important functions of the bridge inspection program, since the usefulness of the information gathered in the field depends on its current and future availability to the bridge operator.

For each structure there should be an inventory that contains complete information on the bridge, including a general description, history, plans, inspection reports, a stress analysis with data on the capacity of the structure, and recommendations for repairs and improvements. Once a basic inventory has been established for a bridge, succeeding inspection reports need only provide updates of the original inventory report to reflect the conditions found during the current inspection, or to record any modifications made to the structure since the last previous inspection. Many agencies have developed their own standard structure inventory and appraisal form that must be filled out by the inspector and made part of the permanent bridge inventory. A sample form is shown in Figure 1.

TP 350d (7/81)

NEW YORK STATE DEPARTMENT OF TRANSPORTATION
BRIDGE INSPECTION AND CONDITION REPORT

SHEET 6 OF 20

REGION N, COUNTY 3 — BRIDGE IDENTIFICATION NUMBER 2 2 4 0 0 1 9

FEATURE CARRIED: Bklyn. Br. & City St. FEATURE CROSSED: I278,City Sts., FDR Dr., & E. River

INSPECTED BY ______ TITLE Team Leader DATE MO. 10 DAY 15 YEAR 88

Span No.	Deck Elements										Superstructure						Pier										Utilities						Contractor Code	Rec. Code	TX CD
	Wearing Surface	Mono Deck Surface	Curbs	Sidewalks & Facias	Railings & Parapets	Railing Paint	Scuppers	Gratings	Median	Recom-mendation	Deck Structural	Primary Member	Secondary Member	Paint	Joints	Recom-mendation	Brg. Anchor Bolt. Pads	Pedestals	Top of Pier Cap or Beam	Stem Solid Pier	Cap Beam	Pier Columns	Footings	Erosion or Scour	Piles	Recom-mendation	Lighting Standards	Lighting Fixtures	Sign Structure	Utilities	Utilities Support	Recom-mendation			
10 11 12	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	116 117	118 119	120
041	5	8	5	6	6	6	8	8	5	5	4	4	5	4	2	4	5	5	8	5	3	5	9	8	8	5	5	5	5	5	5	5	99	16	3
042	5	8	5	6	6	6	8	8	5	5	6	5	8	8	8	5	8	8	8	5	8	8	9	8	8	5	5	5	8	5	5	5	99	16	3
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044	4	8	5	6	5	5	8	8	6	5	8	5	8	8	8	5	8	8	8	5	8	8	9	8	8	5	8	8	5	5	5	5	99	16	3
045	4	8	4	6	5	5	3	5	6	5	8	5	8	8	5	5	5	8	8	5	8	8	9	8	8	5	5	5	8	5	5	5	99	16	3
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050	4	8	5	6	5	5	8	8	5	5	8	5	8	8	8	5	8	8	8	5	8	8	9	8	8	5	8	8	8	5	5	5	99	16	3

REMARKS:

see sheet 17

BD 188 (3/81)

BRIDGE INSPECTION AND CONDITION REPORT

SHEET 17 OF 20

BIN 2240019

FEATURE CARRIED: Bklyn Br. & City St. FEATURE CROSSED: I278,City Sts.,FDR Dr. & E.Riv.

INSPECTED BY ______ TITLE Team Leader DATE 10/15/88

REMARKS:

TP 350, refer to sheet 6 of 20

041 - [30] Same conditions as 039, 040 - [30].

041 - [32] Same condition as 039, 040 - [32].

041 - [33] Heavily corroded and cracked support angles of the roadway joint. West bound roadway (Flag No. 89-150)

043 to 045 - [19] Roadway wearing surface has poor rideability and extensive map cracking.

045 - [21] North outer curb is spalled and cracked, reinforcing steel is exposed.

045 - [25] Scupper at Brooklyn bound outer curb is clogged with dirt and debris, no longer operational.

046 to 050 - [19] Roadway wearing surface has poor rideability and has extensive map cracking.

046 - [25] Scupper at Brooklyn bound inner curb is clogged with dirt and debris. No longer operational.

047 - [21] North outer curb spalled and cracked, reinforcing steel exposed.

047 - [25] Same as 046 - [25], on Manhattan bound outer curb.

048 - [29] Bridge underdeck has efflorescence, random cracking and wetness throughout. Photo No. 39.

048 - [30] Crack in floorbeam to girder connection (Flag report no. 88-904). Fascia stringer has moderate to heavy corrosion full length. Photo No. 40.

048 - [32] Paint on fascia stringer in poor condition. Paint is also chalky. Moderate corrosion, full length.

FIGURE 1. Sample bridge inventory form.

Strength Assessment

Materials Testing. Determining the actual strength of the materials incorporated in a bridge structure, especially in older structures, is an important part of the inspection and rating process. Normally procedures call for the testing of samples that are removed from convenient places in the structure.

The taking of concrete test cores usually presents no problems except on heavily travelled roadways where interfering with traffic should be avoided. Concrete cores are tested not only for their compressive strength but can also be subjected to a variety of other tests that help to establish the future serviceability of the concrete. These other tests include petrographic and chemical analysis to determine the basic composition of the concrete materials, cement and air content analysis, chloride ion analysis to establish the level of chloride contamination of the concrete (a chloride concentration of 1.3 lbs/yd^3 is normally considered the level above which the corrosion of reinforcing steel becomes irreversible), and freeze-thaw cycle tests (since freeze-thaw deterioration is the most prevalent and most pervasive type of deterioration in the northern area of the country, this test is very important in determining whether to repair or replace a deck slab).

Steel samples are usually taken from low-stress members such as stiffener plates, gusset plates and diaphragms; or, if necessary, they can be obtained from the edge of main carrying members in a section along their length where calculated stresses are lowest. Normally, the size of the removed material is not sufficient to make a test coupon with standard dimensions as used in the mill testing of new material and on which all ASTM and AASHTO requirements are based. The testing laboratory normally has to revert to so-called sub-size specimens that, for some properties, require the application of correction factors for comparison with the standard mill test samples that form the basis for acceptance requirements. Mill test samples are taken from specified locations in a new plate or rolled member; samples from other randomly selected locations can produce strength results as much as ten percent below those obtained from the specified location in the same piece of steel.

Load Testing. The calculated strength of a structure, whether based on specified allowable material strength or on strength established by materials tests, often produces results that require restrictions on the use of the facility. When such restrictions, such as load or speed posting or complete closure, impose unnecessary hardships on the public, actual load testing provides an alternative method to establish a structure's acceptability.

Load tests are most commonly performed on structures where the condition of the deck slab or the supporting superstructure produces calculated stresses that require posting or closure. The test is usually performed by operating a truck of known dimensions and weight over the questionable portion of the structure which is instrumented with strain gages. Stress readings normally fall considerably below calculated values. The lower readings are most likely due to frame action in the superstructure members and/or composite action between the deck slab and superstructure, even where no built-in provisions for composite action exist. The AASHTO code permits acceptance of such tests under certain operating and monitoring conditions.

In extreme cases, the load testing of an entire structure can be performed. This was done twice recently on the Williamsburg Bridge in New York City to verify the deflection of the cables and their interaction with the stiffening trusses. The load test results were then compared with the results of a three-dimensional analysis of the cable and stiffening truss system.

Service Life Assessment

Functional Capacity. The service life of a bridge does not depend solely on its strength. The question whether to rehabilitate or to replace often depends on whether a structure is, or will soon be, functionally obsolete and on whether it is economically and environmentally possible to sufficiently improve its functional capabilities.

Many bridges were built at a time when cars and trucks were smaller and lighter, speeds were considerably slower and traffic density was but a fraction of today's. Ten-foot wide

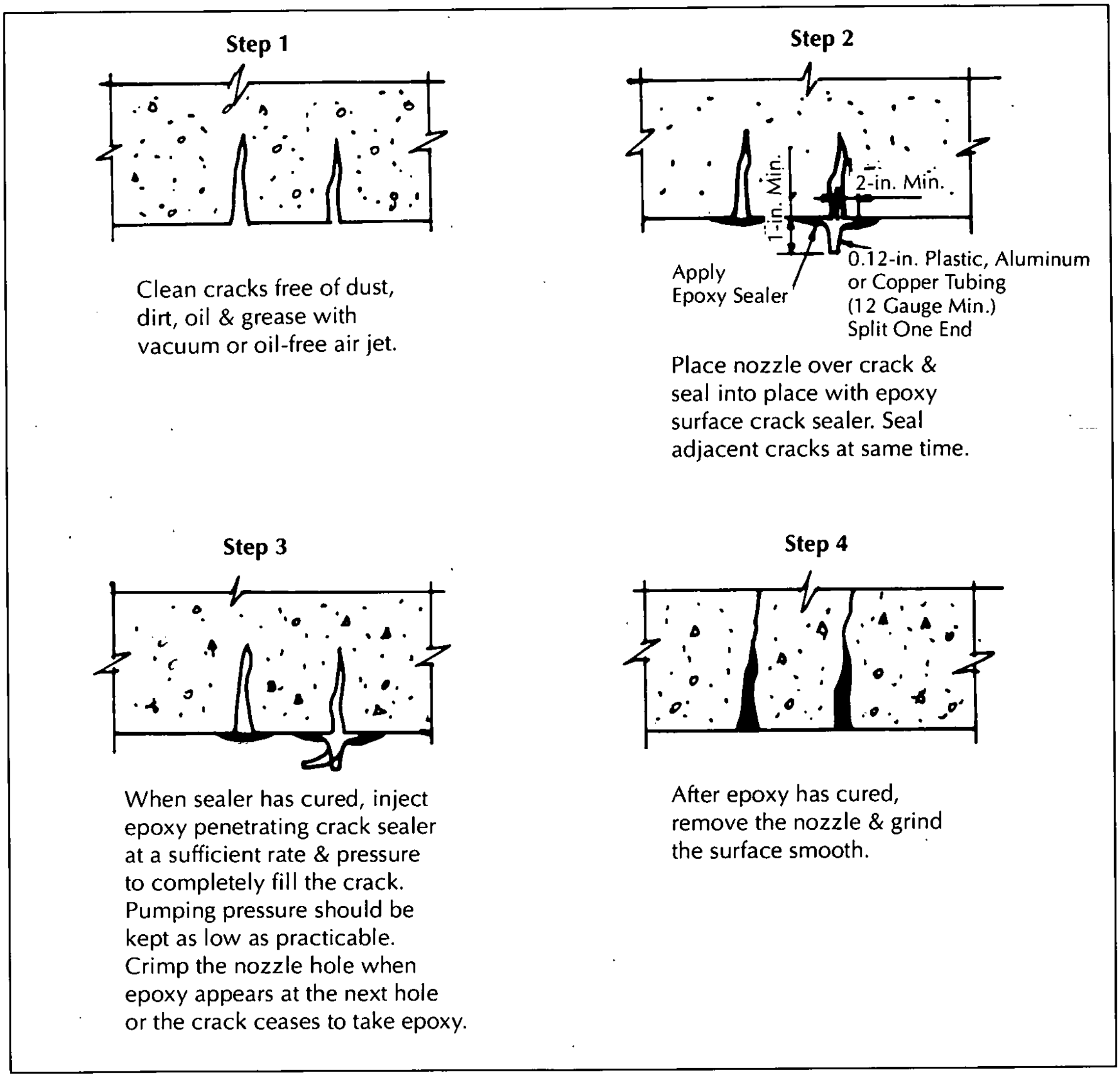

FIGURE 2. Typical crack repair.

lanes are no longer satisfactory. Traffic studies, based on anticipated regional and local changes in population, business and real estate development, are a prerequisite for the proper assessment of a structure's anticipated service life.

Fatigue. In rating a structure, fatigue strength is determined based on fatigue cycles and allowable stress at the time of rating. For a service life assessment, fatigue cycles and allowable stresses have to be projected into the future and the often drastic reduction in fatigue strength, especially for riveted construction, must be taken into account.

A considerable improvement in a structure's fatigue rating can be obtained by replacing rivets with high-strength bolts since a higher fatigue stress range is permitted for mechanically-fastened connections. Replacing rivets with high-strength bolts also provides a convenient method to increase the load capacity of an old structure because of the higher allowable stresses permitted for bolted construction. For structural or economical reasons, however, this solution is not always feasible.

Repair of Structural Systems

Typical Repair Details. The rehabilitation of

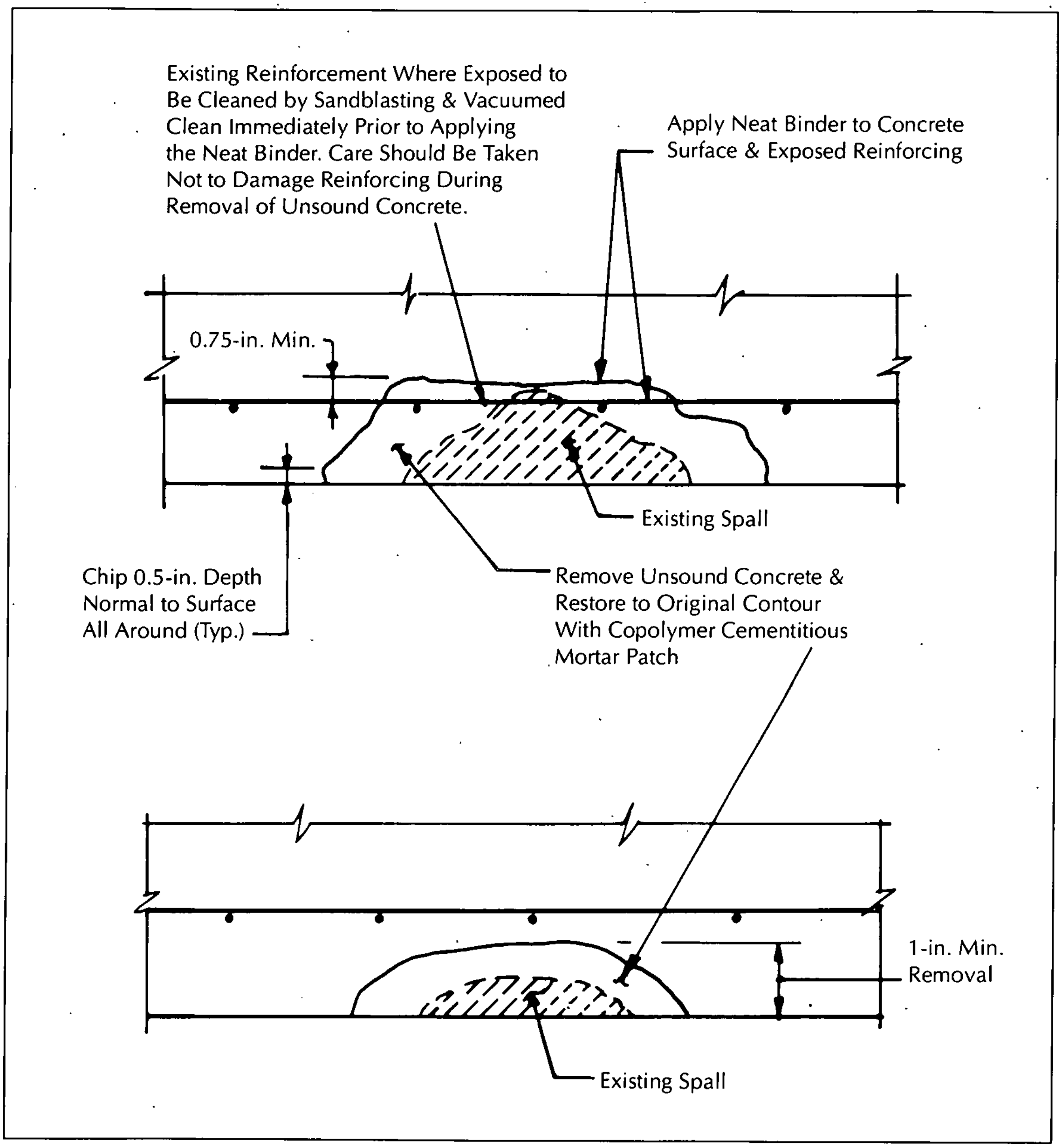

FIGURE 3. Typical spall repair.

structures requires a high degree of engineering expertise and creativeness as well as a thorough knowledge of materials and construction procedures. Design codes and standards, which provide the designer of a new structure with guidelines within relatively narrow limits, must be applied very judiciously in the rehabilitation design. The designer must judge whether material condition, construction detail or actual usage load can justify deviations from specified standards that often can make the difference between rehabilitating or replacing a structural member or the entire structure.

Nevertheless, a certain standardization of procedures covering repair methods and details has occurred over the years, primarily as a result of the extensive bridge rehabilitation programs already carried out by the various state highway departments.

Foundations. Since foundations normally are below ground or water level and out of sight, little thought is often given to their condition. The recent collapse of the Schoharie Creek Bridge, however, has highlighted the consequences of insufficient attention to subsurface structures. In-depth inspection of a bridge should include test pits or inspection by divers to ascertain the condition of the foundation structure. Any deficiency found should be immediately repaired. However, conditions rarely allow for the typification of repair details and the designer must rely heavily on ingenuity to solve the problem.

Substructure. Cracks and spalls are a common occurrence in concrete substructures (abutments, walls and piers). Typical details have been developed by most agencies. Static, narrow cracks are generally repaired by epoxy urethane or conventional grout pressure injection (see Figure 2). If the crack penetrates the full thickness of the structure and the pressure-injected material cannot be contained, epoxy mortar treatment, chemical or portland cement is used. Typical repair details for two conditions of spalls are shown in Figure 3.

Bearing shoes connect the superstructure to the substructure. Corrosion and deterioration of bearings occurs typically under roadway joints, caused by the accumulation of moisture and dirt on abutment and pier seats. The replacement of such deficient bearings requires the careful jacking of the bridge superstructure to avoid local overstressing and the cracking of the roadway deck. Good maintenance, including timely repair of joint seals, can prevent bearing deterioration.

Steel Superstructure. Prior to making decisions on the repair of corroded steel members, representative parts of the structure should be blast-cleaned of all corrosion products, since its appearance usually exaggerates actual damage, particularly to corroded rivet heads.

In addition to rivet heads, corrosion usually affects the edges of plates and rolled members and areas where dirt can accumulate. Feathered or knife-edges should be ground smooth. The acceptable metal loss in thickness or width of a member should be determined by calculations or experience and standardized on repair plans. Losses exceeding these standardized limits should be repaired by such means as adding welded patch plates, or removing and replacing a member locally. Excessively corroded rivets are normally replaced by high-strength bolts.

Major repairs, including rehabilitation requiring a necessary increase in the strength of a member, can be provided by adding coverplates, replacing rivets by high-strength bolts in connections, or completely replacing individual members. Occasionally, prestressing or post-tensioning with cables or high-strength rods has been found feasible. Some typical details are shown in Figures 4 and 5.

Concrete Superstructure. Concrete superstructure members (cast-in-place and precast beams, prestressed beams and boxes) frequently develop cracks; spalls are a less common occurrence. Cracks can be repaired by injection similar to the procedure shown for substructure components in Figure 2. For the repair of spalls in cast-in-place or precast beams, shotcrete is the preferred material (see Figure 6).

Deck Slabs. The deck slab is the bridge member most susceptible to wear, deterioration and corrosive attack. Outward signs of trouble are cracks, spalls and potholes. Determining the reasons for these defects is essential to arriving at a proper decision concerning the rehabilitation or replacement of the deck structure. Other factors entering into this deliberation are the extent of damage, cost of repair, cost of future repairs for any continuing or expected additional problems, and the structure's anticipated service life. Non-destructive testing — such as infrared thermography, ground-penetrating radar, or electric potential measurements (saturated copper-copper sulfate half cell method — see Figure 7) to determine laminations and chloride ion content of the concrete — is often warranted to assist in the decision-making process.

If the decision is made to rehabilitate the existing deck slab, several rehabilitation methods and materials are available, depending on the nature of the problem to be repaired:

1. Epoxy injection of cracks. This method is recommended only if the chloride content of the concrete is at a low level.

2. Removing and replacing concrete in

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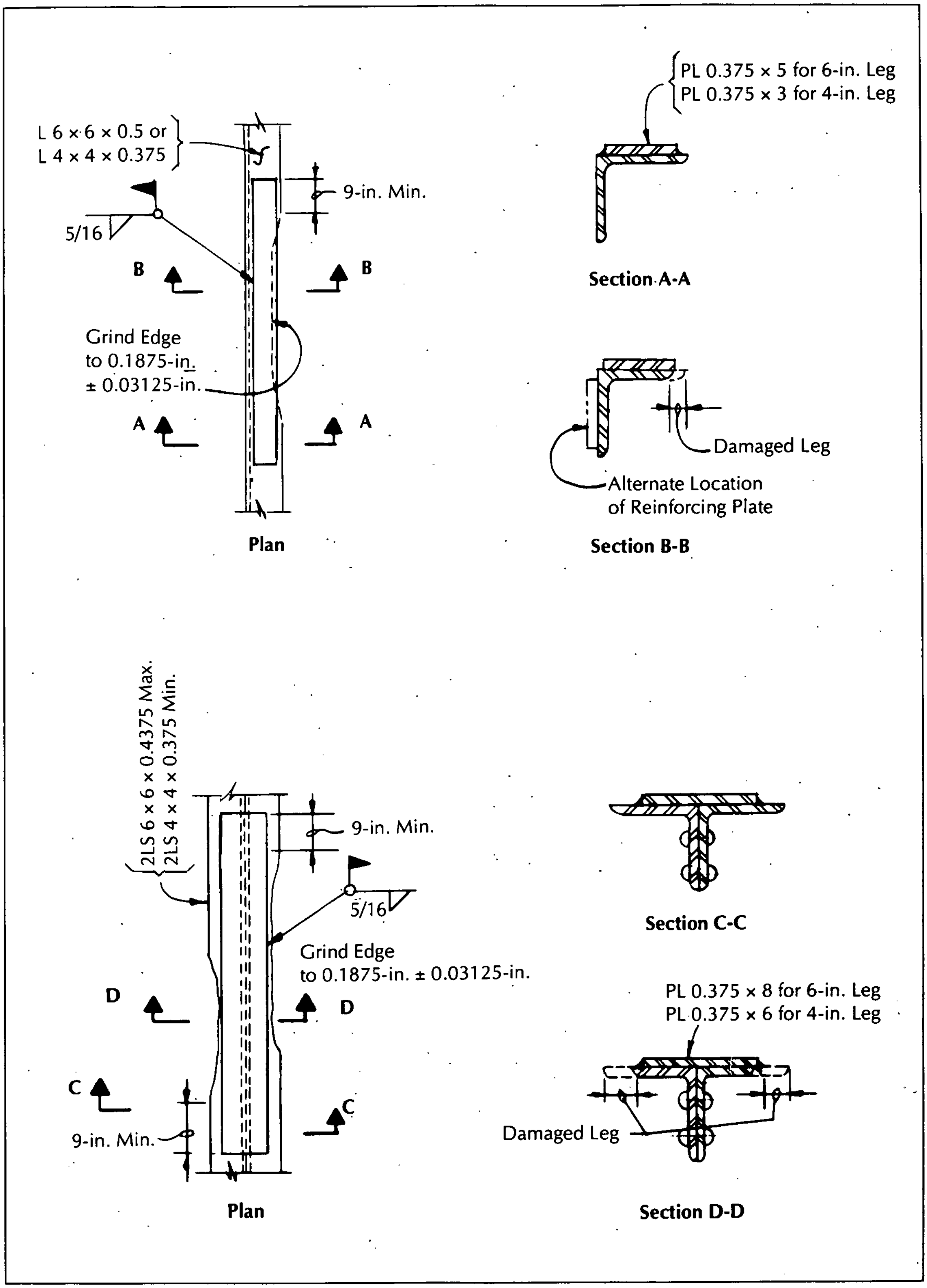

FIGURE 4. Typical structural steel repair — angle repair.

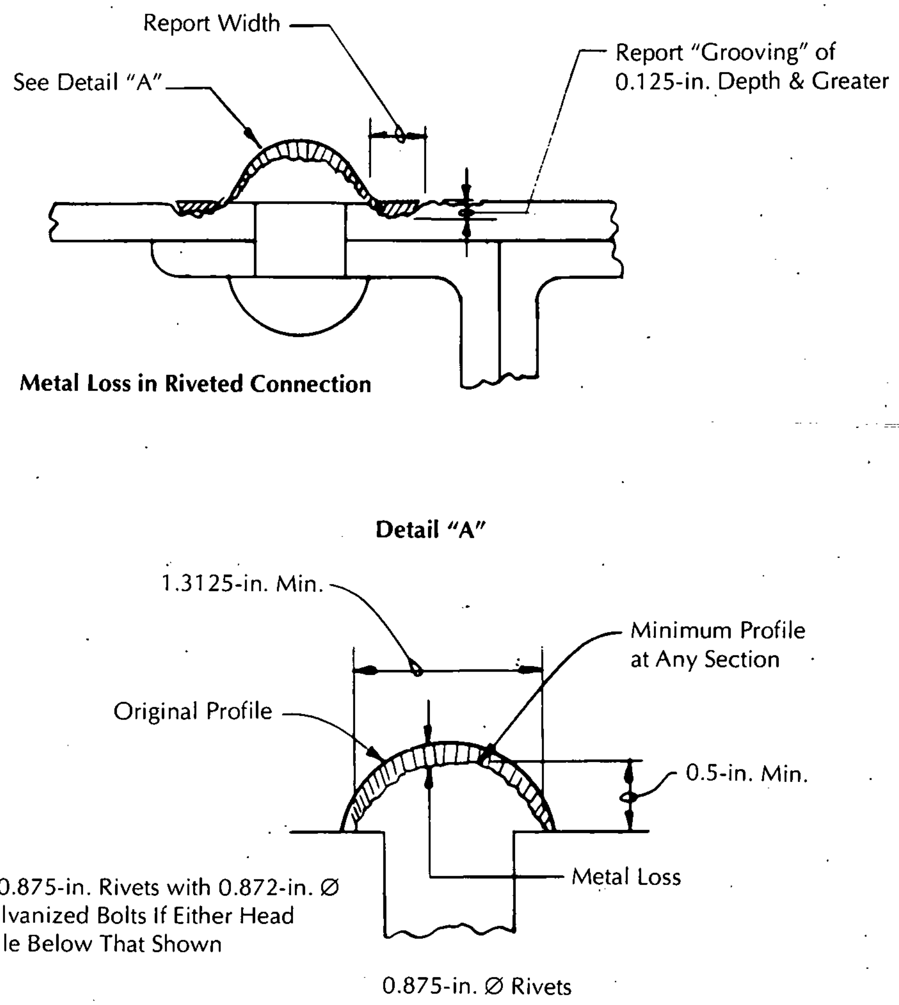

FIGURE 5. Typical structural steel repair — rivet replacement.

spalled areas. This method is recommended only if the spalled areas are limited in number and size, and if the chloride content of the concrete is at a low level. Various materials with different drying times can be used for the patching of spalls depending on the time available for keeping traffic off the repaired area.

3. Removing concrete above the top layer of reinforcing steel (where chloride contamination is generally at its worst) and replacing it with normal concrete, latex-modified concrete (LMC) or silica fume concrete.

4. Scarifying the concrete surface and applying thin overlays (LMC, silica fume or bituminous concrete).

5. Installing a cathodic protection system.

The variety of repair methods and materials is almost limitless and greatly varies from state to state. However, caution must be exercised in selecting and applying the more exotic materials such as LMC or silica fume. These materials require proper mobilization, equipment, trained personnel and supervision that are normally available only on large projects.

Reinforcing steel corrosion as a result of chloride contamination is the most frequent

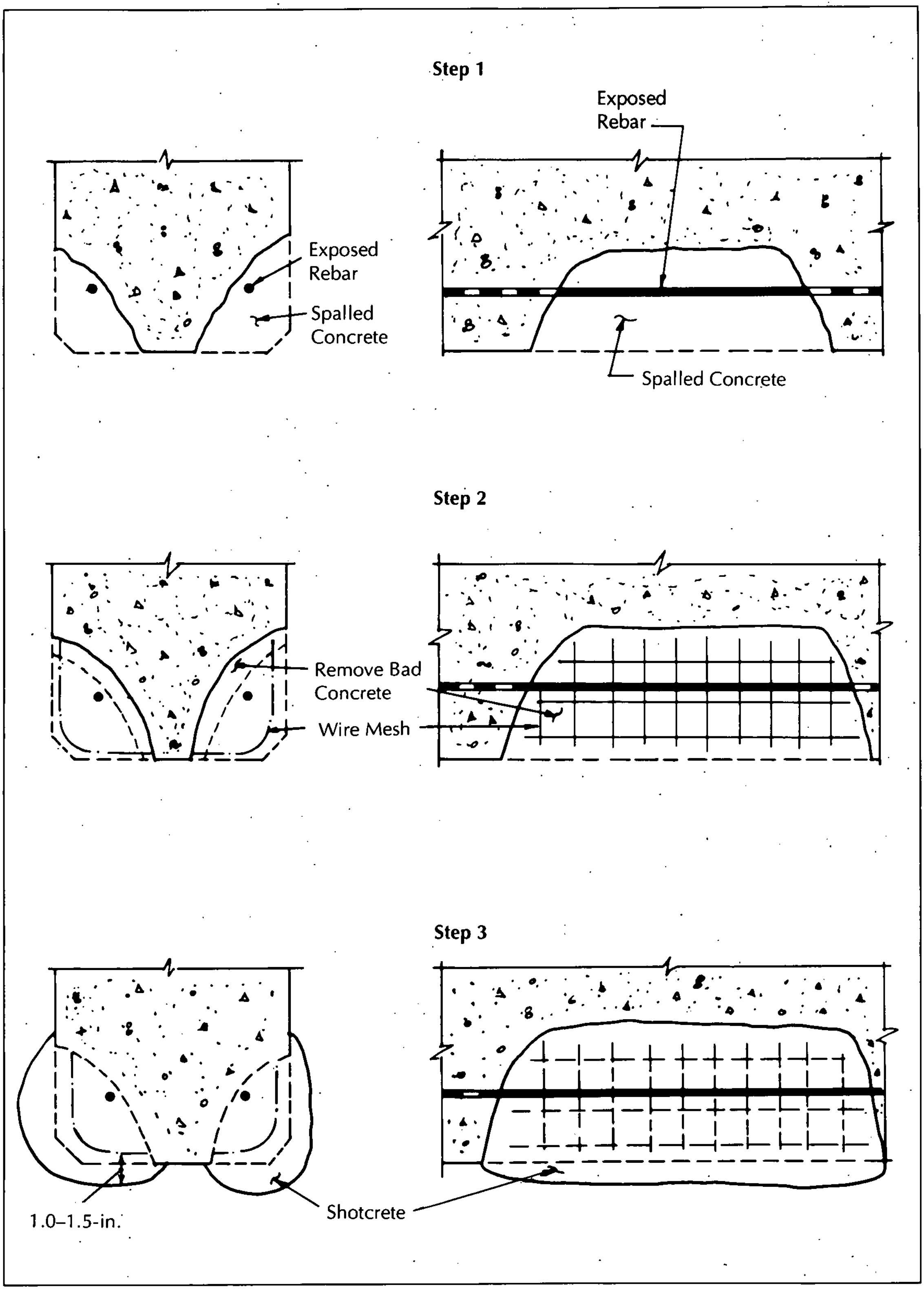

FIGURE 6. Typical shotcrete repair.

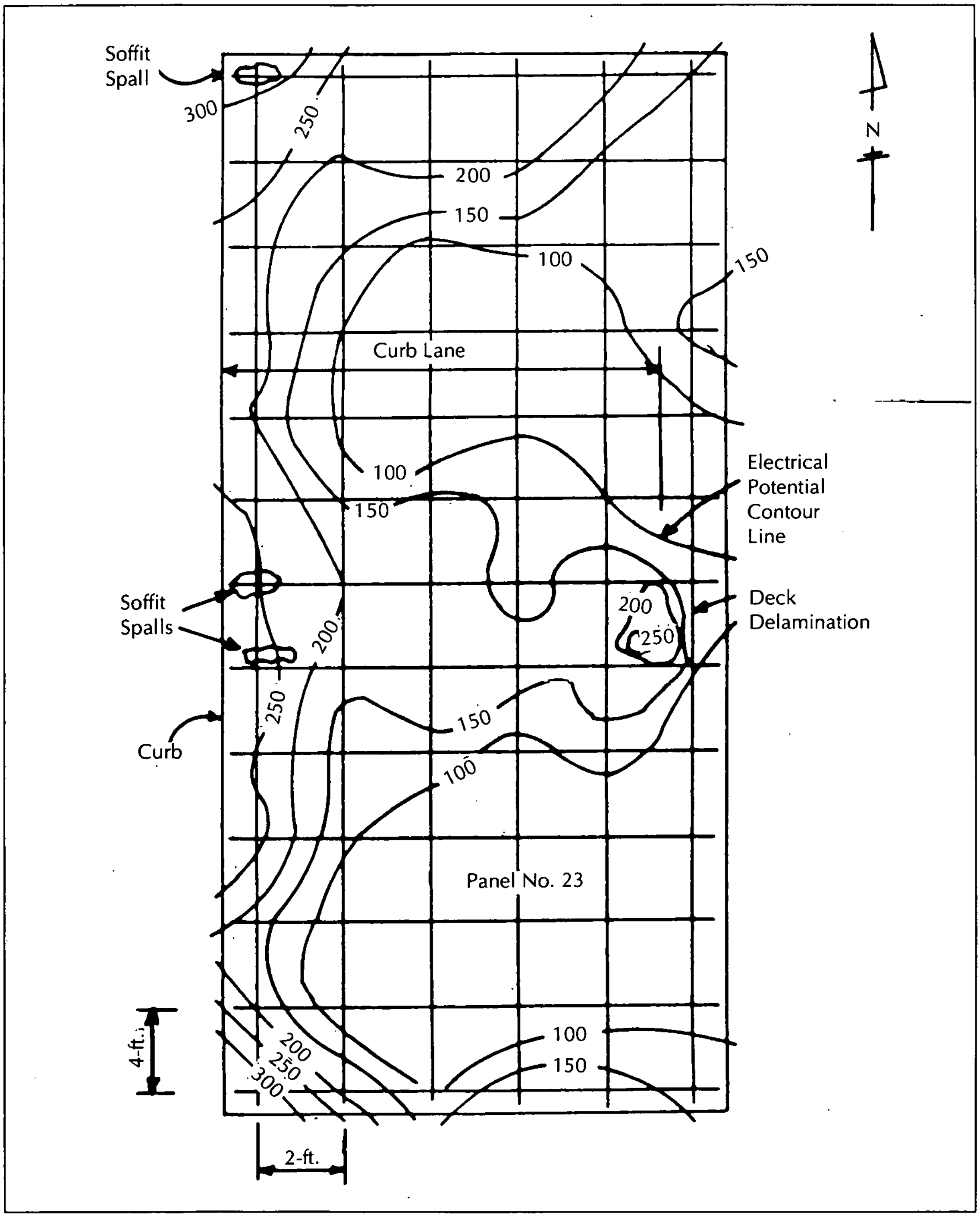

FIGURE 7. Electrical potential measurements.

cause for the deterioration of bridge decks. Cathodic protection is the only known system that will effectively stop this corrosion after it has started. Cathodic protection systems were first installed on bridge decks in California in 1974. Since then, demonstration projects have been installed in many states and in Canada, and are encouraged by the FHWA. Initial cost and necessary continued maintenance are factors that have prevented the widespread use of this method so far.

Suspension System. Suspension bridges make up only a relatively small fraction of bridges in the United States. However, because of their prominence, it is worthwhile to list a few common maintenance and repair problems.

Where problems exist, their solution normally requires engineering imagination and innovative ideas. The main cables are, as a rule, little affected by corrosion. However, suspender ropes are susceptible to the accumulation of moisture and dirt and corrosion at their bottom attachment detail to the suspended structure. The replacement of suspender ropes has become almost a routine operation. Nevertheless, check calculations are necessary to determine whether the suspended floor can be left unsupported during rope replacement or whether installation of temporary suspender ropes is necessary.

Cable band castings are the one location on the cables where routine maintenance and repair will most likely be required during the rehabilitation of a suspension bridge. Unless they are properly caulked around their uphill circumference and along the top joint between casting halves, they provide entry ports for water running down along the cable. Such entry must be avoided at all costs. On the other hand, the bottom joint between casting halves must be kept open and all caulking, if present, should be removed to permit any water that has penetrated into the cable to exit at this point. The bolts that hold both halves of the band together and provide the friction for holding the bands in place and preventing sliding downhill must be checked occasionally and be retightened if necessary. This retightening is now performed with hydraulic jacks.

Seismic Retrofitting. The risk of earthquakes severe enough to affect the safety of bridge structures is not limited to California. The AASHTO seismic risk map identifies large areas in the East and Southeast, in addition to the West Coast and Alaska, where earthquakes of sufficient force to create damage must be expected.

The major damage caused by earthquakes usually results from shifts of the substructure supports or from heavy vibrations of the superstructure, causing the dislocation of bearings and loss of support. The total or near total collapse of bridge superstructures in the San Fernando earthquake as a result of loss of bearing supports started a serious research effort, backed primarily by the California Department of Transportation, to find ways to confine and control damage to predictable levels and locations. That research indicated that restrainers utilizing cables, or rods with springs or neoprene compressive end details, would help to keep structures from vibrating apart or falling off their bearing supports, while permitting sufficient movement for temperature expansion and contraction.

Guidelines for the seismic retrofitting of highway bridges have been published by the FHWA.[4] A number of preventive retrofit projects have been completed with the goal of increasing the resistance of bridges to seismic forces and to minimize the possibility of total collapse. The cost of such retrofit measures is justified by the avoidance of possible loss as a result of an earthquake.

Limitations and Precautions

Maintenance of Traffic Flow. Other factors than design-related ones need to be considered in the planning of bridge repair and rehabilitation. Probably the most important of these factors are the maintenance and protection of traffic. Traffic impacts not only the repair and replacement of roadway slabs (where traffic demands affect construction schedules as well as construction sequences and details), but also substructure repair (which can impact adjacent roadways) and superstructure repair work above the travelled lanes of a roadway spanned by the bridge (where detouring traffic below, or adequate shielding or netting, is required). Occasionally, traffic in the lanes carried on the bridge may have to be interrupted to permit local jacking to replace bearings, temporary disconnection of joints to replace corroded members or replace rivets with high-tensile bolts, or similar operations that could temporarily weaken the portion of structure being repaired.

Systems Compatibility. The compatibility of the repair with the original construction should

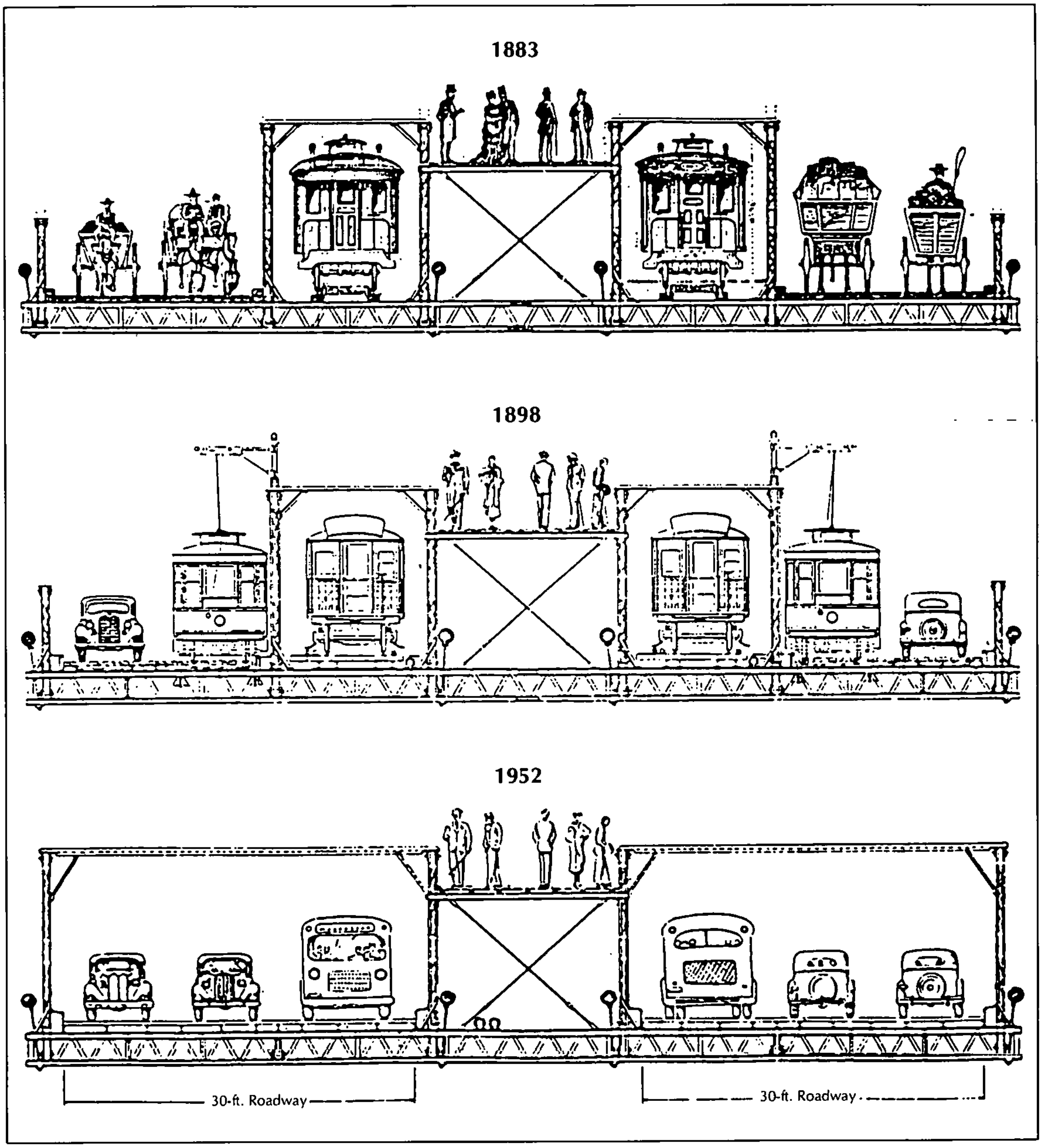

FIGURE 8. Brooklyn Bridge rehabilitation stages.

be considered. For instance, field welding of high-carbon steel found in old structures can cause more problems than it would solve. Weld repair to riveted or bolted construction can create fatigue problems because it changes the relative stiffness of the assembly.

In concrete construction, attention must be given to the joining of new concrete to old concrete. Rather than relying on some instantaneous decision-making by construction personnel at the site, proper details should be included in construction plans and specifications. Some of the overlay materials are not compatible with remnants of previous, removed paving material or with the curing compound applied to fresh concrete. The manufacturer of the overlay material should always be consulted.

Case Studies

Over the last thirty years many bridges have been rehabilitated. In order to gain a better understanding of the finer points of the choice of rehabilitation over replacement, and since the decision-making process is in many ways site-specific, it is best to review some of the significant bridge rehabilitation projects.

Brooklyn Bridge

The Brooklyn Bridge has gone through several phases of rehabilitation to keep up with its age and the changing demands on its services. When the bridge was opened to traffic in 1883, it carried on each half of its cross section a 16-foot, 7-inch wide outer roadway for two horse-drawn vehicles and one railway track for a Pullman railroad car. An elevated pedestrian promenade occupied the space between the two interior cables (see Figure 8). In 1898, the outer roadways were modified to carry one lane of automobile traffic and one trolley car track each. In 1944, the elevated railway was discontinued and their tracks were taken over by the trolley cars. The space formerly used by the trolleys was now available for a second lane of automobiles.

Following the recommendation made in the "Technical Survey" report released in 1945, the intermediate trusses were removed in 1952, the outer trusses were rebuilt and the overhead bracing was extended to the outer truss.[1] These changes resulted in the present two 3-lane, 30-foot wide roadways for automobile traffic (see Figure 8). Trucks are not permitted on the span.

As part of the federally-mandated inspection program, the Brooklyn Bridge was subjected to a complete and detailed inspection in the late 1970s. The extent of deterioration and corrosion found during this inspection resulted in the recommendation for a fifteen-year rehabilitation program (1980-1995) that includes:

- Rehabilitating the cable anchorages, including enlarging the anchorage chambers, realigning the cable splay strands and replacing badly corroded cable wires or strands.
- Replacing suspender ropes and diagonal stay ropes.
- Strengthening the suspended bridge structure, particularly the roadway trusses.
- Rehabilitating the pedestrian promenade.
- Rehabilitating approach ramps.
- Replacing roadway decks on approaches.
- Improving lighting and bridge drainage systems.
- Rebuilding the protection system at the base of the Brooklyn Tower.

At this time, rehabilitating the cable anchorages has been completed and all suspender ropes have been replaced. The replacement of the diagonal stay ropes is in progress. Strengthening the suspended structure and replacing the roadway decks is scheduled for the near future.

George Washington Bridge

The George Washington Bridge was initially conceived as a double-deck structure with the upper deck accommodating seven lanes of vehicular traffic and the lower deck for four tracks of heavy rapid transit trains or additional vehicular lanes (see Figure 9). The lower deck was to be added when the need for such additional capacity arose. Owing both to the economic conditions at the time of bridge construction in the late 1920s and real traffic demands, the upper deck and the approaches were built to accommodate a total of six traffic lanes, three on each outer roadway. The center portion of the roadway deck was left open, to be completed at a later date when traffic volume demanded it. This demand came with the automobile explosion following World War II, and the center portion of the upper deck was completed in 1946 to accommodate a reversible two-lane roadway.

A future expansion of the bridge to serve the ever-increasing metropolitan traffic was recommended in the "Joint Study of Arterial Facilities" performed by the Port Authority of New York and the Triborough Bridge and Tunnel Authority in 1954.[5] This study also included a recommendation for the construction of the Verrazano-Narrows Bridge and the Throgs Neck Bridge. The lower deck was added to the bridge in 1962 and provided two additional three-lane roadways for a total bridge capacity

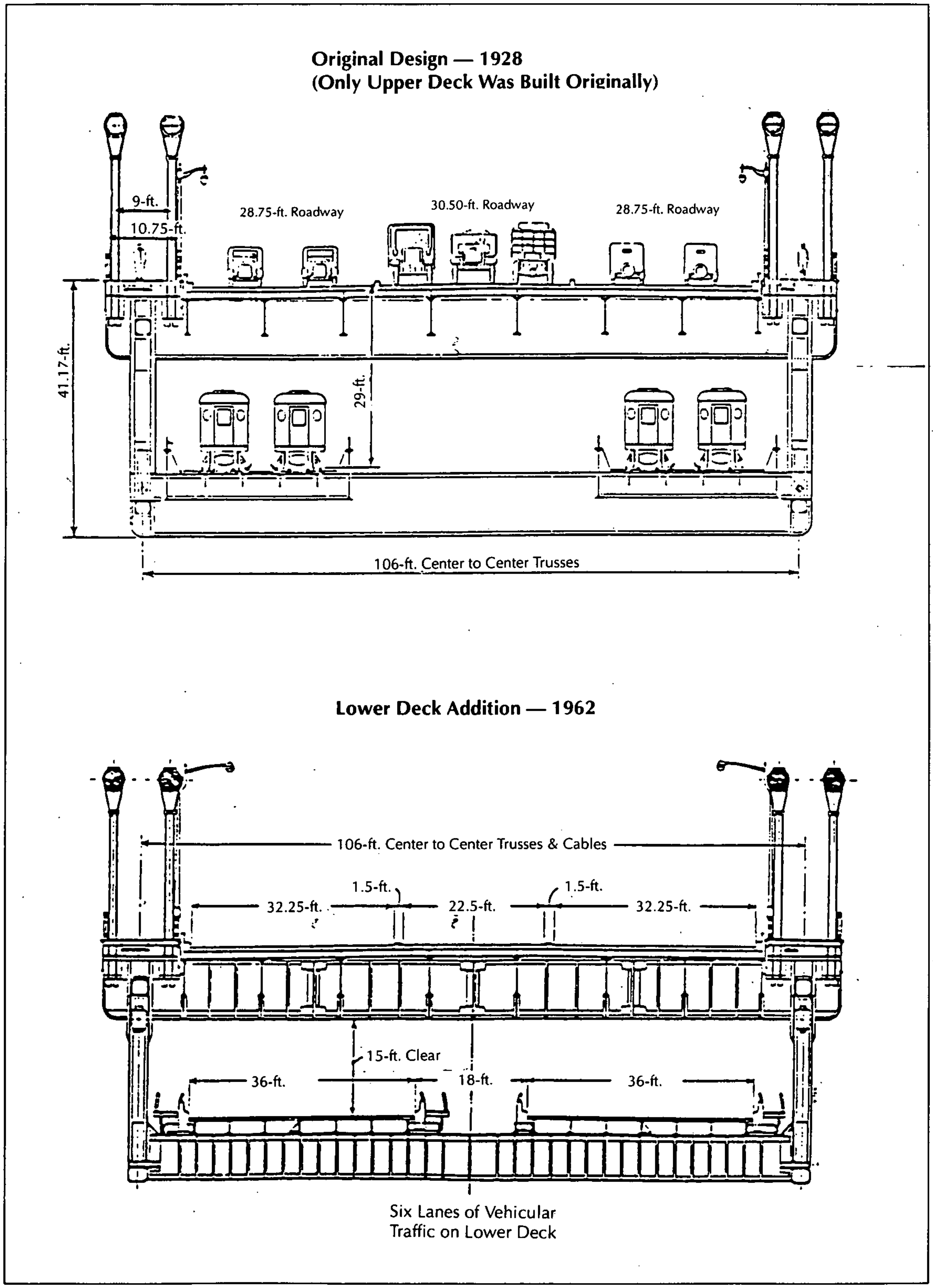

FIGURE 9. George Washington Bridge rehabilitation stages.

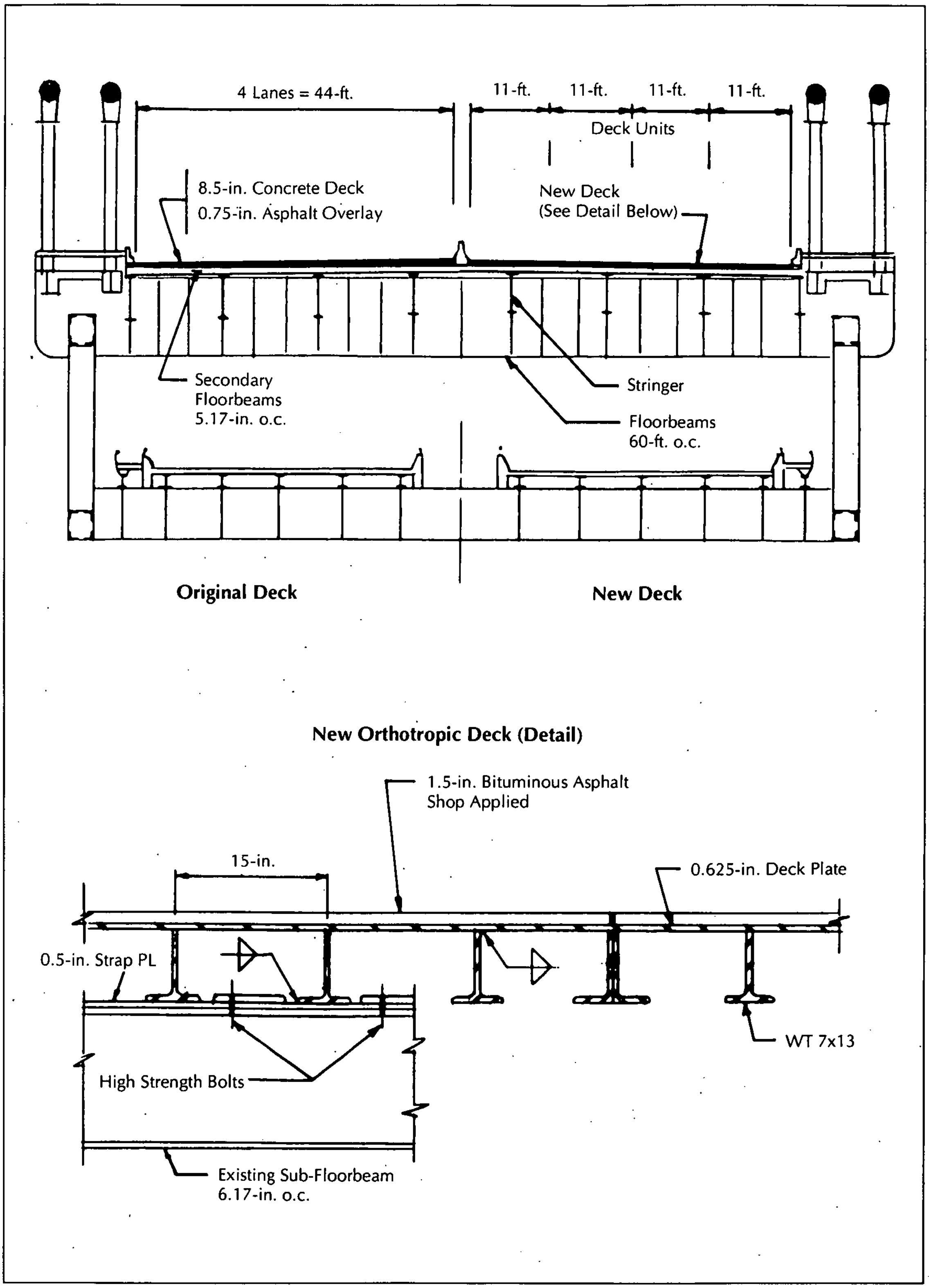

FIGURE 10. The George Washington Bridge orthotropic steel deck.

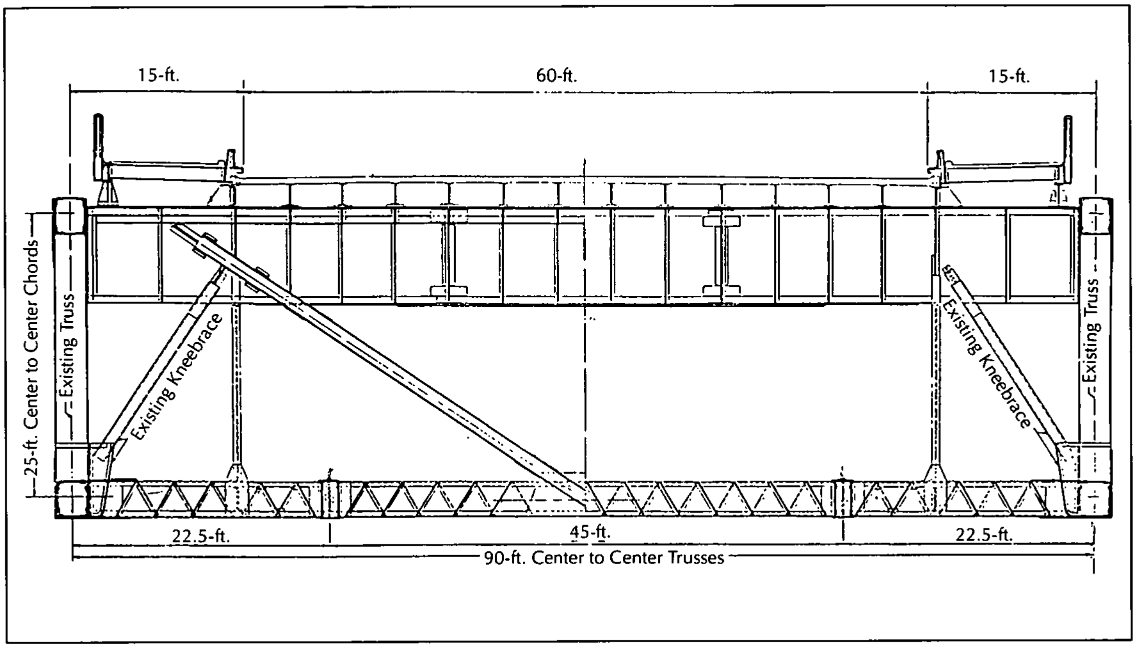

FIGURE 11. The lower lateral system of the Golden Gate Bridge.

of fourteen lanes (see Figure 9). Rehabilitation work was performed on portions of the upper deck roadway concurrently with the lower deck construction. This rehabilitation included work on the roadway joints and fingerdams of the upper deck. In addition, several suspender ropes were removed for testing and replaced by new ropes, and all cable bands were retightened and recaulked.

In the following years, more and more maintenance repairs were required on the upper deck roadway. A study performed by the Port Authority showed that in the ten years between 1961 and 1970, 25 percent of the total deck area had to be patch repaired. As a consequence, it was decided to replace the deck rather than keep on repairing the rapidly deteriorating concrete slab.

The new orthotropic deck that was installed from 1977 to 1978 consisted of a 0.625-inch thick plate of ASTM A588 weathering steel, stiffened by WT7x13 ribs welded to the deck plate and connected with high-strength bolts to the existing subfloorbeams (see Figure 10). The project required replacing each night a 44-foot wide by 60-foot long section of the roadway (or one half-width of the bridge between existing roadway expansion joints). Adjacent sections of the deck were not disturbed during this nightly operation. The new deck modules consisted of four 60-foot long by 11-foot wide panels that were installed separately and then bolted together along their longitudinal edges. The panels were prepaved with an 1.5-inch thick asphaltic concrete pavement and were immediately ready for traffic after installation.

To maintain traffic flow, New Jersey type barriers were installed for the full length of the bridge. During peak hours, all eight lanes were available to carry traffic. During off-peak hours, and at night, all traffic was diverted to one of the two four-lane roadways. The other roadway was prepared for slab removal during off-peak hours; actual deck removal and replacement took place at night. The well-orchestrated use of the various trades permitted maximum utilization of workers and machines in the limited space available. By 6 A.M. the new panel would be in place to permit flow of the daily rush-hour traffic. The entire deck replacement project was completed well within the specified two-year period.

Golden Gate Bridge

The location of the Golden Gate Bridge where the Pacific Ocean enters San Francisco Bay exposes it to fierce winds, salt spray and almost daily fog, all of which have an extremely detrimental effect on the condition of the bridge. With its seismic exposure to the movements of the nearby San Andreas and Hayward faults, and ever increasing traffic demands added to its problems, the bridge has become a textbook example for bridge rehabilitation.

Aerodynamic Improvements. Heavy winds began to barrage the Golden Gate Bridge even during construction. Severe storms during the first decade of its operation culminated in the storm of December 1, 1951, when a strong southwest wind peaked at 69 miles per hour and created double amplitudes of 130 inches at the southeast quarter point and 108 inches at the southwest quarterpoint of the mainspan. During the height of the storm, which lasted in great intensity for more than six hours, the suspended structure oscillated longitudinally through the full length of travel permitted by the expansion provisions at the towers. Considerable damage was caused by this storm; parts of the lateral wind system connections at the towers had to be replaced.

As a result of this storm, the District Board of Directors authorized a Board of Engineers to investigate the feasibility and desirability of adding a lower lateral bracing system to the bridge that would effectively stiffen the original longitudinal trusses at each side of the bridge (see Figure 11). This system, which was installed in 1954, has solved the wind stability problem on the bridge and, for all practical purposes, has reduced the motions to values unobjectional to the traveling public. The bridge experienced a storm in December 1982 that greatly exceeded the storm of 1951 in intensity and length. While the bridge had to be closed to traffic because of the danger to automobile traffic (one light truck was actually blown over on its side), bridge movements were well within acceptable limits and no damage to the bridge was reported.

Concurrently with the installation of the lower lateral bracing system, travelling maintenance platforms were installed in the mainspan and both sidespans that now greatly facilitate bridge inspection and maintenance.

In-depth Inspection. In the early 1960s a comprehensive painting program was initiated that was supposed to provide the entire bridge structure with a paint system that was guaranteed to last at least 20 years between repainting cycles. After extensive tests, a system of inorganic zinc-rich primer with vinyl top coat was selected. However, as soon as painting operations were started, it was recognized that widespread and severe corrosion had taken place in many parts of the structure. Consequently, a complete inspection of all structural components of the suspended structure and approaches was authorized and undertaken between 1967 and 1969. This program included the inspection of the main cables and the removal for testing purposes and replacement of several suspender ropes. As a result of this in-depth inspection it was found necessary to:

- Replace all suspender ropes and their connections to the stiffening trusses;
- Make extensive structural repairs of corroded members in the approach viaduct structures; and,
- Study further the condition of the roadway slab.

Suspender Rope Replacement Program. The testing and inspection of the removed suspender ropes indicated that there was severe corrosion in areas that were inaccessible for maintenance directly above the bearing socket. A progressive general loss of the galvanized protective coating throughout the length of the ropes, both on the exterior and core wires, was noted. More important, the bearing connections to the stiffening trusses were extensively corroded, showing severe loss of metal section in plates and stiffener angles and complete loss of rivet heads in many areas. Due to the configuration of this detail, it was impossible to properly maintain this area or to inspect and discover the serious structural deficiencies while the ropes were in place.

Since the safety of the entire suspended structure was put into question as a result of the discovery of extreme corrosion in the suspender rope connection detail, immediate replacement of the ropes and their attachment details to the stiffening trusses was considered a necessity. Because of the severity of the condition, this replacement program was carried

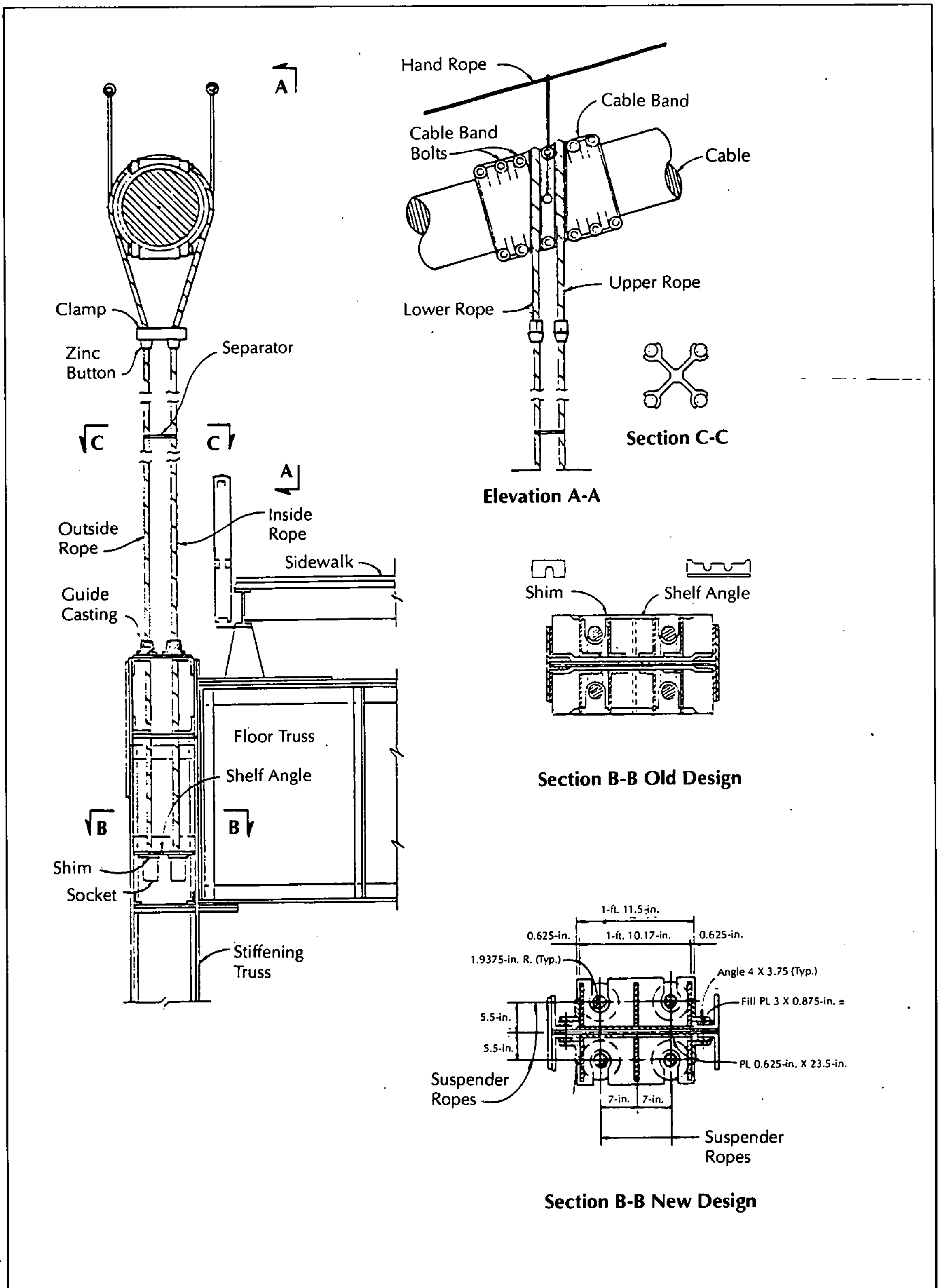

FIGURE 12. The suspender rope assembly for the Golden Gate Bridge.

out in two steps. The first provided for the replacement of every other suspender rope and connection to safeguard the structure; the second stage replaced the remaining ropes. The new bearing connection detail provides ample space for inspection and maintenance (see Figure 12), and the new suspender ropes have been provided with Class C galvanized coating (3 oz/ft^2) on the outer wires and Class B coating (2 oz/ft^2) on the inner wires to guarantee a 50-year life.

The contract documents required that the contractor provide temporary suspenders before removing the existing suspender ropes. Anticipated and permissible jacking forces for every suspender panel point were made available to the contractor as part of the contract documents.

The contractor elected to work with traveling platforms riding on the two main cables from which all temporary ropes and jacking equipment were suspended. This concept proved to be extremely successful, so much so that the entire replacement operation was hardly noticed by the commuting public. The only effect on traffic was that there were three short periods of approximately two hours at midnight when the bridge had to be closed to traffic to permit erecting and removing the traveling platforms.

Approach Repairs. The high level approach roadways are carried by long-span steel trusses and girders, supported primarily by trussed steel columns. Extensive corrosion was found during the in-depth inspection on both approach viaducts on anchor bolts, rivets, structural angles of chord members and diagonals, gusset plates, tie plates and similar members.

Additional anchor bolts were installed to secure the bases of all approach viaduct tower columns. Defective rivets were replaced with galvanized high-tensile bolts and individual corroded steel members are being repaired or replaced as part of a long-range maintenance program by bridge maintenance personnel. To facilitate access for inspection and maintenance operations, an inspection walk was installed for the full length of both approach viaducts in 1978.

Seismic Improvements. When the Golden Gate Bridge was designed, earthquake engineering was in its infancy. The design analysis made at that time assumed earthquake accelerating forces equivalent to five percent of gravity. Because of the exposed location of the bridge, its susceptibility to seismic disturbances has over the years received repeated attention. The most recent study was made based on basic research performed at the Earthquake Engineering Research Center of the University of California at Berkeley and published in their report, "The Effects of Seismic Disturbances on the Golden Gate Bridge."[6] The engineering analysis, utilizing most up-to-date knowledge gained from the 1971 San Fernando earthquake, revealed that the suspension bridge itself was originally designed with a sufficient safety factor to withstand the maximum earthquake forces expected in the Bay area, with no or only very limited and inconsequential local structural damage. However, the approach viaducts were designed to a much lesser standard and required local structural modifications to secure them against collapse during a major earthquake.

Consequently, earthquake restraining features were installed in 1981. Designed in accordance with the requirements of California Department of Transportation standards, these restraining features consisted of three basic types:

- Structural steel members, including rods, ropes and springs to prevent separation of the superstructure from the supporting steel towers (see Figure 13).
- Longitudinal and transverse steel bracing members of the towers themselves.
- Longitudinal and transverse concrete struts to tie together the individual tower column footings.

Adding these members greatly increased the stability of the high approach viaducts and their ability to resist earthquake motions.

Roadway Replacement. As recommended in the report of the 1969 inspection, a detailed investigation of the condition of the roadway slab and its supporting stringers was subsequently carried out over several years and concluded that an extensive rehabilitation with relatively brief life-time benefits or a complete

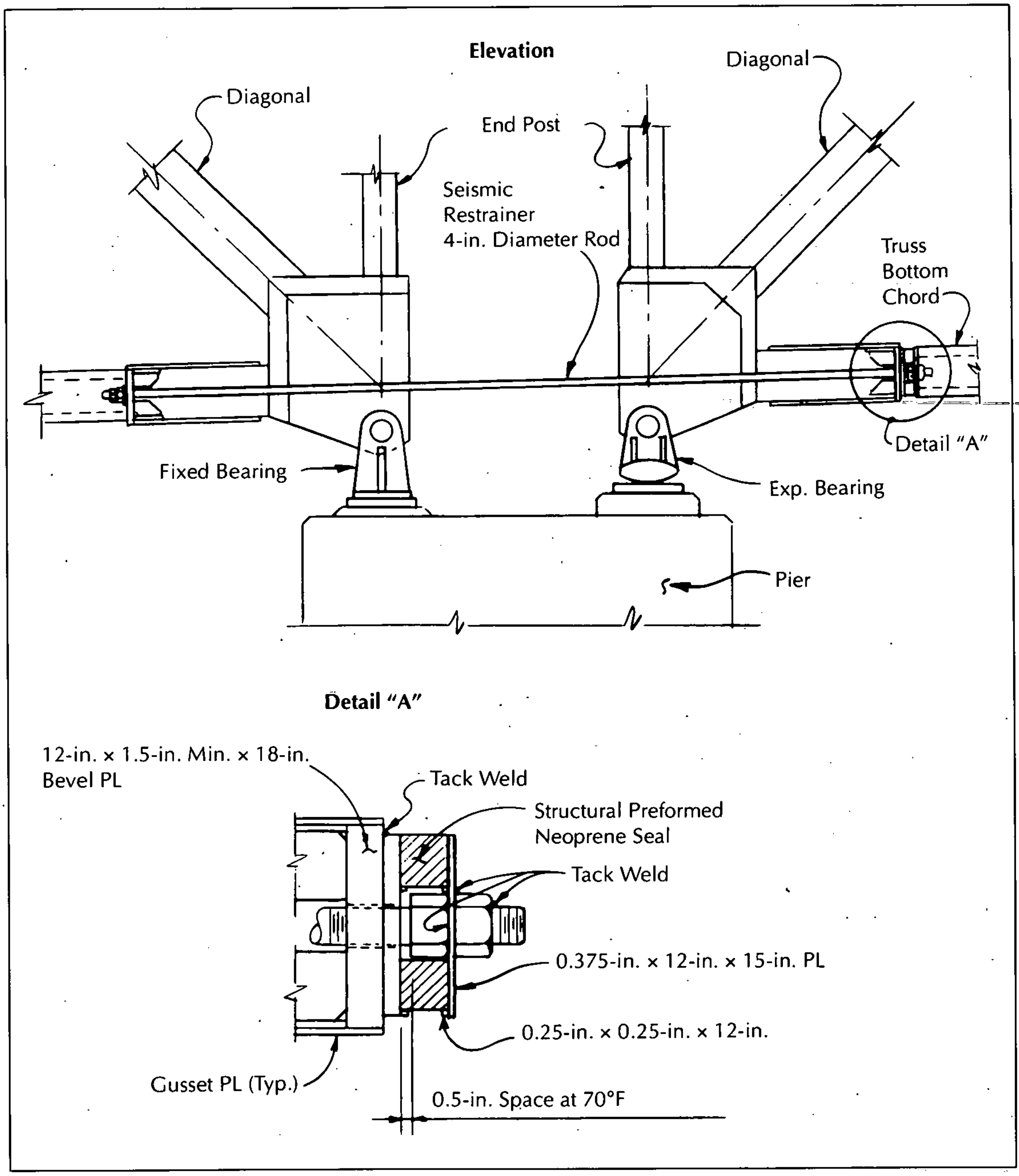

FIGURE 13. Seismic restrainer for the Golden Gate Bridge approach viaducts.

replacement of the roadway slab was necessary. The investigation revealed such defects as:

- A general wearing of the riding surface, in particular along the edges of transverse expansion joints.
- Widespread cracking of the concrete slab, consisting of transverse cracks along reinforcing bar trusses, longitudinal cracks along the distribution steel, random crazed pattern cracking, and shear cracks (on the Marin anchorage deck).
- Scaling and spalling of riding surface due to wearing and internal delaminations.

- Separation of the roadway slab from supporting stringers at expansion joints, probably caused by water leakage.
- Separation of the roadway slab from supporting stringers over intermediate floorbeams.
- Cracking and spalling of concrete haunches, opening up avenues of attack on slab and stringer top flanges.
- Excessive chloride ion contamination of the concrete in the areas of the reinforcing bar mats, in particular the bottom layer, resulting in rusting of reinforcing bars and in concrete spalls at the bottom of slab.

Most surprising and disturbing was the discovery of high chloride ion content in the area of the bottom reinforcement (see Figure 14). Normally, a higher chloride concentration can be expected in the area of the top reinforcing mat resulting from the use of chloride de-icing material. However, such materials are not used in the Golden Gate Bridge area. In this particular case, salt particles are apparently carried by the ever-present fog and deposited on the underside of the slab from where they seem to travel upward into the concrete slab.

An analysis indicated that replacing the deck slab rather than repairing it was by far the more economical solution. Consequently, a complete replacement of the roadway slab of the entire bridge, including approach viaducts, was authorized by the District's Board of Directors.

Since the bridge provides the only direct vehicular route between San Francisco and the counties to the north, deck replacement had to be designed to permit full use of all lanes during the daily rush hour periods, restricting all necessary construction operations to off-peak hours and at night. These traffic restrictions required that the replacement elements be modular, prefabricated, compatible with the existing deck at its interface, and immediately usable upon installation.

The new orthotropic deck (see Figure 15) is composed of a 0.625-inch plate stiffened with 11-inch deep, 0.375-inch thick longitudinal trapezoidal shaped ribs, all of ASTM A709 Grade 36T, Zone 2 impact structural steel. The typical deck module is between 14 feet 3 inches and 16 feet 9 inches in width and 50 feet in length, corresponding to the basic structural module of the bridge. The orthotropic deck is fitted with 0.5- by 12-inch deep subfloor-beams transversely at each end and at the midpoint. This design resulted in a 25-foot span between subfloorbeams. Welded steel plate pedestals of

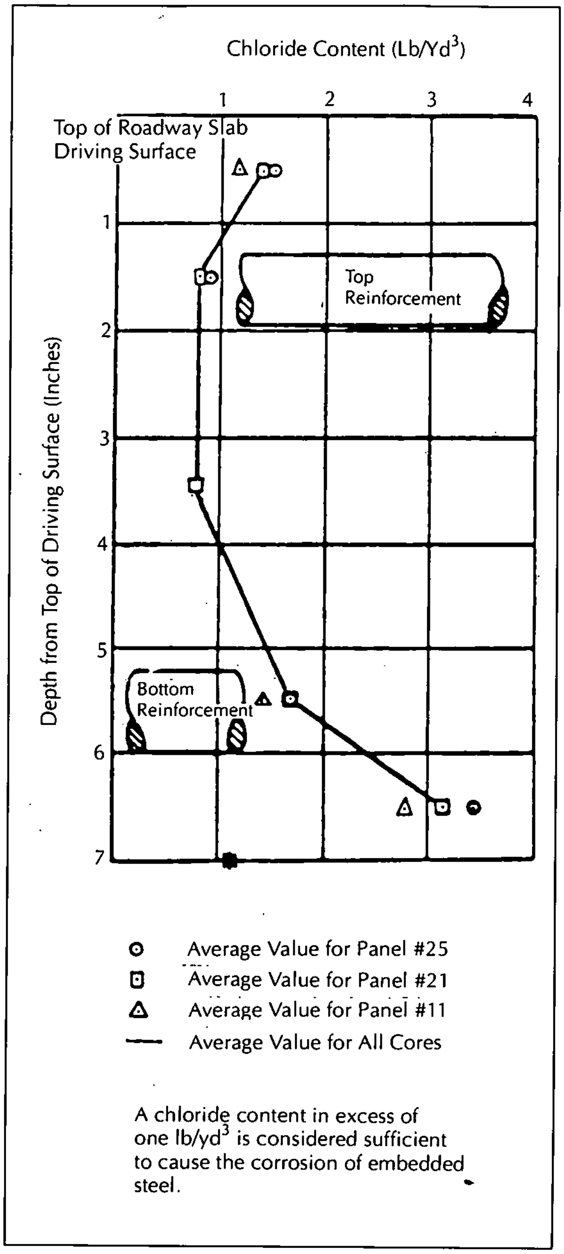

FIGURE 14. Roadway chloride contamination on the Golden Gate Bridge.

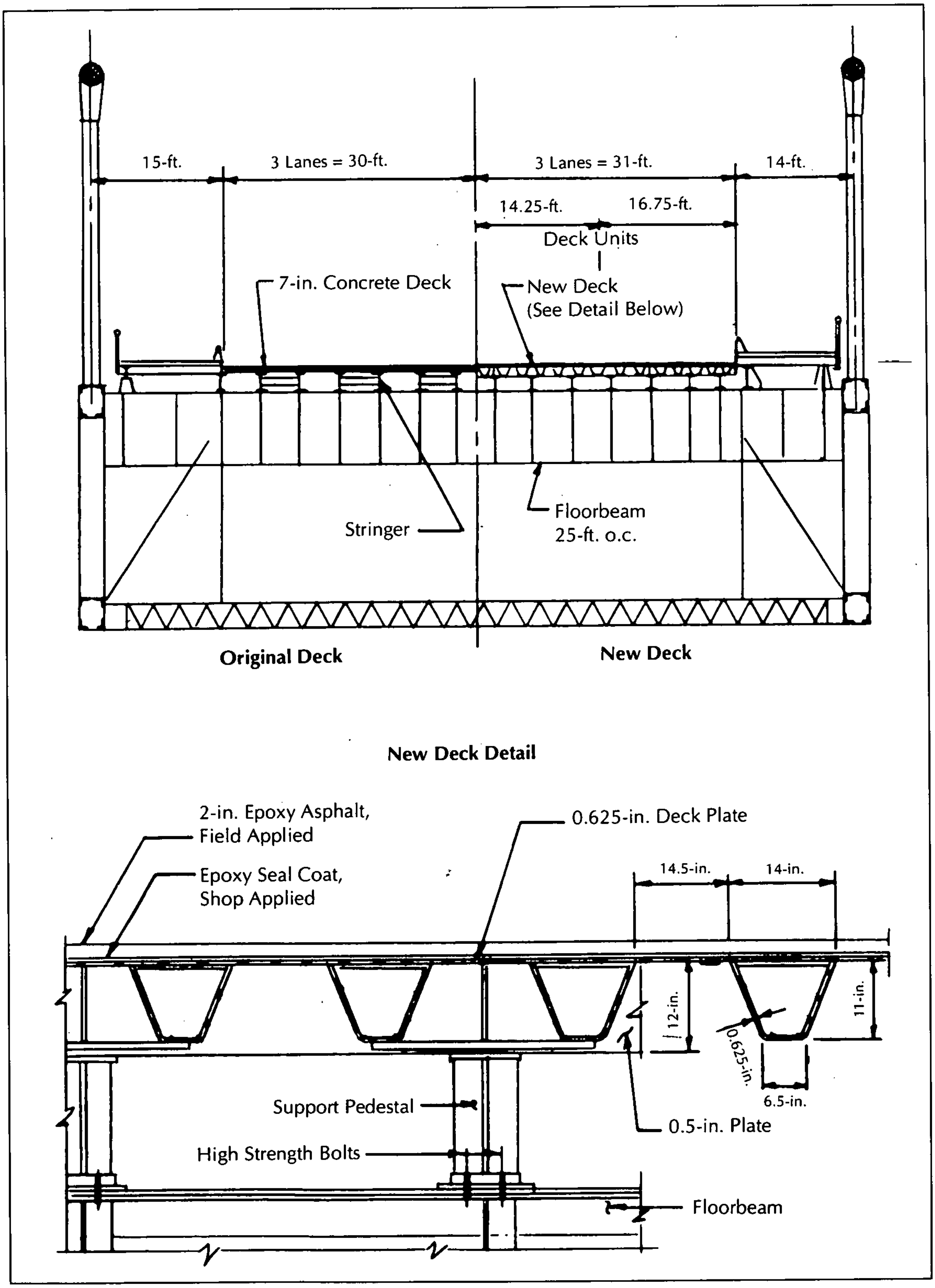

FIGURE 15. The orthotropic steel deck for the Golden Gate Bridge.

ASTM A709 Grade 50T steel connect the deck element to the main floorbeams of the bridge. Twenty-eight million pounds of structural steel were required for the fabrication of the new deck sections and other components of the project that included the suspended spans, and the San Francisco and Marin approach viaducts for a total area of new deck of 567,000 square feet.

Except for bolts in the field splices of transverse subfloorbeams and in the deck-to-support pedestals-to-floorbeam connections, the new deck consists of all-welded construction. The fabrication and installation of the 756 orthotropic deck panels required applying a wide range of welding techniques, from fully automatic full-penetration groove welds (as in the more than twelve miles of weld joining the deck plates in the shop and in the longitudinal splicing of adjoining deck units in the field) to simple manual fillet welds.

Since adequate fabrication facilities were not available in the San Francisco Bay area, the majority of the fabrication was performed in Utah, with other parts coming from Oklahoma and Texas. All fabricated components were shipped to a marshalling yard near the site, where the deck units were preassembled and paved with a temporary riding surface consisting of 0.5-inch crushed stone embedded in epoxy mastic. Field installation of the new deck included removing the existing concrete roadway and its supporting steel stringers; removing, rehabilitating and reinstalling sidewalks; and installing the new orthotropic steel deck. Reinstalling the sidewalks one foot outward from their original position permitted the widening of the roadway from the original width of 60 feet to 62 feet, thus providing 11-foot wide curb lanes for safer operation of trucks and buses.

Two high-speed 25-ton mobile hydraulic cranes were acquired specifically for this project. Traffic constraints required the contractor to perform all preliminary work necessary to remove the old concrete slab and install the new steel decks during the day from a 500 foot long scaffold platform suspended under the deck. The actual deck replacement operation could be performed only at night. Typically, one sidewalk section and two 20-ton deck sections, or a 50-foot long portion of one-half width of the bridge were replaced each night. Traffic interferences was kept to a minimum; the entire bridge was available daily to carry rush-hour traffic. Redecking was completed 401 working days after installing the first deck unit.

The final wearing surface, composed of a 2-inch thick course of epoxy-fortified asphalt concrete that was compatible with the temporary riding surface, was placed after orthotropic steel deck erection had been completed.

Because of its concrete beam and slab construction, the deck over the Marin anchorage was the only area on the bridge that was not replaced with the new orthotropic steel deck. Cracks in the concrete slab were repaired with epoxy injection prior to applying the epoxy-asphalt pavement.

Painting. Painting operations have continued throughout the last several years. In this process, all steelwork is being sandblasted to bare metal before receiving its new paint system of zinc-rich primer paint and vinyl top coat, retaining its landmark color of international orange. Completion of this re-painting process is finally in sight.

Other Deck Replacement Projects

Throgs Neck Bridge Approaches. The Bronx and Queens approach viaducts to the Throgs Neck Bridge in New York City carry two 38-foot wide three-lane roadways separated by a median divider. Rolled beam stringers spanning between relatively shallow floorbeams with long cantilevers support the 7.5-inch thick reinforced concrete deck. The floorbeam cantilever supports the heavily travelled exterior truck lane as well as part of the middle lane. The floorbeams are braced by two deep plate girders with simple spans ranging between 140 and 190 feet.

In the early 1970s, severe cracking and spalling was noted in the exterior lanes, which soon began spreading into the remaining part of the roadway. Inspection and design checks determined that this deterioration was caused by overstress in the concrete deck that resulted from the effects of differential deflections of longitudinal stringers elastically supported on the flexible floorbeam cantilevers. Such effects

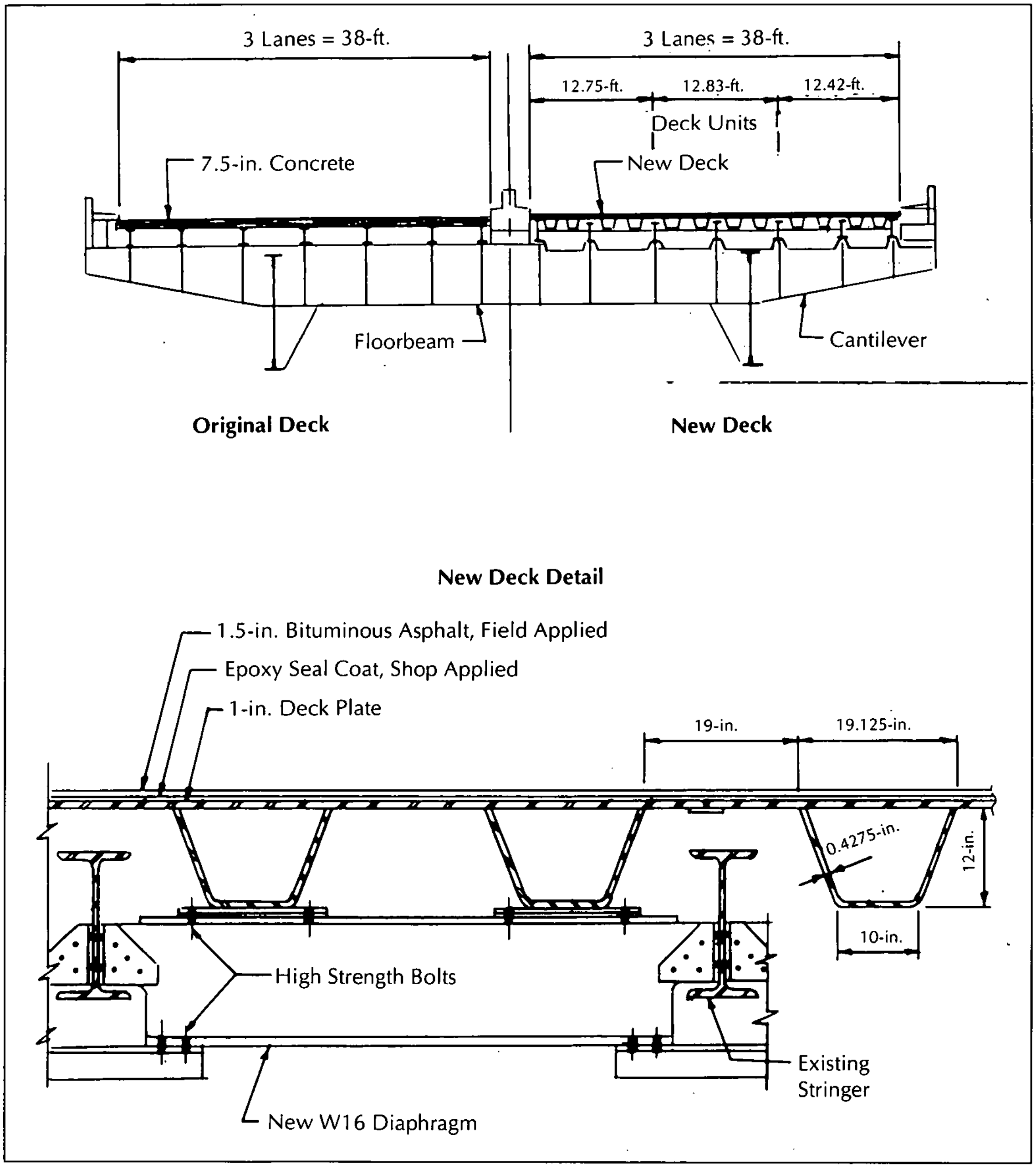

FIGURE 16. The orthotropic steel deck for the Throgs Neck Bridge.

are not recognized in the AASHTO design specifications that base concrete deck design on the assumption that stringers provide rigid support. Inadequate distribution reinforcement and chloride contamination bolstered the decision to replace the concrete decks.

The new orthotropic deck (see Figure 16) consists of a relatively heavy 1-inch thick plate that was required by the shape and spacing of the trapezoidal closed-cell ribs that had to be fitted between the longitudinal stringers. The ribs are 0.44 inch thick and 12 inches deep, and are supported by new W16 diaphragms that transfer the load to the existing stringers. Deck plate and ribs are of ASTM A709, Grade 36T steel with Zone 2 impact requirements. The new orthotropic deck is fully continuous within each span of the approach viaduct; longitudinal and transverse deck plate splices were field-welded and rib splices were bolted. The temporary riding surface consisted of a 0.125-inch thick shop-applied epoxy and grit seal coat that was topped in the field with a 1.5-inch thick bituminous asphalt course as the final surface.

Deck units were up to 52 feet long and between 12 and 13 feet wide. Erection proceeded along one roadway at a time from beginning to end, with traffic diverted during each night to one lane of the other roadway. Sections of existing concrete slab were removed and new deck panels installed for the full width of the roadway each night, with all lanes open in the morning. The total area of replaced deck in both approach viaducts was 492,000 square feet.

Benjamin Franklin Bridge. This suspension bridge across the Delaware River in Philadelphia has a 1,750-foot mainspan and was opened to traffic in 1927. It carries seven lanes of traffic with a daily volume of 100,000 vehicles, and two transit rail tracks. The original 6.5-inch thick reinforced concrete deck slab was progressively deteriorating as a result of heavy traffic and chloride contamination from deicing salts. Corrosion of the supporting steel stringers below the frequent open joints added to the problem. Replacement of the entire 600,000-square-foot roadway area with an orthotropic steel deck was decided in 1982.

An open-rib system was chosen for the new deck (see Figure 17). While somewhat heavier than a closed-rib system, it offered the advantages of simple splices for the continuous deck system, easier connection details to the existing floorbeam supports, and total accessibility of the deck underside for maintenance. The 0.625-inch thick deck plate is stiffened by specially rolled 12.5-inch deep bulb sections, all of ASTM A36 steel. The deck is directly supported on the existing floorbeams that permitted removing the corroded roadway stringers. The deck units were made fully continuous; field splices of deck plates and ribs were made with high-strength and interference body bolts. The elimination of all deck joints removed the maintenance problems that had added to the demise of the old concrete deck. The continuity in the suspended spans also permits the new deck to act as a fully participating component of the stiffening truss system of the bridge in carrying stresses, increasing the flexural and torsional rigidity of the bridge and improving its aerodynamic characteristics.

The base surfacing course of 1.25-inch thick epoxy asphalt was placed on the deck plate under controlled conditions in the shop. The final 1.25-inch thick bituminous asphalt course was placed in the field after completing the deck installation.

Erection of the new deck units proceeded in four construction phases. During each phase, five lanes were open to traffic during peak commuting hours and four lanes in off-peak hours. Work was performed during daytime hours between fixed traffic barriers.

Bronx-Whitestone Bridge Approach. Deck replacement with orthotropic steel plates is not restricted to suspension bridges and other large area projects. It has been successfully employed on small, simple span bridges where savings in weight were desired and in cases where closure to traffic could be tolerated only for a short period.

On the Bronx-Whitestone Bridge approach in Queens, a three-level structure carries the Whitestone Expressway on- and off-ramps over the Cross Island Parkway. Deterioration of the concrete deck of the uppermost level (on-ramp) became so severe in 1984 that complete deck replacement was considered the only acceptable solution.

Since the only detour available for the heavy truck and automobile traffic using this ramp led through local residential streets, the closure of this ramp bridge for the period normally required to place a new concrete slab was unacceptable. The solution was the construction of a pre-paved welded orthotropic steel deck of a design similar to that prepared at the same time for the Throgs Neck Bridge approaches. Replacement of the deck for this two-lane wide and 70-foot long bridge was performed over a weekend, with traffic diverted from 9 P.M. Friday night to 6 A.M. Monday morning.

Tobin Bridge

The Tobin Bridge in Boston was built with a reinforced concrete deck, although it was orig-

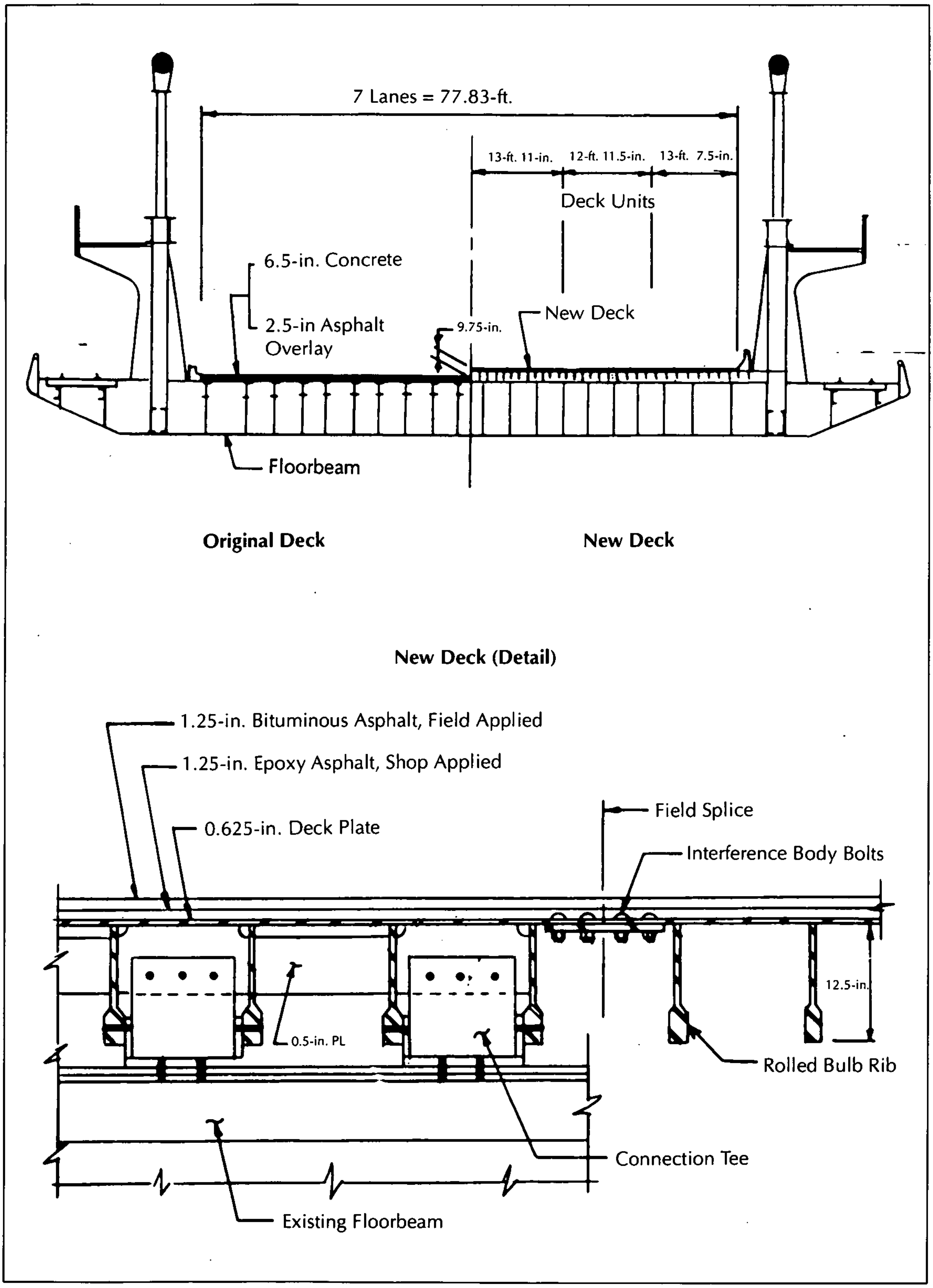

FIGURE 17. The orthotropic steel deck for the Benjamin Franklin Bridge.

inally designed for a steel grid system. Even though it was opened in 1950, by the late 1960s there was so much serious deterioration that the deck had to be replaced with a partially filled steel grid system. The replacement work was installed one lane at a time.

Some ten years after the new deck was installed, it again began to show indications of severe deterioration, both underdeck and on the surface, particularly along the lane lines. A detailed inspection determined that the predominant problem was the lane line deterioration that probably resulted from the difficulty in placing concrete in the narrow spaces of the grid floor adjacent to active traffic. In other areas of the deck, local deterioration most likely resulted from poor consolidation of the concrete and infiltration of surface water. In all cases, the visible damage consisted of break-up and potholing of the asphalt overlay, severe rusting and loss of the metal form pans used in placing the concrete fill, and local break-up of concrete fill. The latter was considered of primary importance because of the danger any metal object or loose concrete falling from the upper deck would pose to traffic on the lower deck.

A large number of rehabilitation and replacement options were investigated that included patch repairs, concrete replacement, grid replacement and even orthotropic plate deck replacement. Each option was reviewed on the basis of initial costs, operational impacts and life-cycle costs.

Since investigations and tests indicated that the steel grid itself and the weld connections to the subfloorbeams were in satisfactory condition, it was decided to remove the overlay pavement and all concrete fill, to make local repairs to the steel grid where necessary, and to place new concrete for the full depth of the grid floor.

This rehabilitation is being carried out in stages. The first stage, a portion of the upper deck on the Boston approach, has been completed. Removable wood forms were employed and silica fume concrete was used to provide impermeability. A 0.375-inch thick epoxy concrete overlay was placed over the concrete-filled grid floor. The second stage, consisting of work on the Boston approach upper deck that incorporates the same rehabilitation method, has yet to be completed.

Royal Gorge Bridge

Considered the highest bridge in the world, the Royal Gorge Bridge spans the gorge of the Arkansas River near Canon City, Colorado, at a height of 1,053 feet above the tracks of the Denver and Rio Grande Railroad that hugs the canyon walls only a few feet above the river. Built in 1929, the bridge has a main suspended span of 880 feet and a total length between abutments of 1,200 feet. Steel framed towers perched at the rim of the canyon support the two parallel wire cables, each about 9 inches in diameter and containing 2,100 No. 9 galvanized steel wires. The unstiffened, timber-decked floor is 18 feet wide. Wire rope wind cables anchored to the canyon wall provide the necessary wind stability.

The main cables were anchored in concrete-filled trenches cut into solid granite. Several years ago severe rusting began to appear at the stone abutments where the cables entered the trench. Careful excavation found that more than fifty years of burial in the ground had taken a severe toll. Water running inside the cables had been trapped in the crevices of the concrete and corroded the embedded cable wires causing a reduction of as much as 40 percent in the strength of the cable. Since the cables outside the anchorages were found to be in excellent condition, it was decided to replace all four cable anchorages and both ends of each cable, a feat never before attempted.

New anchorages consisting of rock anchors and structural steel members embedded in concrete were constructed on either side of each existing cable anchorage to receive the ends of new parallel wire strands. These strands were brought to a point approximately 100 feet from the anchorage where a new splay cable band had been installed on the existing cable. At this point, wires of the existing cable were individually spliced to a companion wire of the new strand extending up from the new anchorage. A total of 8,400 individual wire splices were thus made to connect the existing cables under proper tension to their new anchorage ends. The new cable anchorages are completely open to inspection and easily accessible for

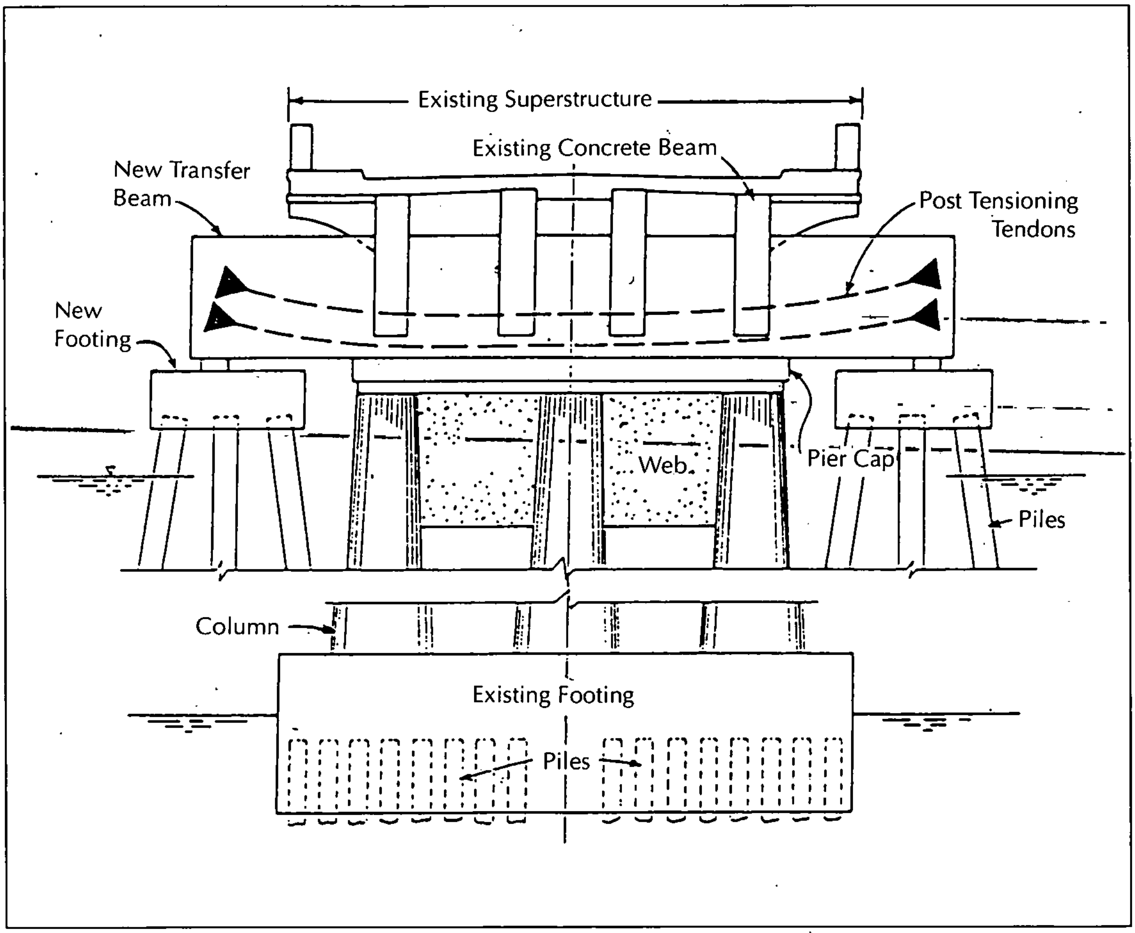

FIGURE 18. Foundation rehabilitation for the Ashley River Bridge.

maintenance.

The rehabilitation included replacing all suspenders that connect the bridge deck to the cables and completely reconstructing the wind cable system. Traffic was restricted on the bridge during all these operations.

Connecticut Bridge Rehabilitation Program

Spurred on by the tragic collapse of the Mianus River Bridge on the Connecticut Turnpike, the State of Connecticut embarked on a comprehensive Transportation Infrastructure Renewal Program that put the state into the forefront of bridge rehabilitation in the country. During a ten-year period that started in 1985, a total of 1,620 state bridges and 1,300 local bridges are scheduled for rehabilitation, reconstruction and improvement, at a total cost of $1.5 billion. Federal funds will pay for 80 percent of the costs on state and interstate highway bridges. The state will aid local governments in various ways in financing the costs for local bridge rehabilitation.

In the initial program, some 500 bridges were identified by state department of transportation engineers as being in poor to fair condition, with another 110 bridges expected to deteriorate to poor to fair condition each year of the program. Engineering contracts for the inspection and rehabilitation design for groups of bridges were initiated on an expedited basis; construction contracts followed the approval of consultant inspection reports and rehabilitation designs.

Work performed for this renewal program includes every imaginable item from improving foundations, repairing cracks and spalls in abutments, replacing bridge bearings, replacing rivets and corroded steel members, repairing cracks in concrete beams and bridge slabs, replacing bridge decks with new concrete slabs, grid floors and orthotropic steel decks to widening or replacing entire bridges.

Ashley River Bridge

While rehabilitating or replacing a bridge superstructure has become a familiar occurrence, the unusual replacement of a bridge foundation provides an excellent example of innovative engineering and imaginative design. The bridge crosses the Ashley River in Charleston, South Carolina, and connects the historic Charleston Peninsula with downtown and the state highway system. Completed in 1926, the bridge is 1,733 feet long and it carries 40,000 vehicles a day on its three lanes. The superstructure consists of a 202-foot long double-leaf bascule channel span, flanked by concrete T-beam approaches that have an average pier spacing of 76 feet. The approach piers consist of three-column bents with a concrete cap and partial depth diaphragms, resting on an unreinforced pile cap supported by precast concrete piles.

An underwater inspection in 1987 revealed extensive losses of column section, voids in the pile caps and major cracking. At one location, the tops of several piles were not in contact with the pile cap above. A preliminary analysis indicated that load and stability margins were severely reduced and the bridge had to be posted with load and speed restrictions.

Alternative studies of rehabilitation methods and total replacement were evaluated in the light of several considerations:

- Historic and architectural significance of the bridge;
- Speedy return to maximum traffic levels;
- Maintaining the reduced level of traffic during construction; and,
- Cost.

The solution that met all criteria favorably was the replacement of the deficient piers (see Figure 18).

Groups of new 24-inch square prestressed concrete piles were driven adjacent to each approach pier and capped with a new concrete footing. Cast-in-place concrete beams were then placed to span transversely between these new pile foundations to support the existing bridge superstructure. Specially designed falsework and concrete placement procedures had to be employed to support the weight of the freshly placed concrete without adding loads to the existing piers. Post-tensioning tendons and some normal reinforcing steel of the new support and load transfer beams were threaded through the existing T-beam webs. Shallow jacks placed between the top of the new footings and the bottom of the new support beams were used to transfer the superstructure load from the existing piers to the new footings prior to the grouting of the new permanent beam bearings.

A total of 18 piers were reconstructed at a cost of about $3.6 million. The entire operation from inspection and discovery of the foundation problem through design and construction was completed within one year.

Summary

The concept of regularly scheduled inspections has become well established throughout the country. Nevertheless, problems persist. Bridge failures, and the sudden unscheduled complete or partial closures of bridges such as New York City's Williamsburg and Manhattan Bridges, are all too frequent reminders of long years of lack of timely attention and "deferred" maintenance, of wasteful management and of utter disregard for the long-term needs and safety of the public.

Adherence to a long-range inspection program will permit the early identification and tracking of problems. It will enable the bridge operator — as was the case, for example, with the George Washington and the Golden Gate Bridges — to properly schedule necessary rehabilitation efforts with minimum impact on the community and maximum cost benefits. Fortunately, the importance of such programs is now generally recognized.

Bridge rehabilitation design requires familiarity with materials, equipment and construction procedures in addition to a detailed knowledge of the behavior of the structure. While there is a certain similarity in the problems befalling different bridges that permits typifying rehabilitation methods, details of application usually vary from structure to structure and demand the engineer's wide range of experience and full attention on an individual basis.

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FRANK STAHL *is Chief Engineer of the Transportation Division for Ammann & Whitney. He has been with the firm for 43 years, serving in such positions as Draftsman, Designer, Project Engineer and Project Manager. He has received such awards as the ASCE Thomas Fitch Rowland Prize, the ASCE Innovation in Civil Engineering Award of Merit and the ASTM Award of Merit.*

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The History of Leather Industry Waste Contamination in the Aberjona Watershed: A Mass Balance Approach

Performing a mass balance analysis is an important step in determining the amount of hazardous materials discharged within a given area.

JOHN L. DURANT, JENNIFER J. ZEMACH & HAROLD F. HEMOND

There is concern that leather industry wastes that were discarded into the Aberjona watershed in eastern Massachusetts may constitute a potential human health risk. Chemicals used in hide- and skin-tanning processes, as well as chemicals found in tannery wastes (in particular, chromium, which is a common tanning agent), have been shown to be toxic to aquatic organisms and humans,[1,2] mutagenic and carcinogenic in animal assays,[3-5] and carcinogenic in human epidemiology studies.[4] The Aberjona watershed, a 25-square-mile area ten miles north of Boston (see Figure 1), was once a major center for tanning, leather finishing, and hide and leather rendering. Between 1838 and 1988 approximately 100 tanneries, leather-finishing companies, and rendering factories operated at over 67 sites in Woburn, Winchester, and Stoneham (see Figure 2 and Table 1[6-24]).

Records from as early as 1871 to the mid-1930s indicate that the Aberjona River and its tributaries were the main conduits by which tannery and rendering factory wastewater was discarded. Tannery and rendering factory sludges were commonly disposed of on site or at centrally located dumping areas.[11,20,25-44]

At present, there are six sites in the watershed that are being investigated for the presence of leather industry wastes.[8,17,18,22,45,46] Five sites are being investigated by the Massachusetts Department of Environmental Protection (DEP) under the provisions of Massachu-

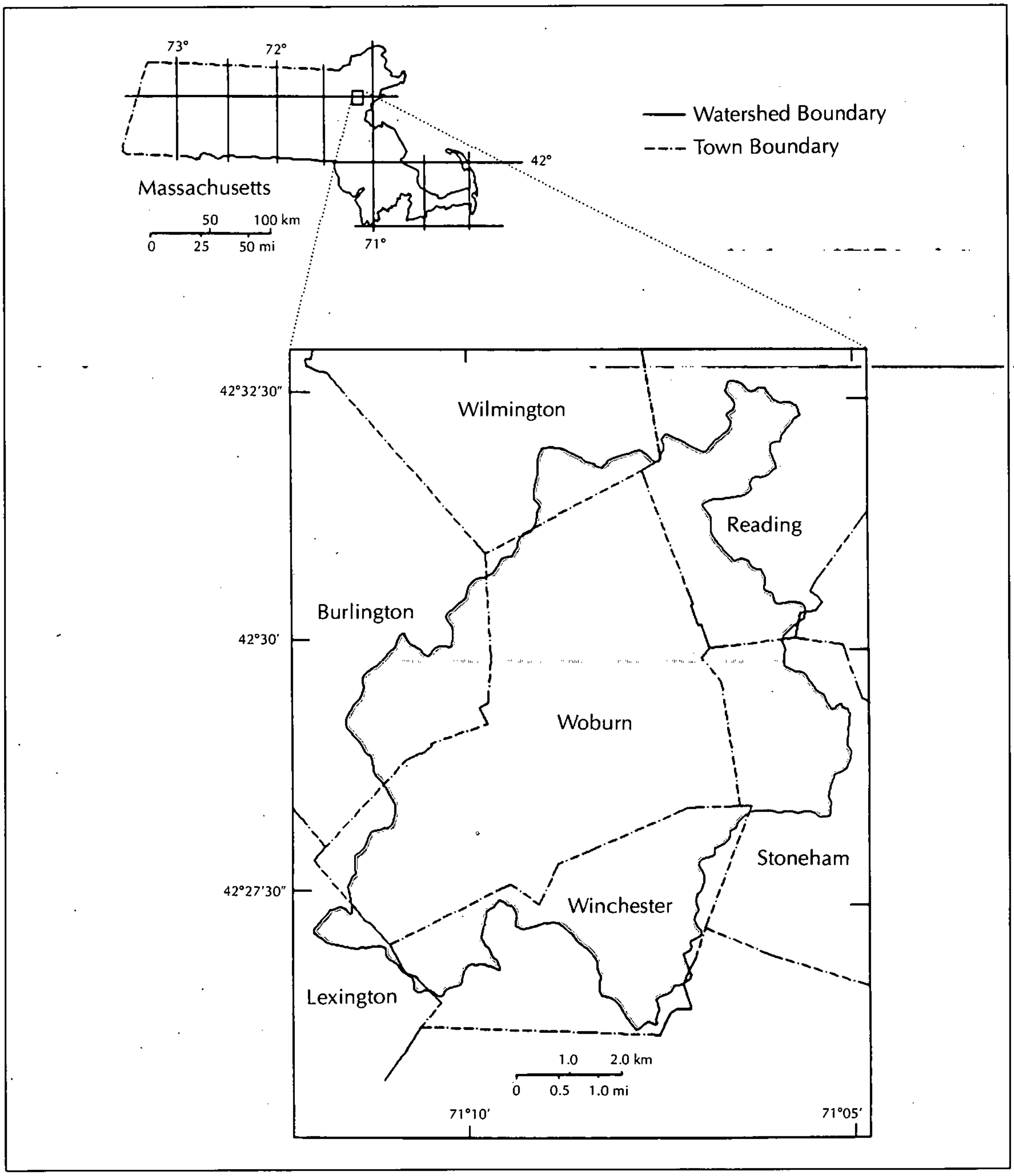

FIGURE 1. Study area location map.

setts General Law, Chapter 21E, section 3(A)b and the Massachusetts Contingency Plan (310 CMR 40.00). The sixth site, the "Industriplex" Superfund site, is being investigated by the United States Environmental Protection Agency (EPA) under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) and is currently ranked fifth on the "National Priorities List."

Possible links between environmental contaminants and human health effects in the Aberjona River watershed are being investigated. Work is being done to determine how hazardous chemical wastes are distributed in

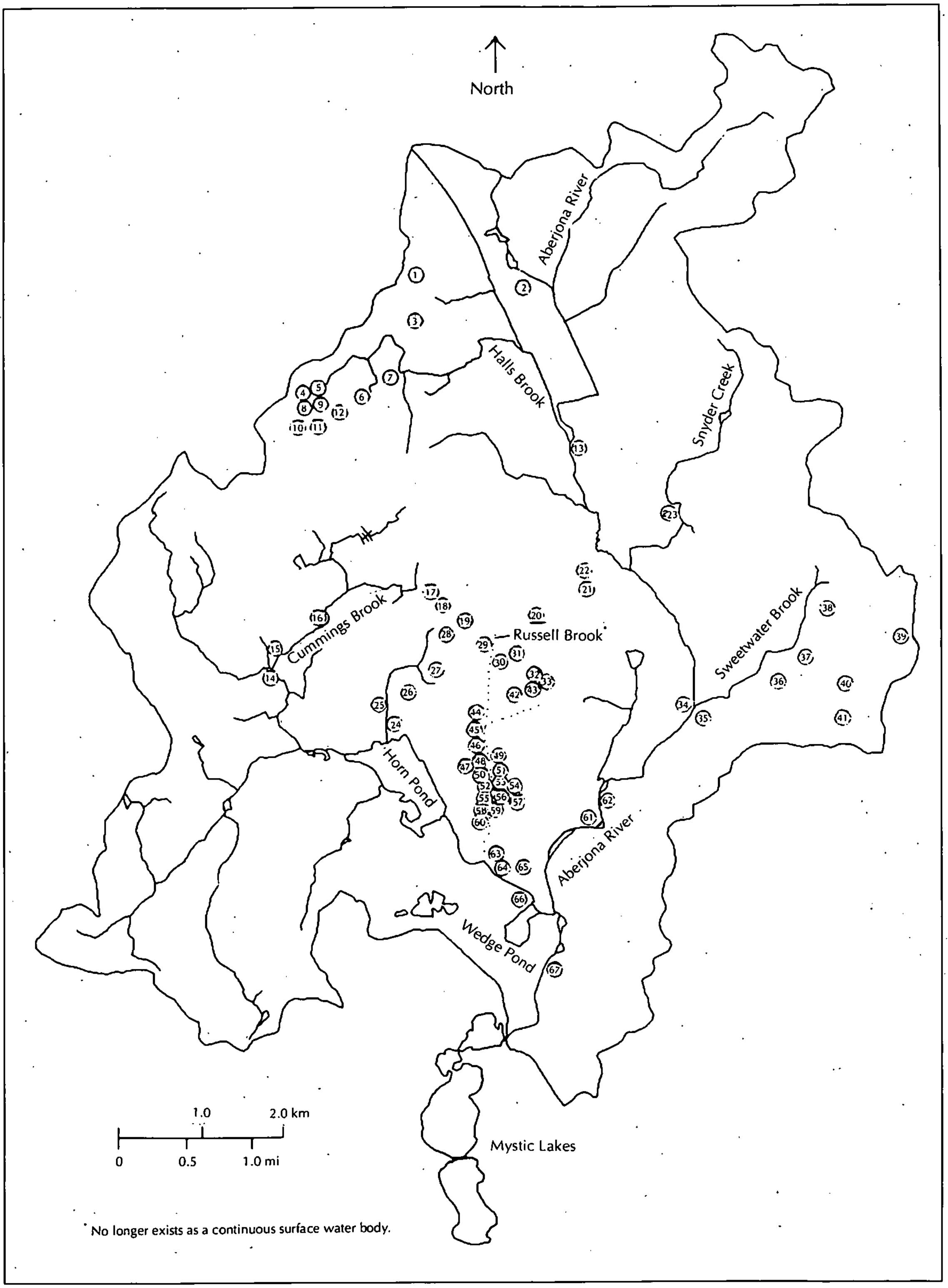

FIGURE 2. Location of tanneries, leather-finishing companies and renderers in the Aberjona watershed between 1838 and 1988.

TABLE 1
Tanneries, Leather-Finishing Companies & Rendering Factories in the Aberjona Watershed (1838-1988)

Site	Last Company to Operate at the Site	Type of Operation	Approximate Dates	Reference(s)
1	Woburn Hide & Leather Co.	Tanning	1957-1960	6,7
2	Stauffer Chemical Co.	Rendering	1934-1968	8
3	Algonquin Leather Co.	Tanning	1918-1926	9
4	Foucar Leather Co.	Finishing	1918-1926	9
5	Rathburn Leather	Tanning	1875-1939	9,10
6	Eaton, Winn & Co.	Tanning	1875- ?	10
7	North Star Japanning Co.	Finishing	1926- ?	9
8	Porter Japanning Factory 2	Finishing	1918-1939	9
9	Porter Japanning Factory 1	Finishing	1894-1939	9
10	Linscott Heel Manufacturers	Tanning	1888-1926	9
11	Bond & Tidd	Tanning	1875- ?	10
12	Bond Leather Specialists	Tanning	1918-1926	9
13	H.W. Clark Patent Leather	Finishing	1904- ?	9
14	Woburn Degreasing Co.	Rendering	1871-1977	11,12
15	Bacon's Patent Leather Co.	Finishing	1871- ?	11
16	Colgate & Son Tannery	Tanning	1871- ?	11
17	E.G. Place Split Leather	Tanning	1888- ?	9
18	W.P. Fox Grain & Split	Tanning	1888-1904	9
19	Kinney & Murphy	Tanning	1875-1894	9,10
20	Paterson Patent Leather	Finishing	1926- ?	9
21	Murray Leather Co.	Finishing	1918-1979	9,13
22	J.J. Riley Co.	Tanning	1918-1988	9,13
23	Crescent Tanning Co.	Tanning	1918-1940	9,14
24	Morocco Manufactory	Tanning	1871- ?	11
25	Stephen Dow & Co.	Tanning	1875-1894	9,10
26	Prime Tanning Co.	Tanning	1888-1926	9
27	Bay State Japanning Co.	Finishing	1913-1926	9,13
28	Amer. Hide & Leather Fact. H	Tanning	1875-1904	9,10
29	Winn Tannery	Tanning	1875- ?	10
30	J.H. Connolly	Tanning	1875- ?	10
31	Murray Leather Co.	Finishing	1875-1961	9,10,15
32	Woburn Japanning Co.	Finishing	1875-1961	9,10,15
33	Griffin Place Curry Shop*	Tanning	1894-1918	9
34	Tanners Degreasing Co.	Rendering	1939-1977	9,12
35	Atlantic Gelatin	Rendering	1875-Present	9,10,16
36	A. Buckman Co.	Tanning	1924- ?	9
37	J.H. Murphy Curriers	Tanning	1924- ?	9
38	Blank Brothers Curry Shop	Tanning	1887-1903	9
39	Best Leather Nut Co.	Tanning	1924- ?	9
40	W.H. Tidd	Tanning	1840-1903	9
41	Van Tassel Co.	Tanning	1897-1924	9
42	Ballard Japanning Co.	Finishing	1904-1926	9
43	J. Kendall Chrome Tannery*	Tanning	1888-1918	9
44	Prime Tanning Co.	Tanning	1875-1934	9,10,17
45	Tolman-Fox Corp.	Tanning	1875-1938	9,10,18
46	W.P. Fox Leather**	Tanning	1875-1918	9,10
47	Dorrington Leather Co.	Tanning	1888-1939	9
48	Amer. Hide & Leather Fact. D	Tanning	1875-1939	9,10
49	E. Cummings Leather Co.	Tanning	1888-1926	9
50	E.C. Cottle***	Tanning	1888-1894	9
51	Watauga Tanning Co.	Tanning	1888-1894	9
52	Middlesex Leather Co.***	Tanning	1888-1904	9
53	Cottle Leather Co.	Tanning	1888-1918	9
54	American Hide & Leather	Rendering	1918-1926	9
55	B.H. Nichols Grease Factory	Rendering	1888-1904	9
56	Beggs & Cobb Factory 1	Finishing	1888-1926	9
57	Beggs & Cobb Factory 2	Finishing	1888-1926	9
58	Kean Brothers & Bedell	Finishing	1926- ?	9
59	Amer. Hide & Leather Fact. E	Tanning	1875-1926	9,10
60	Amer. Hide & Leather Fact. S	Tanning	1875-1939	9,10
61	J.O. Whitten Co.	Rendering	1872-1980	19,20,21,22
62	A.H. McLatchy Co.	Finishing	1916-1929	9,20
63	Pantasote Leather Co.	Tanning	1899- ?	9
64	Haley Patent Leather Co.	Finishing	1904-1916	9
65	Beggs & Cobb	Tanning	1871-1957	11,20,21,23
66	Blank Brothers Tannery	Tanning	1876-1910	19,21,24
67	Waldmyer Tannery	Tanning	1838-1894	21

* In 1918 incorporated into Woburn Japanning at Site 32. ** In 1918 incorporated into Fox & Sons at Site 45. *** In 1904 incorporated into Amer. Hide & Leather Fact. D at Site 48.

and move through the watershed, and how humans may be exposed to and affected by particular waste chemicals. In order to help identify which hazardous chemicals are most widely distributed in the wastershed, mass balance techniques are being employed to quantify chemical consumption and waste generation by specific industries in the watershed, with special emphasis here on the area's major industry. The mass balance approach is employed to estimate the amounts of four metals — chromium, copper, lead and zinc — produced as by-products of tanning and leather finishing. (Since there were insufficient records to properly characterize the rendering industry, wastes generated by rendering operations were not included in the mass balance).

The Rise of the Leather Industry in the Aberjona Watershed

The history of tanning in the Aberjona River watershed spans over 320 years. The first tannery was built in Woburn in 1666.[47] During the 1700s several more tanneries were constructed in Woburn, but it was not until after the Middlesex Canal was completed in 1803 that the tanning industry became firmly established. Built to facilitate the exchange of raw materials and manufactured goods between Boston and the city of Lowell to the north, the canal had a significant impact on the economies of the smaller communities that developed along its banks. The canal ran through what is now Woburn center, providing Woburn's tanneries direct access to markets from which they could acquire new hides and skins, and to which they could distribute finished leather products. By 1837 there were four tanneries in Woburn employing over 75 workers.[48]

The early development of the leather industry in the watershed was helped considerably by the concurrent development of machine making, chemical production, and shoe and boot manufacturing. Machinists produced new and innovative tanning machinery; chemical companies both supplied chemicals to, and derived raw materials from, tanning operations; and, shoe and boot manufacturers provided a steady market for finished leather. Although all three support industries were important to the early success and growth of the tanning industry, the making of shoes and boots had perhaps the most significant impact. Along with Philadelphia and Lynn, Massachusetts, the Aberjona watershed was one of the nation's largest manufacturing centers for leather footwear. In 1850, there were 26 shoe and boot manufacturing shops in Woburn alone.[48]

By the 1860s the production of leather had become the dominant industry in the watershed. The construction of the Woburn branchline to the Boston & Maine Railroad in 1844, the increasing supply of skilled tannery workers, the continued demand for finished leather by local shoe and boot manufacturers, and the growing reputation of the quality of Woburn leather goods all contributed to the prosperity of the leather industry. In explaining the dominance of the leather industry in the watershed, historians also suggest that the quality and supply of water was an important factor. In 1920, one historian wrote:

> From the beginning of tanning in this city [Woburn], it has become a well known fact that the opportunities here presented for tanning were unexcelled, and that better results could be obtained here because of the water properties, than in any other known locality.[47]

Not only were there abundant supplies of surface water from which to draw water for production and in which to discharge wastes, but there were considerable groundwater reservoirs as well. According to the United States Geological Survey, the Aberjona watershed has some of the most transmissive aquifers in the northeast Massachusetts coastal drainage basin.[49]

Peak Years of the Leather Industry

The most productive period in the history of the leather industry lasted from the late 1870s to the 1920s. During that period, from 15 to 20 tanneries and leather-finishing companies were consistently in business, nearly 55 percent of all wage earners in the area were employed in the leather industry, and the value of tanned and finished leather products accounted for over half of the total annual value of goods produced in the watershed.[50]

Two factors that had a significant impact on the growth and success of the industry in this period were the introduction of chrome-tanning methods and the increased specialization of the industry in the production of "upper" leather (*i.e.*, the leather from which the upper parts of shoes are made). Prior to 1900, most tanning was performed using tanning agents that were derived from plants — principally, tannins from wood, leaf and bark extracts. "Vegetable" tanning, as it is known, was performed in vats of tannin solution in which hides and skins were soaked for as long as several weeks, depending on the thickness of the leather and the desired qualities of the tanned product. The introduction of chrome-tanning methods to the watershed around the turn of the century, however, revolutionized the production of light leathers by greatly reducing the time necessary for tanning. Chrome tanning, in which chromium salts — usually basic chromium sulfate — are used as the principal tanning agents, is completed within six to 24 hours, and produces a leather that has greater heat and abrasion resistance than vegetable-tanned leather.

The specialization of the tanning industry in the production of upper leather was influenced not only by the development of chrome-tanning methods, but also by technological innovations and market demand. Such inventions as the belt knife splitting machine (used to separate the grain side of the leather from the flesh side or "split"), the staking machine (used to soften leather), the shaving machine, and embossing and buffing machines improved the productivity of upper leather tanneries greater than tenfold.[47] Likewise, the use of trucks instead of railroad cars and horse-drawn wagons to deliver leather to market both increased the speed of distribution and allowed access to new distribution centers.

In response to market demands for new types and styles of finished leather goods, tanneries and leather finishers produced patent leather for shoes, and special grades of upper leather such as glove grain, pebble grain and crimping splits. By the 1920s, tanneries and finishers had markets in England, Europe and South America. In the United States, the cities of Woburn and Winchester were referred to as the nation's "home of upper leather manufacturing."[51] In order to keep up with demand, it was estimated that in the late 1920s tanneries in Woburn were producing approximately 30,000 sides of leather per day, or seven million sides annually.[47]

The Decline of the Leather Industry

The finished leather industry had its best years in 1927 and 1928, and then experienced significant losses as a result of the stock market crash in 1929 and the depressed national economy in the early 1930s. In 1928, the value of leather goods produced in Woburn was just over $10 million, 1,299 wage earners were employed in the leather industry, and 24 tanneries and leather-finishing companies were in business. By 1932, however, the value of leather goods produced in Woburn had decreased by two-thirds to just over $3.2 million, the number of employees had been reduced to 759, and the number of tanning and leather-finishing businesses had fallen to 16. The leather industry hit bottom in 1940 when only six tanneries remained and the value of goods produced was $380,000.[50]

Despite the downturn in the finished leather economy in the 1930s, other sectors of the leather industry — specifically, leather and hide rendering — still managed to post modest gains. Rendering companies took advantage of the cheap surpluses of hides and unfinished leather, and built large factories to manufacture grease, gelatin and glue. By 1939, five rendering plants were operating in the watershed.

In 1940 there were eleven tanneries, leather-finishing companies, and rendering factories in the watershed. Between 1940 and 1948, the industry posted modest gains as the value of products sold reached its highest levels since 1929. By the 1950s, however, it was clear that the industry was stagnating. No new establishments were going into business, and industry profits were not keeping pace with growth in other sectors of the local economy. Increasing competition from foreign companies for market share, fluctuations in wholesale prices and rising production costs also contributed to the slow demise of the industry. The remaining companies began going out of business one by one in the late 1950s. The last company to go out of business closed in January 1988, thus ending the long tenure of the leather industry in the watershed.

Surface Water Contamination

There is a substantial historical record documenting leather industry waste contamination of surface water bodies in the watershed. Much of this history was documented by the Massachusetts State Board of Health and later by the body that replaced it, the State Department of Public Health. In one of its first investigations of the relationship between industrial and municipal waste disposal practices and the contamination of drinking water supplies, the Board of Health studied the problems in the Upper Mystic Lake watershed. In 1871 a report was issued on the condition of Upper Mystic Lake (which then provided drinking water to Charlestown, Somerville and East Boston), its main tributary, the Aberjona River, and other water bodies in the watershed. Although no industrial or municipal waste contamination was found in Upper Mystic Lake, the report indicated that tannery wastes were present in Horn Pond (which was then part of Woburn's water supply) and its tributaries.[11] Subsequent reports by the Board of Health in 1874 and 1875 described the extent of tannery waste contamination in Russell Brook, a tributary to Horn Pond Brook.[25,26] Investigators identified eight tanneries that were directly discharging effluent to the brook. Sewage from nearby homes and coal degassing wastes were also adding to the foul condition of the brook, leading Board of Health officials to speculate that the contaminated water had contributed to the recent increase in mortality rates in the community:

> Within the last ten years, there has been a large number of deaths in this district, especially from consumption, typhoid fever, diphtheria and scarlet fever. During the past summer and fall, when the brook [Russell Brook] was in its worst condition, there was sickness in most of the houses. It is fair to infer that the prevalence of disease was influenced, if not caused, by the polluted stream . . . .[26]

In 1876, just five years after declaring Upper Mystic Lake water "unquestionably good and wholesome," Board of Health investigators returned to the watershed to assess conditions in the Aberjona River. Fueled by growing concerns that discharges of municipal and industrial wastes would lead to the contamination of Upper Mystic Lake, investigators found that a 1.5-mile-long section of the river directly upstream of Upper Mystic Lake received inputs of glue manufacturing wastes, "putrescent animal matter and lime" from tanneries, and sewage.[27] Fifty-five factories (of which twenty were "leather-works") were identified on tributaries to Upper Mystic Lake, and it was estimated that "about seven percent of the water that flows in upper Mystic Pond is drainage from [these] factories."[27] In their report, Board of Health investigators also observed that "[f]ish have been killed in this pond, and cattle have refused to drink the water of the 'Abajonna' River."[27]

The Board of Health (and later the Department of Public Health) continued to make examinations of surface water conditions in the watershed between the late 1870s and the 1950s. During that period, health officials focused much of their attention on promoting the establishment of legislation that would prevent further pollution of surface waters in the watershed, and on the construction of a sewer system that could meet both municipal and industrial waste disposal needs. Particular emphasis was given to Russell Brook and the Aberjona River, where tannery and rendering wastes were frequently found. Investigations of Russell Brook in 1904 and 1907 (and again in 1915 and 1921) revealed widespread contamination by tannery effluent discharges.[20,28,29,31] Likewise, leather industry waste contamination was reported in the Aberjona River in 1912, 1915, 1922, 1927 through 1929, 1931 through 1934, 1936 and 1939.[20,30-35,37-42]

Development of the Sewer System

The development of the sewer system in the watershed has a complex and interesting history. The first major sewer line in the watershed was constructed in Winchester in 1878, along the course of the Aberjona River. Fearing that discharges of industrial wastes and raw sewage would contaminate drinking water supplies in

Upper Mystic Lake, the city of Boston built the "Old Mystic Valley Sewer," complete with a precipitation facility to separate liquid and settleable wastes. Sewage and industrial effluent from Winchester center and factories operating on the Aberjona River were treated in settling tanks and mixers before being discharged into Lower Mystic Lake. From its inception the Old Mystic Valley sewer system proved to be inadequate to handle the volume of wastes generated by its users. Also, the water quality of Lower Mystic Lake rapidly deteriorated, leading the Board of Health to write in its 1884 annual report that the sewer provided "but a partial remedy for the evil of the Mystic Valley."[52] The Old Mystic Valley sewer was used until 1895 when connections were finally completed to sewer lines that discharged at Deer Island into Boston Harbor.[6]

After the turn of the century, worsening pollution problems in the watershed prompted area residents to issue complaints against Woburn and Winchester companies that were found to be discharging waste into surface waters.[48] In addition, Board of Health investigators continued to document the extent of contamination in Russell Brook and in the Aberjona River, and made concerted efforts to identify the offending dischargers.[28,29] In response to increasing public pressure to take action, the Massachusetts General Court passed two pieces of pollution control legislation. One piece of legislation (Chapter 235), passed in 1907, prohibited the pollution of Horn Pond Brook and its tributaries. The other law (Chapter 291), passed in 1911, prohibited the pollution of the Aberjona River.[6] The Chapter 291 Acts were intended to prohibit:

> [T]he entrance or discharge of sewage into any part of the Aberjona River, or its tributaries, and to prevent the entrance or discharge therein of any substance which might be injurious to public health or might tend to create a public nuisance.

The Acts established a maximum fine of $500 for each offense. In addition, the Board of Health was instructed to provide technical advice to assist companies in reducing discharges to the Aberjona River or its tributaries.[53]

Despite the clear mandate of the 1907 and 1911 legislation, their implementation and enforcement were made difficult because many tanneries and rendering companies were either unable or unwilling to comply with the pollution control laws. Prior to the passage of the Acts, leather industry firms that were not sewered typically stored their wastewater in lagoons to permit solids to settle before discharging the effluent to surface waters. Because the Metropolitan District Commission (MDC) sewer system (formerly the Old Mystic Valley sewer system) did not extend into north Woburn where many leather industry firms were located, companies had no alternative but to discharge their wastes into surface waters. Furthermore, with pressure mounting at both the local and state levels to prevent further pollution of the Aberjona River from sources in north Woburn, leather industry firms recognized that the extension of the MDC sewer was inevitable, and they were therefore reluctant to invest in expensive waste treatment technology.

Although there was almost universal support for the development of the Woburn extension sewer, conflicts over the allocation of costs significantly delayed its construction. Between 1921 and 1923, several bills were introduced in the state legislature to provide for the construction of the sewer as part of the MDC system, but in each case the bills were defeated because other communities felt the cost of the sewer extension should be borne by the city of Woburn and not the state. After considerable debate, a compromise was reached in which the legislature agreed to share the costs of constructing the sewer extension.[48] Work on the sewer line finally began in 1927, but due to problems caused by excessive groundwater infiltration, the sewer was not put into operation until 1932.[6]

Land Disposal of Waste Sludge

The disposal of waste sludges presented an additional problem for tanneries and rendering factories in the watershed. Tanning and rendering wastewater contains high concentrations of solids — mainly hide and leather residues such as fleshings, hair, trimmings, shavings, buffing dust, *etc.* — that readily settle and create dense sludges. Because these sludges frequently caused sewer lines to become clogged and to eventually overflow, tanneries and rendering factories in the watershed were required to pretreat their wastewater in settling lagoons before discharging it to the sewer. Sludges were then removed from the lagoons and placed in either on-site dumps or in public landfills.

Several problems caused by these sludge dumps were reported by the Department of Public Health and other investigators. For example, in 1915, the Department of Health observed in its annual report that:

> In the course of many years large quantities of organic matter, chiefly from tanneries, have been deposited upon the ground at many places in this valley, and the natural effect of the rainfall is to carry matters from these deposits, partly in solution and partly in suspension, into the streams.[31]

In 1920, a Red Cross investigator reporting on health and sanitary conditions in Woburn noted:

> Because of the fact that chrome-tanning sludge is not allowed to flow into the Metropolitan Sewerage system, this material is kept in catch basins for two months and then piled upon a dump which is near Russell Brook. From this material a very irritating, obnoxious odor goes forth.[43]

Also, between 1921 and 1922, while conducting a survey of the watershed to assess the condition of fish populations in the Aberjona River and its tributaries, State Department of Fisheries and Wildlife biologists identified three tanning sludge dumps that were draining into either Russell Brook or its tributaries.[20] Similarly, in 1970 a Department of Public Health investigator found that leachate emanating from rendering residue dumps on the Stauffer Chemical Company property was draining into Halls Brook.[44]

Even though tanneries and rendering companies in the watershed were required to perform primary treatment to remove settleable materials prior to discharging wastewater into sewer lines, solids were invariably introduced into the sewerage. As a result, the deposition and accumulation of solids in the sewers contributed to several incidents of sewer line overflow. Between 1927 and 1929, for example, the MDC sewer in Winchester regularly overflowed, causing raw sewage and industrial wastes to drain directly into the Aberjona River.[33-35] Also, for several years after it went on line, the Woburn extension sewer repeatedly overflowed, and, as a result, tanning and rendering wastes from companies in north Woburn spilled into the river.[41,54-56] In order to reduce the frequency of sewage overflows, the Department of Public Health tried to institute a program of periodic sewer cleaning.[41,56] The program successfully decreased the incidence of overflowing; however, in its report on sanitary conditions in the Aberjona River and the Mystic Lakes in 1957, the Department of Public Health noted that material removed from sewer lines during cleaning was often left in piles near the manholes from which it was removed and, therefore, was a potential source of surface water pollution.[6]

Leather Industry Waste Sites

There are currently six sites in the watershed that are being investigated for the presence of leather industry waste contamination. The Massachusetts DEP is investigating two former rendering factory sites and three former tannery sites under the Oil and Hazardous Materials Release Prevention and Response Act of 1983 (*i.e.*, MGL c.21(E)). The federal EPA is directing the investigation and remediation of the "Industriplex" site — where a large rendering factory once operated — under CERCLA (*i.e.*, Superfund).

60 South Bedford Street. Tanning and rendering wastes were first discovered at 60 South Bedford Street (Site 14 on Figure 2) in October 1984. Water from a brick vault uncovered during the installation of a swimming pool in a residential area was found to contain low concentrations of metals and volatile organic compounds. A second vault was later found that contained "a red sludge with animal hairs." Sludge samples were analyzed and found to be contaminated with high concentrations of chromium and lead. A title search revealed that from the mid-1830s until the turn of the century a tannery operated on the site, and that between the 1900s and 1977, the site was used by a hide and leather degreasing company.

Following the discovery of the vaults, emergency measures were taken to reduce risks posed by the contaminants present on the site. A trench was excavated from which contaminated groundwater was pumped, the sludge materials and vaults were removed, and wells were installed to monitor the migration of pollutants in the groundwater. A Phase II "Comprehensive Site Investigation" has been planned to determine whether additional waste materials are present on the site and whether contaminant migration in groundwater could impact local drinking water supplies.[45] The site was placed on the state DEP's list of "confirmed" hazardous materials sites in January 1987.[57]

5 Green Street. An assessment of the 5 Green Street Site (Site 45 on Figure 2) was performed in October 1984 to determine whether petroleum products or other hazardous materials were present on the property. Six test pits were excavated and soil samples from one of the test pits were found to contain elevated concentrations of chromium. Site investigators attributed the chromium to tanneries that had operated on the site from before 1875 until 1938. Although other metals including beryllium, thallium and barium were also detected in soil samples, investigators concluded that the contamination does not pose a threat of off-site migration, and it was recommended that no further action be taken on the site.[18] The DEP placed the site on its "Remedial Sites List" in January 1987.[57]

8 Green Street. The results of an investigation of the 8 Green Street site (Site 44 on Figure 2), performed in December 1986, indicate that groundwater beneath the property is contaminated with petroleum products and metals. Both oil and grease were detected, as well as low concentrations of arsenic, cadmium, mercury and lead. Historical records indicate that tanneries operated on the site from around 1875 until 1934. A number of filled pits were also discovered on the property. Investigators speculated that "the pits contain materials associated with the tanning business such as leather scraps, wood, animal remains, minor amounts of grease and solvents, *etc.*"[17] As a result of the investigation, the DEP was notified, and in October 1988 the site was placed on the DEP's list of "Locations to Be Investigated."[57]

J.O. Whitten Company Site. An evaluation of the former J.O. Whitten Company property in Winchester (Site 61 on Figure 2) was performed in December 1984. A total of 33 test pits were excavated, eight monitoring wells were installed and numerous soil, soil gas, sludge and groundwater samples were collected. In addition, surface water and sediment samples were taken from the Aberjona River that abuts the eastern edge of the property. It was found that the soils and sediment samples were contaminated with arsenic, chromium and mercury, the groundwater and surface water samples contained arsenic, barium, cyanide, toluene and benzene, and the soil gas samples had concentrations of mercury vapor. Historical records indicate that a tannery operated on the site from 1872 until around the turn of the century. The property was then purchased by the J.O. Whitten Company which operated a gelatin, and later a glue, manufactory there until 1980.[22] The DEP placed the site on its list of confirmed sites in January 1987. In January 1989, the site was given "Phase III" status, indicating that the development of the remedial response plan was underway.[57]

J.J. Riley Company Site. The J.J. Riley Company tannery (Site 22 on Figure 2) was first investigated by the EPA in 1980 to determine whether waste disposal practices at the site had resulted in violations of Resource Conservation and Recovery Act or Clean Water Act standards. During a site inspection, EPA investigators were told by company officials that two lagoons had been used until 1970 for the separation of settleable solids from chrome-tanning wastewater prior to discharging the wastewater to the MDC sewer. Although the lagoons were no longer in use, the investigators noted that materials leaching from the lagoons could pose a threat to groundwater. The investigators were also told that waste sludge from an existing sedimentation tank was routinely piled on the ground near the lagoons.[58] In 1983, officials from the DEP inspected the tannery. In their report, the state inspectors wrote:

With reference to non-hazardous sludges,

> John J. Riley Co. appears to be in violation of M.G.L. c.24 section 43 which prohibits the discharge of pollutants to the waters of the Commonwealth without a valid permit.... The Company also appears to be in violation of Chapter III, section 150A, of the Solid Waste Disposal Act.[59]

As a result of the EPA and the DEP investigations, the site was placed on the state's "Locations to Be Investigated" list in January 1987.[57]

Industriplex Site. The "Industriplex" site (Site 2 on Figure 2) is one of the oldest industrial sites in the watershed. It was first developed in 1853 by the Chemical Works Company, which made acids and other chemicals for textiles, paper and leather producers. In 1863, the Chemical Works Company was acquired by Merrimac Chemical, which used the site to manufacture arsenic- and lead-based insecticides and explosives such as trinitrotoluene (TNT). By the turn of the century, Merrimac Chemical had developed over 400 acres of the site and it soon became one of the largest chemical producers in New England. Between 1927 and 1936, ownership of the chemical works changed three more times as the Monsanto Company (from 1927 to 1934), the New England Chemical Company (from 1934 to 1936) and Consolidated Chemical Industries rebuilt the facility into a rendering factory. The companies used hides and leather scraps from tanneries in the watershed as raw materials to make glue and grease. Consolidated Chemical used the site until 1960, when it was purchased by Stauffer Chemical Company. Stauffer maintained the glue manufactory until it went out of business in 1968.

Shortly after Stauffer abandoned the glue works, the property was acquired by the Mark Phillip Realty Trust. The trust wanted to develop the entire 400-acre site into an industrial park. As development proceeded in the northern end of the site, workers began to uncover piles of waste materials that the chemical companies had buried. In June 1979, the Army Corps of Engineers took action against the realty trust when it was discovered that dredging spoils and fill material were being dumped into the Aberjona River and adjacent wetlands. Acting under the authority of section 404 of the Federal Water Pollution Control Act, the Corps served a cease and desist order to the developer, thereby temporarily barring work on the site. In its preliminary assessment of wetlands violations by the developer, the Corps noted that there were increased levels of heavy metals, biochemical oxygen demand (BOD), bacteria and sedimentation in the Aberjona River. Suspecting that additional waste materials were also present on the site, state DEP and federal EPA officials conducted their own investigations. These investigations revealed sludge lagoons contaminated with high levels of chromium, an earthen pit filled with lead- and arsenic-laden soil, twenty acres of rendering residue piles that were generating large quantities of hydrogen sulfide and methane gas, and plumes of benzene and toluene in the groundwater. As a result of these discoveries, the EPA obtained a court order to prevent further development on the property. In October 1981, the site was named to the EPA "Superfund Interim Priorities List" of sites eligible for federal clean-up funding. In December 1982, the site was added to the final EPA "National Priorities List."[60]

Mass Balance Analysis of Leather Industry Wastes

Taking into account the chemical characteristics of the wastes produced by tanning, leather-finishing and rendering operations, as well as historical manufacturing records, mass balance techniques can be used to estimate the amounts of waste chemicals produced by tanning operations. Because much of the tanning industry in the watershed specialized in making chrome-tanned upper leather for shoes, special focus is given to chrome tanning of cattlehide.

Cattlehide Tanning & Leather Finishing

Tanning is the chemical process by which hides and skins are converted into non-putrescible leather. Tanning is accomplished by first removing the epidermal layer and subcutaneous flesh layer of the hide, followed by chemically stabilizing the remaining middle layer that is composed mainly of the protein collagen. Leather finishing involves any of several chemical processes such as bleaching, fat-liquoring and coloring, or mechanical operations such as

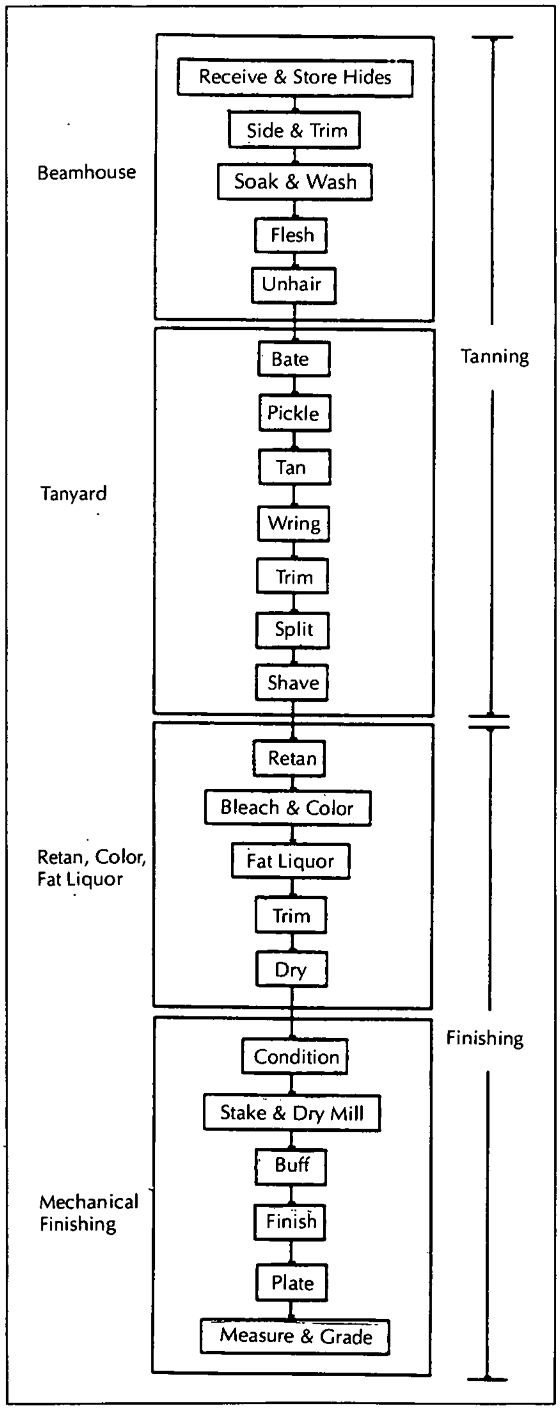

FIGURE 3. Process flow diagram for a "complete" chrome tannery.

drying, staking and buffing. Finishing is performed to alter the surface characteristics of leather, such as thickness, texture, feel, *etc.*, for making specific leather goods. While there are basic steps to produce finished, chrome-tanned leather from raw cattlehide, there was perhaps wide variation in tanning practices among the many tanneries in the watershed. In the absence of a complete record of each company's methods, the general practices of the industry as a whole are reviewed.

When hides are removed from freshly slaughtered cattle, they are typically salt-cured to prevent bacterial decay. As a result, upon arriving at a tannery, cattlehides are often dehydrated and contain large amounts of undissolved salt, dirt, blood, manure and non-fibrous protein. In order to prepare the hides for tanning, new hides are first processed in what is called a "beamhouse" where they are rehydrated and cleaned (see Figure 3). After being "sided," or cut in half along the backbone, new hides are soaked to restore lost moisture and then washed to remove extraneous matter. The flesh layer is then cut away to allow easier penetration and more effective action of the tanning agents. Finally, the hair and epidermis are removed from the hide. Unhairing is frequently done by soaking hides in a series of successively stronger lime baths. Lime causes collagen fibers to separate, thereby allowing the dissolution of non-fibrous proteins. Lime-softened hides are then immersed in solutions of sodium sulfide, the strength of which can be controlled either to loosen hair for subsequent hair recovery or to pulp hair if hair recovery is not desired.

Once hides have been prepared in the beamhouse, they are transferred to the "tanyard" where tanning is performed. In the first tanyard process, called "bating," the surface properties of the lime-soaked hides are adjusted to facilitate tanning. Hides are soaked in solutions of buffering salts, such as ammonium sulfate or ammonium chloride, and proteolytic enzymes, such as trypsin and chymotrypsin. Bating reduces the pH and swelling of the hide, peptizes protein fibers and removes protein degradation products. It also softens the hide texture by removing unhairing chemicals and non-fibrous proteins. After bating, hides are typically immersed in pickling solutions of salts and acids to reduce the pH of the hides so that chrome-tanning salts do not precipitate on the protein fibers during tanning.

Once bating and pickling have been completed, the hide is ready for tanning. Tanning is accomplished by milling the hides in baths containing chrome liquor (*i.e.*, high concentrations of chromium salts dissolved in water). Trivalent chromium in the liquor binds with the carboxyl groups (–COOH) on different peptide chains, thus increasing the chemical stability of collagen molecules. In chrome tanning, the most widely used process is the "one-bath" method, in which basic chromium sulfate is the tanning agent. Following tanning, hides are split into two distinct layers: the upper layer or grain layer, and the lower layer or split. The grain layer is more valuable than the split and, thus, many tanneries process only the grain layer, selling the splits to split-finishers or rendering factories. In the final tanyard step, the grain layer is shaved on a shaving machine to uniform thickness.

After tanning, most cattlehide leather requires considerable finishing work before it can be made into leather goods. Typical finishing processes include vegetable retanning, bleaching, coloring and fat-liquoring. Vegetable retanning, in which chrome-tanned leather is given short baths in weak solutions of vegetable tannins, results in leather that is in general fuller, plumper, more easily tooled and more water resistant than non-retanned leather. In bleaching and coloring processes, pigments and synthetic dyes — many of which contain cadmium, chromium, iron, lead, titanium and zinc[61] — are used to give leather its desired appearance. Fat-liquoring is a procedure in which oils, greases and waxes are applied to leather to keep it soft and pliable, and to increase the strength and tear resistance of the leather fibers.

A number of mechanical operations are also performed during leather finishing. The most common are trimming, drying, staking, dry milling and buffing. Trimming removes the rough edges and improves the appearance of the leather and makes the sides easier to handle for subsequent finishing steps. Trimming is often repeated several times during leather finishing; as a result, trimming scraps can become a sizeable fraction of the solid waste stream. Because unfinished leather typically contains a significant amount of water, sides are dryed until the desired residual moisture content is achieved. In drying processes, sides are either stretched on metal frames, pasted on large plates or hung on racks and then placed in low-temperature ovens, heated rooms or outdoors in direct sunlight. Buffing, or light sanding, of the grain side is typically performed to improve the final appearance of the leather.

Characterization of Chrome-Tanning & Finishing Wastes

The chemical properties of chrome-tanning and leather-finishing wastes have been well characterized. In studies by the New England Interstate Water Pollution Control Commission[62] and the EPA,[63,64] which were conducted in order to assist the leather industry and pollution abatement agencies in their efforts to reduce waste pollution, tanning and finishing wastes were chemically analyzed. The results of these analyses indicate that tanning and finishing wastes are composed of complex mixtures of dissolved chemicals as well as settleable and nonsettleable solids. Wastewater samples were found to contain dirt, blood, manure, bactericides, salt, fleshings, grease, lime, acids, enzymes, hair, unfixed tanning agents, dyes, pigments, oils and buffing dust. Waste solids were shown to be composed mainly of protein and fat from fleshings, trimmings, shavings and buffing dust, in addition to undissolved tanning and finishing chemicals. A list of tanning and finishing chemicals used in a typical complete chrome tannery is presented in Figure 4. The figure also shows the amounts of waste solids produced in each tanning and finishing component process.

Efforts have been made to identify the hazardous chemicals in tanning and finishing wastes that pose the greatest risks to human health and the environment. In assessing the chemical composition of tanning and finishing wastes, EPA-contracted investigators classified wastes as "potentially hazardous" if hazardous constituents were present at levels exceeding a selected threshold. Potentially hazardous waste was defined as:

> [W]aste or combinations of waste which pose a substantial present or potential haz-

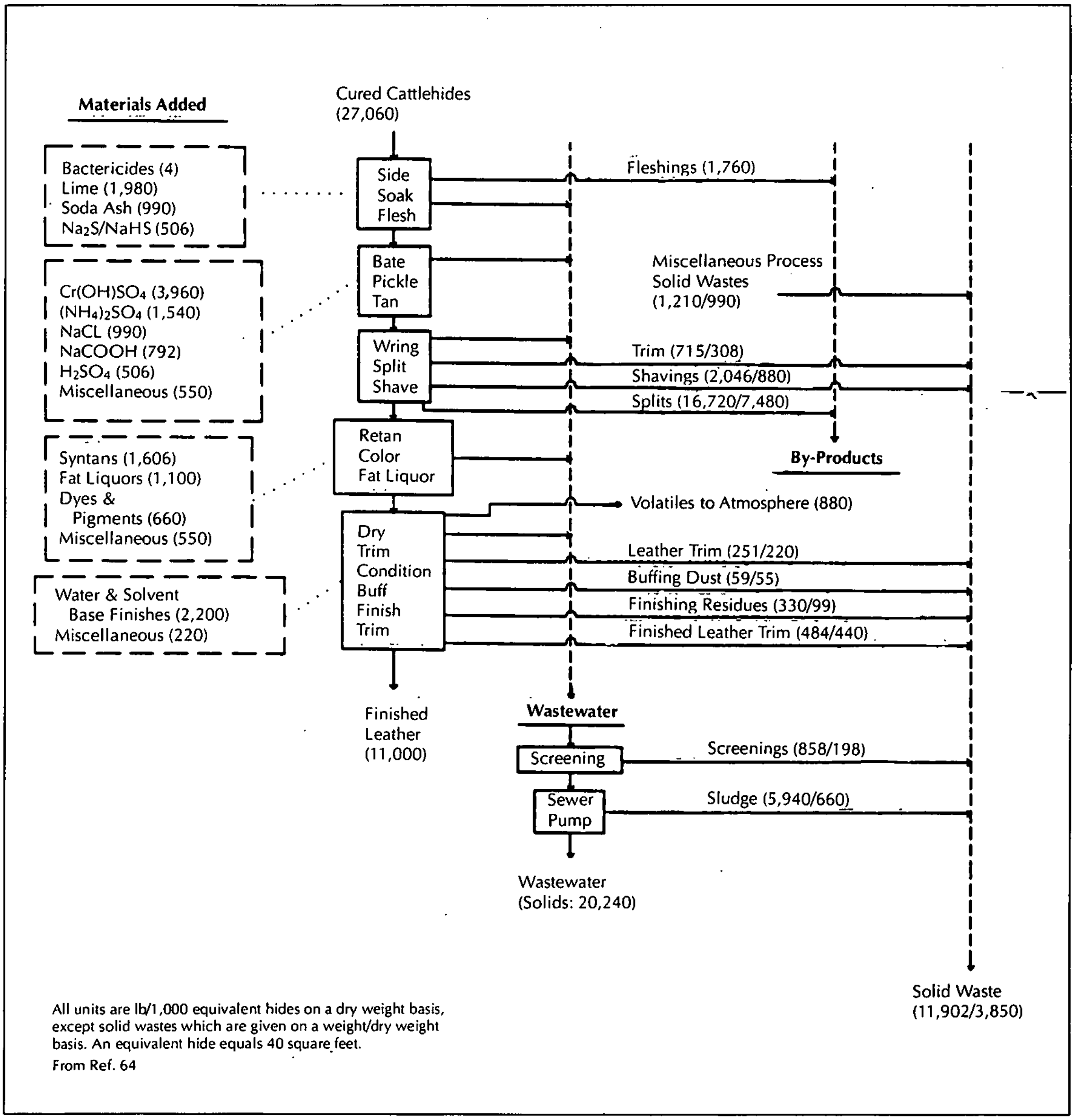

FIGURE 4. Materials used and wastes generated by a "complete" chrome tannery.

ard to human health or living organisms because such waste is lethal, non-degradable, or persistent in nature; may be biologically magnified; or otherwise cause or tend to cause detrimental cumulative effects.[64]

Waste constituents were considered hazardous if they were radioactive, infectious, explosive, flammable, irritants or strong sensitizers, corrosive or toxic. The hazardous concentration threshold for various constituent chemicals was selected as the mean of background concentrations in soils in the United States.

In their study, the investigators analyzed waste samples collected at different points in the solid waste streams of 28 tanneries in the United States. It was found that chromium (trivalent), copper, lead and zinc were present in several waste samples at levels that exceeded their hazard thresholds. Citing the well-established toxic properties of chromium, copper, lead and zinc, the investigators concluded that

TABLE 2
Concentrations of Metals in Complete* Chrome Tannery Wastes

Metal***	Concentration Range (lb/1,000lb)§	Weighted Mean Concentration (lb/1,000lb)	Concentration Range (mg/l)	Weighted Mean Concentration (mg/l)
Wastewater**				
Chromium§§	3.3-5.8	4.0	40-120	76
Copper	1.2×10^{-1}	1.2×10^{-1}	2.3	2.3
Lead	7.7×10^{-2}-1.4×10^{-1}	1.3×10^{-1}	1.5-1.7	2.5
Zinc	4.2×10^{-2}-6.7×10^{-2}	6.2×10^{-2}	0.8-1.3	1.2
Waste Solids§§§			(mg/kg)	(mg/kg)
Chromium	1.2×10^{-1}-3.2	8.9×10^{-1}	7.5×10^{2}-2.0×10^{4}	5.4×10^{3}
Copper	4.6×10^{-5}-7.7×10^{-1}	3.5×10^{-2}	4.8×10^{-1}-7.9×10^{3}	3.6×10^{2}
Lead	8.6×10^{-4}-4.0×10^{-1}	5.6×10^{-2}	7.1-3.3×10^{3}	4.6×10^{2}
Zinc	8.6×10^{-4}-2.2×10^{-2}	1.7×10^{-2}	7.3-1.9×10^{2}	1.5×10^{2}

* In a "complete" tannery, both tanning and finishing are done.
** Includes concentration in settleable suspended solids. In converting units it is assumed that 6,300 gallons of water are used per 1,000 pounds of hide tanned. (From Reference 63.)
*** Chromium is used primarily in tanning agents; copper is used in bactericides; lead and zinc are used in dyes and pigments.
§ Units are expressed as pounds of constituent in waste per 1,000 pounds of hide tanned.
§§ Values for chromium in wastewater are from References 62 and 65.
§§§ Values from Reference 64. Based on 1.625 lb/ft^2 average hide density.

the solid wastes that contained these metals were potentially hazardous. Other hazardous constituents including arsenic, beryllium, cadmium, mercury, selenium, zirconium, phenols and pesticides were also found in the waste samples, but at concentrations that were below the selected thresholds.[63]

Concentrations of chromium, copper, lead and zinc in wastewater and waste solids samples from "complete" chrome tanneries where both tanning and finishing were performed are presented in Table 2. In general, the average levels of chromium are an order of magnitude greater than the levels of the other metals. Although concentrations of these metals have been shown to be fairly steady in equalized discharges, unequalized effluent can have a widely varying composition. Bailey, for example, found that the chemical properties of tannery effluent fluctuated considerably as a function of discharge rate.[66] Samples that were collected over a 24-hour period from a catch basin in which effluent was held prior to discharge to the sewer showed the following variations:

- Suspended solids: 0 to 8,500 mg/l
- BOD: 100 to 10,000 mg/l
- Sulfide: 0 to 500 mg/l
- pH: 3.0 to 11.0

Samples of equalized effluent, however, showed considerably less variation:

- Suspended solids: 100 to 500 mg/l
- BOD: 600 to 900 mg/l
- Sulfide: 0 to 24 mg/l
- pH: 7.5 to 8.5

The concentrations shown in Table 2 are for equalized discharges of wastewater and waste solids.

In addition to the rate of discharge, chemical interactions in raw tannery wastes can have a large effect on concentrations of dissolved constituents. Chelation by organic matter and dissolution due to the presence of carbonates can cause concentrations of metals — especially chromium — to deviate significantly from predicted levels. In order to compensate for the effect of such interactions, the amounts of metals generated in tannery wastes are normalized by the weight of hide tanned. Normalized concentrations are used in the mass balance analysis to predict the total amounts of metals generated in tanning and finishing wastes.

Hide & Leather Rendering

Rendering is the process by which grease and glue are extracted from animal hides, bones and leather. Rendering is typically performed by cooking raw materials in vats of water in order to liquefy fats and collagen. Grease is recovered by skimming off the fat layer that forms on the water surface. Glue is made by concentrating the dissolved collagen in the glue-stock.

When chrome-tanned leather (*i.e.*, scraps, trim and splits) is used in rendering, it is typically treated with acids so that rendering products are free of chromium. Leather is first placed in lime baths to allow fibers to swell, thereby increasing the surface area over which the detanning agents can act. The limed leather is then washed in solutions of sulfuric acid, which cause the chromium to dissolve from the leather. Because leather contains chromium in concentrations of 1 to 2 grams / ft^2, considerable amounts of dissolved chromium may be present in rendering effluent.

Although it is generally known when and where rendering activities took place in the watershed, detailed records documenting rendering operations could not be located for the majority of rendering companies. The only information that was found was from the Stauffer Chemical Company, which operated a rendering factory at the "Industriplex" site from 1960 to 1968. Records from the late 1960s indicate that chrome-tanned leather accounted for approximately 25 percent (or around 29 tons annually) of the raw materials used by the company, and that nearly 50,000 to 60,000 pounds of rendering wastes (25 percent solids) were generated per day.[8] Information concerning the operations of other rendering companies in the watershed could not be obtained because the companies had either gone out of business or never kept such records. Because there was not enough production or raw materials consumption data to accurately characterize the rendering industry in the watershed, chromium from rendering wastes was not included in the mass balance analysis.

Mass Balance of Metals in Tanning & Leather-Finishing Wastes

Mass balance (or chemical accounting) techniques were used to estimate the amounts of four metals — chromium, copper, lead and zinc — produced in tanning and leather-finishing wastes in the watershed between 1900 and 1936. The 36-year period was selected for three reasons:

- During this period chrome tanning was the dominant tanning method practiced in the watershed;
- It was the period during which the leather industry was most productive; and,
- During this period most tanning and leather-finishing wastes were discharged into surface water bodies and dumps (after 1936, the majority of tanning and leather-finishing companies in the watershed were connected to the sewers, and sewer overflowing was no longer persistently occurring).

Two mass balance methods were used in the analysis. The first method, called the "Value Method," is based on the gross value of finished leather produced by the leather industry. The second method, the "Labor Method," is based on the amount of hide tanned and finished per manhour worked. Data used in the two mass balance methods was obtained from Census of Manufacturers records for the city of Woburn and from national statistics. Manufacturers' records for Winchester and Stoneham were not available for the period of interest.

The two mass balance methods were used to generate independent estimates of the annual amounts of leather produced in Woburn.

In the Value Method, shown in Table 3, the total annual value of products, in dollars, made by tanners and leather finishers in Woburn was compared to the national average unit price of leather ($\$/ft^2$). In the Labor Method, shown in Table 4, the average number of wage earners employed in tanneries and leather-finishing companies in Woburn was compared with national statistics for average number of hours worked per week and production per manhour (ft^2/hr). The amounts of leather, in square feet, predicted by the two methods are shown in column 4 of Table 3 and column 5 of Table 4. In applying both methods, it was assumed that 85 percent of the leather produced was chrome-tanned. The total amounts of chrome-tanned leather estimated by the Value Method and the Labor Method for the 36-year period are 550 million and 1,630 million ft^2, respectively.

In order to predict the amount of metals produced in tanning and leather-finishing wastes, effluent concentrations from Table 2 were used. The amount of chrome-tanned leather (ft^2) produced annually was first multiplied by the average density of an equivalent hide, 1.625 lb/ft^2,[69] to determine the total weight of hide tanned (lb). The weighted mean concentrations of chromium, copper, lead and zinc in wastewater and waste solids (lb/1,000 lb) were then multiplied by the weight of hide tanned to estimate the total amounts of metals (tons) generated in tanning and leather-finishing effluent.

The amount of chromium in tannery wastewater and waste solids estimated by the two mass balance methods is presented in columns 5 and 6 of Table 3 and columns 6 and 7 of Table 4. The two mass balance methods indicate that, between 1900 and 1936, on the order of 2,000 to 4,000 tons of chromium were generated in tannery wastewater, and on the order of 400 to 800 tons of chromium were generated in tannery waste solids. It is further estimated that during this period, tanning and leather-finishing companies produced on the order of 50 to 110 tons of copper, 60 to 120 tons of lead and 30 to 60 tons of zinc in wastewater, and on the order of 15 to 32 tons of copper, 26 to 52 tons of lead and 8 to 16 tons of zinc in waste solids. The results of these estimates are plotted in Figures 5 to 7. The total amounts of the four metals in both wastewater and waste solids predicted by the two mass balance methods are depicted in Figure 8.

Three assumptions were used in applying the mass balance methods. First, it was assumed that the chemical characteristics of chrome-tanning and leather-finishing wastes have not changed significantly since the introduction of chrome-tanning methods. Thus, chemical analyses of tanning and leather-finishing wastes performed in the 1950s and 1970s can be used to characterize wastes generated between 1900 and 1936. This assumption is reasonable for chromium, which is still the most widely used tanning agent; however, because the history of copper, lead and zinc use in tanning and leather finishing is not well documented, it is uncertain whether this assumption leads the mass balance models to overestimate or underestimate the amounts of these metals produced in leather industry wastes. Second, it was assumed that 85 percent of the leather produced in Woburn between 1900 and 1936 was chrome-tanned. This estimate is based on research conducted recently that indicates between 80 and 85 percent of leather produced in the United States is chrome-tanned.[63,68] And third, in using the Value Method, it was assumed that the Census of Manufacturers' value of product data (column 2 in Table 3) represent the value of finished leather. This assumption would result in an overestimation, using the Value Method, of the amount of leather produced if tanners and leather finishers reported profit on the same leather (*i.e.*, if tanners sold unfinished leather to finishers and both reported income on that leather).

Discussion

In the absence of complete historical records documenting the amount of leather produced and describing the chemical characteristics of wastes generated by the leather industry in the watershed between 1900 and 1936, it is difficult to assess the accuracy of the waste metals estimates predicted in the mass balance analysis. Considering the limitations in the data available for the analysis and the uncertainty inherent in the assumptions used, it is possible that the mass balance estimates could be off by as much as a factor of two. Nonetheless, if the results are skewed, then it can be argued that the bias is in favor of underestimation rather than overestimation. Leather industry statistics could not be found in Census of Manufacturers data for Winchester and Stoneham, and, therefore, tanning and leather-finishing wastes generated in these two towns were not included in the analysis (rough estimates suggest that Win-

TABLE 3
Amount of Chromium in Tannery Wastes as a Function of the Total Gross Value of Finished Leather Produced

Year	Total* Value ($1,000)	Cost Per** Square Foot ($/ft²)	Square feet*** Chrome-Tanned Leather (1,000)	Chromium§ in Waste-Water (tons)	Chromium§ in Waste Solids (tons)
1900	3,352	0.299	9,529	31	7
1901	3,252	0.299	9,245	30	7
1902	3,152	0.299	8,961	29	6
1903	3,052	0.299	8,676	28	6
1904	2,952	0.299	8,392	27	6
1905	2,852	0.299	8,108	26	6
1906	2,932	0.299	8,335	27	6
1907	3,012	0.299	8,563	28	6
1908	3,092	0.299	8,790	29	6
1909	3,172	0.299	9,017	29	7
1910	3,252	0.299	9,245	30	7
1911	3,332	0.299	9,472	31	7
1912	3,412	0.299	9,700	32	7
1913	3,567	0.256	11,844	38	9
1914	3,451	0.268	10,945	36	8
1915	6,169	0.278	18,862	61	14
1916	7,397	0.325	19,346	63	14
1917	7,244	0.439	14,026	46	10
1918	7,232	0.412	14,920	48	11
1919	8,465	0.640	11,243	37	8
1920	4,818	0.617	6,637	22	5
1921	2,909	0.312	7,925	26	6
1922	6,409	0.258	21,115	69	15
1923	8,376	0.260	27,383	89	20
1924	8,999	0.264	28,974	94	21
1925	8,561	0.274	26,558	86	19
1926	9,363	0.253	31,457	102	23
1927	10,021	0.320	26,618	87	19
1928	10,019	0.369	23,079	75	17
1929	7,134	0.288	21,055	68	15
1930	5,277	0.238	18,846	61	14
1931	4,341	0.204	18,088	59	13
1932	3,214	0.162	16,864	55	12
1933	3,743	0.194	16,400	53	12
1934	3,631	0.188	16,417	53	12
1935	3,136	0.188	14,179	46	10
1936	3,322	0.196	14,407	47	10
		Totals:	553,219	1,798	400

* Reference 50 (1900-1904, 1906-1913 values interpolated from 1895, 1905 data).
** Reference 67 (values for 1900-1912 are average of 1913-1936 data).
*** It is assumed that 85 percent of the leather produced is chrome-tanned.[63,68]
§ An "equivalent" raw cattle hide is 40 square feet in area. It is assumed that the average weight of an equivalent hide is 65 pounds.[69] The average amount of chromium in wastewater of a complete chrome tannery is 4 lbs/1,000 lbs of raw cattle hide.[62,65]
§§ The average amount of chromium in sludge generated by a complete chrome tannery is 0.891 lbs/1,000 lbs of raw cattle hide tanned.[64]

chester and Stoneham may have produced as much as one-tenth the amount of wastes generated by the leather industry in Woburn). Also, because there was not enough information to adequately characterize the rendering industry in Woburn, it too was excluded from the analysis. In light of recent investigations at former rendering sites in Woburn, the exclusion of ren-

TABLE 4
Amount of Chromium in Tannery Wastes as a Function of the Amount of Finished Leather Produced Per Manhour

Year	Average* Number Wage Earners	Average** Number Hours Per Week	Product*** Per Manhour (ft^2/hr)	Square Feet§ Chrome-Tanned Leather (1,000)	Chromium§§ in Waste-Water (tons)	Chromium§§§ in Waste Solids (tons)
1900	915	39.50	25.56	40,832	133	30
1901	901	39.50	25.56	40,207	131	29
1902	887	39.50	25.56	39,583	129	29
1903	873	39.50	25.56	38,958	127	28
1904	859	39.50	25.56	38,333	125	28
1905	845	39.50	25.56	37,708	123	27
1906	843	39.50	25.56	37,619	122	27
1907	842	39.50	25.56	37,574	122	27
1908	840	39.50	25.56	37,485	122	27
1909	839	39.50	25.56	37,441	122	27
1910	837	39.50	25.56	37,351	121	27
1911	835	39.50	25.56	37,262	121	27
1912	833	39.50	25.56	37,173	121	27
1913	832	39.50	25.56	37,128	121	27
1914	919	39.50	25.56	41,011	133	30
1915	1,274	39.50	25.56	56,853	185	41
1916	1,264	39.50	25.56	56,406	183	41
1917	1,100	39.50	25.56	49,088	160	36
1918	1,040	39.50	25.56	46,410	151	34
1919	1,140	39.50	25.56	50,873	165	37
1920	865	39.50	25.56	38,601	125	28
1921	593	39.50	25.56	26,463	86	19
1922	1,200	39.50	25.56	53,550	174	39
1923	1,568	39.50	25.56	69,972	227	51
1924	1,453	42.54	23.90	65,296	212	47
1925	1,223	43.07	25.81	60,091	195	44
1926	1,259	43.18	24.30	58,390	190	42
1927	1,379	41.19	24.63	61,836	201	45
1928	1,299	41.71	23.53	56,350	183	41
1929	1,105	44.18	23.69	51,118	166	37
1930	911	40.89	24.69	40,652	132	29
1931	795	42.74	26.98	40,520	132	29
1932	759	42.74	24.68	35,387	115	26
1933	842	41.29	27.02	41,521	135	30
1934	916	37.75	27.84	42,550	138	31
1935	814	34.08	28.94	35,485	115	26
1936	762	17.99	26.26	15,911	52	12
			Totals:	1,628,987	3,677	819

* Reference 50 (1900-1904, 1906-1913 values interpolated from 1895, 1905 data).
** Reference 67 (values for 1900-1912 are average of 1913-1936 data).
*** *Ibid.*
§ It is assumed that 85 percent of the leather produced is chrome-tanned.[63,68]
§§ An "equivalent" raw cattle hide is 40 square feet in area. It is assumed that the average weight of an equivalent hide is 65 pounds.[69] The average amount of chromium in wastewater of a complete chrome tannery is 4 lbs/1,000 lbs of raw cattle hide.[62,65]
§§§ The average amount of chromium in sludge generated by a complete chrome tannery is 0.891 lbs/1,000 lbs of raw cattle hide tanned.[64]

dering wastes from the analysis would result in the omission of significant amounts of chromium. At the "Industriplex" site, for example, glue manufacturing wastes are distributed over a 35-acre area, of which approximately half contains chromium at concentrations exceeding 1,000 mg/kg, or 0.1 percent by weight.[60] Using conservative estimates of the

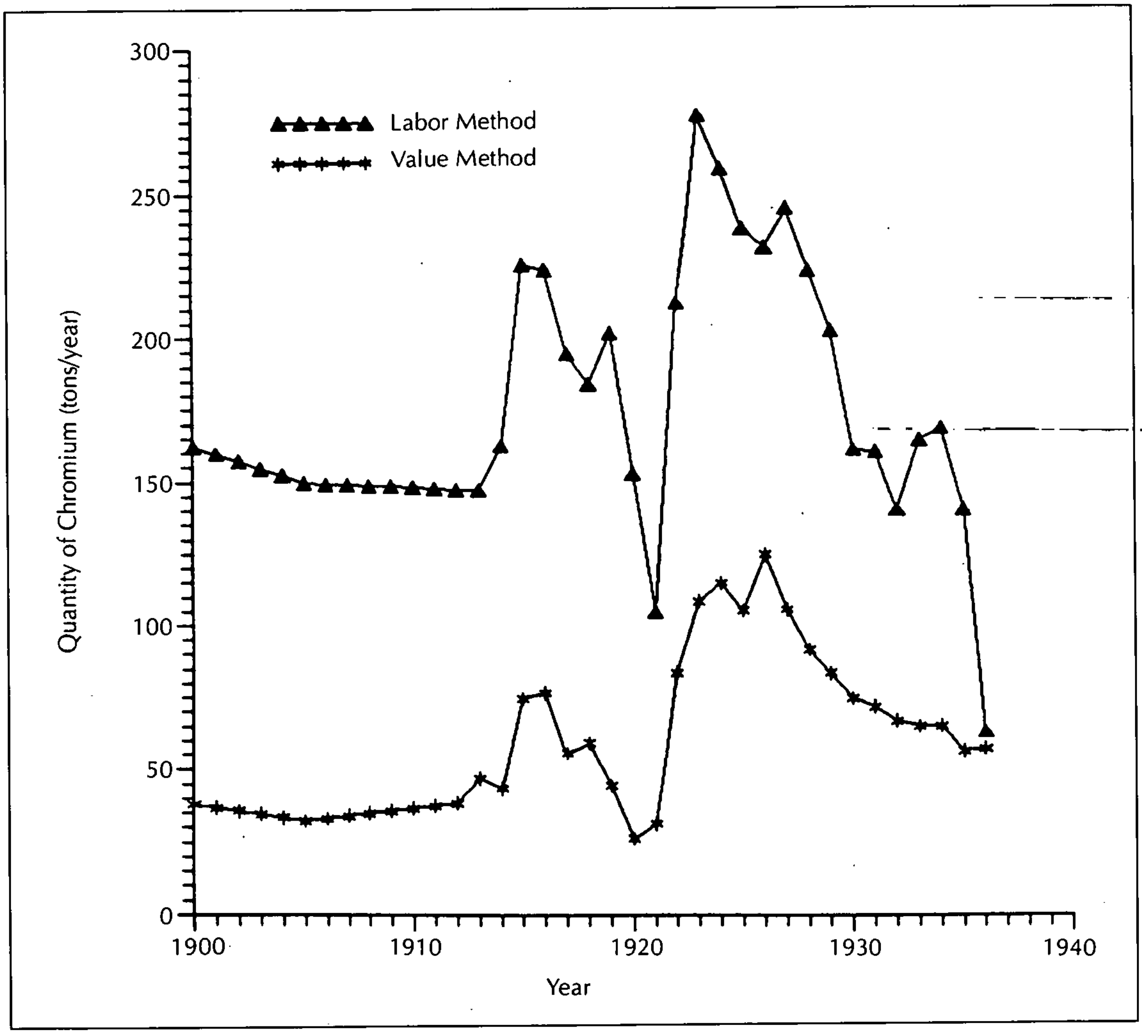

FIGURE 5. Comparison of the total quantity of chromium in tannery wastes as predicted by two mass balance methods.

depth (20 feet) and density (2 g/ml) of the rendering wastes, it is estimated that on the order of 1,000 tons of chromium are present on the site. It follows, therefore, that if wastes from the other rendering companies that operated in the watershed were also included in the analysis, the amount of chromium predicted would be considerably larger.

An important question raised by the results of the analysis is: What has happened to the waste metals generated by the leather industry? It is likely that large amounts of metals discharged in leather industry wastewater are no longer present in the watershed. Wastewater discharged to sewer lines was carried out of the watershed and then either treated at Deer Island or dumped directly into Boston Harbor. Wastewater discharged to the Aberjona River and its tributaries ultimately flowed into the Mystic Lakes. Because leather industry wastewater contains large amounts of solid materials, it is likely that the binding of waste metals to settling solids was a significant transport process. In support of this hypothesis, there is mounting evidence that large quantities of waste metals were deposited in quiescent zones along the course of the Aberjona River and its tributaries, and in the Mystic Lakes.[70,71] Rough estimates suggest that as much as ten percent of the chromium predicted in leather

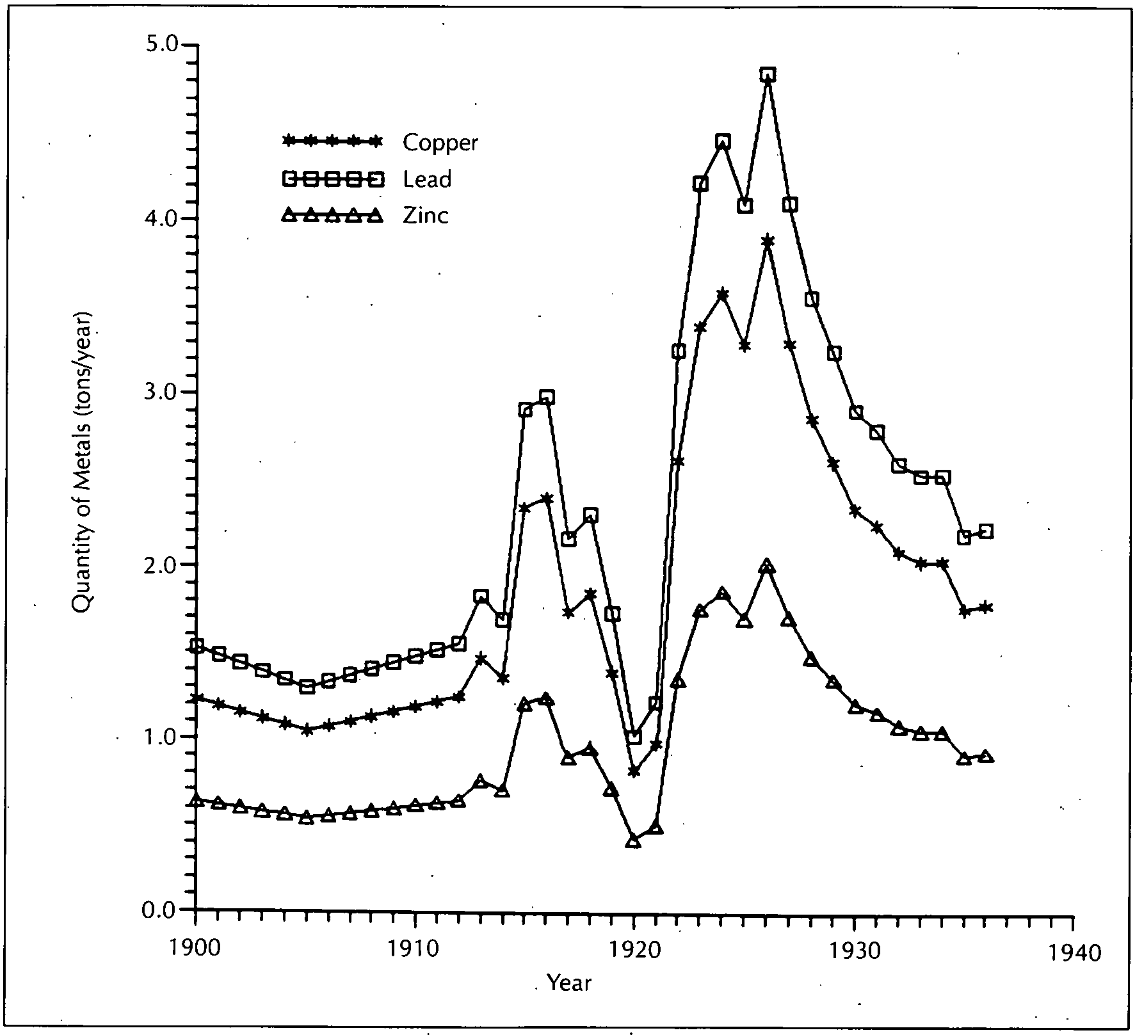

FIGURE 6. The quantity of metals in tannery wastes based on the gross value of the finished leather.

industry wastewater (200 tons) is present in the sediments of the Mystic Lakes. Current research is focused on identifying other surface water bodies where metals may have accumulated.

In addition to finding high concentrations of metals in river and lake sediments, large amounts of waste metals have also been discovered in abandoned lagoons and sludge dumping areas in the watershed. Though efforts have been made to identify the dumping areas that pose the most immediate environmental and human health risks, it is likely that other, less obvious leather industry waste disposal sites are scattered throughout the watershed.

Conclusions

Tanning, leather finishing, and hide and leather rendering were once an important part of the economy in the Aberjona watershed. Records indicate that between 1838 and 1988, approximately 100 tanneries, leather-finishing companies and rendering factories operated at over 67 sites in Woburn, Winchester and Stoneham. For 50 years, between the 1870s and the late 1920s, the leather industry employed nearly 55 percent of all wage earners in the area, and accounted for more than half of the total annual value of goods produced in the watershed. Historical documents and records also indicate

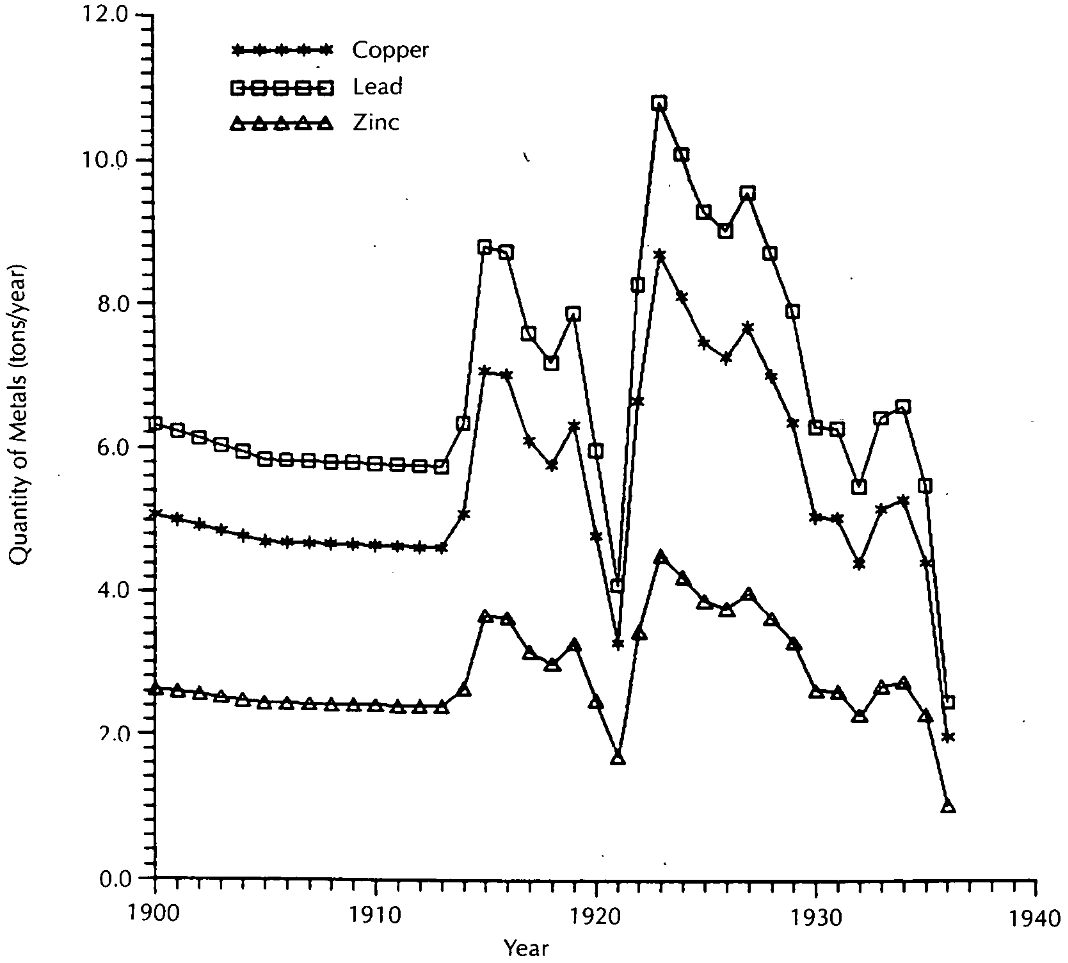

FIGURE 7. The quantity of metals in tannery wastes based on the finished leather produced per manhour.

that the leather industry used considerable amounts of hazardous chemicals, and routinely discharged wastes to surface water bodies, lagoons and dumps throughout the watershed. Mass balance models based on manufacturing statistics estimate that between 1900 and 1936 roughly 2,000 to 4,000 tons of chromium, 65 to 140 tons of copper, 85 to 175 tons of lead and 40 to 75 tons of zinc were generated in leather industry wastes.

Currently, officials from the EPA and Massachusetts DEP are investigating six sites in the watershed that are contaminated with leather industry wastes. On one former rendering site, it is estimated that over 1,000 tons of chromium discharged in leather detanning effluent are distributed over a 35-acre area. Other locations where waste metals have been found in the watershed include depositional areas in ponds, lakes and tributaries.

Pollution problems have been investigated for the past ten years, but not on a watershed-wide basis until the last three years. Surface water, groundwater, sediment, soil and air samples have been collected and analyzed to determine the extent and approximate concentrations of anthropogenic chemicals at sites throughout the watershed. The ultimate goal of this research is to determine how hazardous wastes are distributed in and move through the

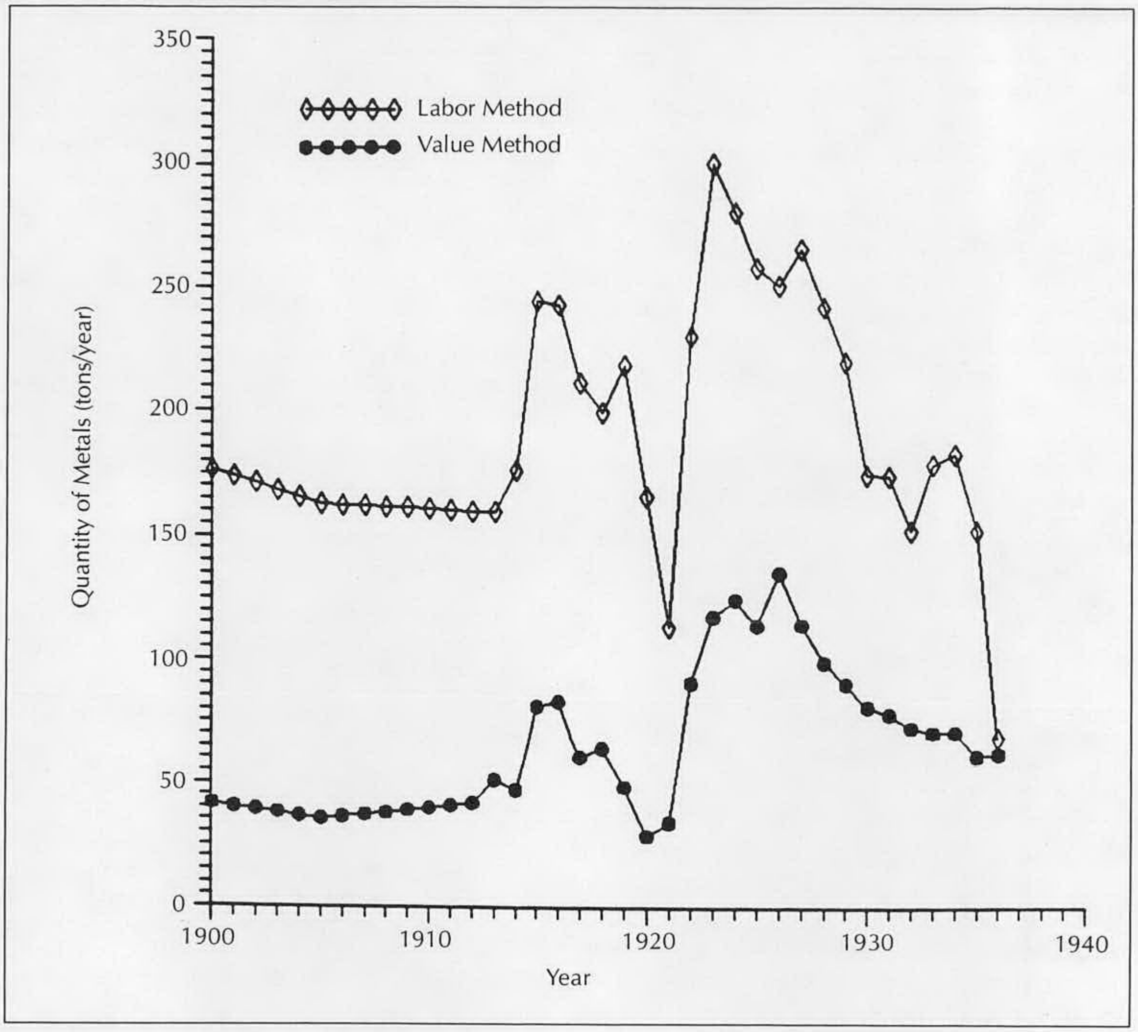

FIGURE 8. Comparison of the total quantities of metals in tannery wastes as predicted by two mass balance methods.

watershed, and how humans may be exposed to, and affected by, particular waste chemicals. An important first step is to identify which hazardous chemicals were most widely used in the watershed, and which are most likely to be present in environmental samples. From the descriptive history of the leather industry, its chemical usage and its waste disposal practices, it is evident that wastes containing hazardous metals — in particular, chromium, copper, lead and zinc — were routinely discharged to surface waters and dumps throughout the watershed. Mass balance analyses indicate that considerable quantities of these metals were present in the wastes. Based on these conclusions, it is hypothesized that a significant fraction of the total amount of metals discharged in the leather industry wastes is still present in the watershed. In testing this hypothesis, researchers have used the historical information to direct sampling and analytical programs toward identifying metals in samples collected in sediment deposition areas and in parts of the watershed where the most active leather industry sites were located.

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JOHN L. DURANT *is a Graduate Research Assistant in civil engineering at the Massachusetts Institute of Technology's Parsons Laboratory for Water Resources and Environmental Engineering. He received a B.S. from the School of Agriculture and Life Sciences at Cornell University. He recently completed work on an M.S.C.E. at MIT and is now pursuing a doctorate in the area of environmental mutagenesis.*

JENNIFER J. ZEMACH *is a senior at the Massachusetts Institute of Technology. She is the founder of the MIT environmental organization Save a Vital Earth (SAVE). She is also a student menber of ASCE.*

HAROLD F. HEMOND *is a Professor of civil engineering at the Massachusetts Institute of Technology's Parsons Laboratory for Water Resources and Environmental Engineering. He received a B.S. in electrical engineering from Worcester Polytechnic Institute, an M.A. in botany from Connecticut College and a Ph.D. in civil engineering from MIT. His principal interests lie in the biochemistry of wetlands, acid rain, environmental instrumentation and groundwater quality.*

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Ethical Engineering Practice & Creativity: Educating Younger Engineers in a Computer Society

Old means of providing the apprenticeship of engineers can no longer keep apace with the benefits in time, cost and creativity that computerization brings.

BRIAN BRENNER

In recent years, advances in technology have had a tremendous effect on the design profession. With the advent of the greater availability of powerful, inexpensive computers and effective software, engineers can now directly solve technical problems in a few hours, ten times as fast as the old manual solutions, which were less accurate.

Much attention has been focused on the technical application of these significant advances in computer science within the profession of civil engineering. Less has been said about another aspect of this subject that is having as great, if not greater, effect on the way engineers do their work. Computers are not only changing the technical quality of civil engineering work, but they are also changing the way engineers go about the business of their profession. This change affects engineers both individually (in terms of how they perform their own work) and collectively (in terms of how they work with and report to each other), especially with regard to the training of new engineers. The question of the conflict between creativity and ethical engineering is integral to this change. It is of particular interest to younger engineers, the ones who are most involved with, and affected by, computer use.

The Apprenticeship Method

Traditionally, civil engineering education has been handled, in a broad sense, by a master engineer-apprentice format. For most design offices, newly-graduated engineers need to acquire several years of that magic, all-important ingredient called "experience" to complete their education. The key elements of civil design could not be learned solely through four or more years of formal education. Only through a period of informal on-the-job education could the younger engineer gain the skills needed to make the jump from engineering graduate to design professional by a sort of "osmosis." The length of this apprenticeship period varied according to the young engineer's chosen discipline within civil engineering and the nature and structure of the organization taking a chance on completing his or her education. This arrangement served the design industry well for many decades.

In the past, all branches of civil engineering design have required weeks of manual calculations to solve design problems. Over the years, clever engineers developed short-cut methods, rules of thumb, and effective approximations to get at the required information. Despite the use of these short cuts, the brunt of the work remained: days of tedious moment distribution, days of tedious processing of geotechnical lab results. For the experienced engineer, this problem was actually an opportunity. Younger engineers were assigned the task of completing these manual calculations.

The basic assumption of this method was that in the process of trudging through this work, the new engineer would indirectly gain the required knowledge that defines experience. By working through different analyses, the younger engineer learned not just how to perform the analysis, but also determined which method was most appropriate to solve a particular design problem. By manually marking up drawings, the engineer not only helped complete the work, but also learned about appropriate details and how drawings were put together. For the senior engineer, it was a good arrangement: the cumbersome manual work provided a format to train inexperienced engineers, and the availability of the younger engineers to do this work freed the more senior engineers to conceptualize the problem and guide it to its solution.

The Effect of Computerization

However, computers — especially the proliferation of the new cheap and powerful personal computers (PCs) — are changing the traditional process of completing design work. In minutes, computers can solve problems that used to require days to complete. For example, an inexpensive PC-based frame program can analyze the whole frame and even select the appropriate members. In this way, a week's worth of the young engineer's time is reduced to a few hours. Lengthy manual calculations are no longer necessary. On the other hand, no longer will the junior engineer gain that intangible — "experience" — by plowing through a mountain of tedious manual work.

Ethics & Creativity

In general, ethical engineering practice requires that engineers provide their clients with safe, economical, utilitarian designs that take into account the various constraints that are recognized to affect the design. In the American Society of Civil Engineers *Code of Ethics*, two of the Fundamental Principles state that engineers should uphold and advance the integrity, honor and dignity of the engineering profession by "using their knowledge and skill for the enhancement of human welfare" and by "striving to increase the competence and prestige of engineering."[1]

With the widespread availability of computers, what is possible in design has been expanded dramatically both in terms of the quality as well as the quantity that can be generated. It can be viewed as being unethical not to provide clients with the type of service that the use of computers can provide, now that that capability exists. In addition, there is the issue of competition to address. Firms employing computers might be better able to compete with firms that use more highly-skilled labor-intensive methods. Organizations with half the personnel of larger firms may be now able to compete effectively.

However, it is equally unacceptable to inadequately train younger engineers. Because the new technology is making impractical the way junior engineers were trained in the past, the design profession must find new ways for young engineers to gain experience.

As the structure of engineering design changes and engineers seek a new format to train inexperienced engineers, the profession, as a whole, should consider the following points:

- Using computers to train new engineers
- Developing standards for computer use
- Motivating younger engineers

Computer Training

First of all, computers can be used to help train younger engineers. Junior designers can learn through the process of iteration, because computers make iterative design a speedier and, therefore, more feasible process. For example, in the same amount of time it takes to solve a complicated building frame by moment distribution, the young designer can run ten frames on the computer, varying assumptions and learning, by trial and error, how the structure behaves. Also, civil engineering software writers can incorporate artificial intelligence methods into the programs so that not just analysis techniques, but the decision-making process itself can be learned.

While it is unlikely that computers will replace human beings in the design office, the machines, when creatively used, can speed the learning process, the gaining of experience. For this process to be successful, management must provide the apprentices with the time to do it. Previously, junior engineers involved in the preparation of manual calculations, however tedious, were considered to be performing "billable" work. This same accounting approach must be provided for periods of education. Successive iterations and a "master-apprentice" analysis of these iterations should be viewed as integral to the design process and be, therefore, billable.

Standards & Guidelines

Consultants and professional societies should develop detailed standards and guidelines for the use of computers within the field of design engineering. Such standards can help form the framework not only for civil engineering computer use, but for the new, computerized education process for younger engineers. When prepared and applied properly, these standards should help fill the gap in the development of engineering expertise. These standards might cover such areas as:

- Recommended or authorized application software (for example, spreadsheets or moment analysis or statistical manipulation);
- Guidelines or instructions on how to use the application software for specific tasks;
- Standard, minimal or average expectations for work performed using computers;
- Standardized formats for data exchange (for example, for computer-aided design file transfer); or,
- Standardized interfaces for applications to reduce the time required to learn new application programs.

While these standards should help engineers avoid repeating past mistakes and provide a means to evaluate work produced using computers, they must not be allowed to become too rigid. Because of the rapidly changing nature of engineering software and hardware, designers must be free to creatively adapt developing technologies to their needs. Computer standards must grow and adapt with the engineers, not stifle creative computer use.

Motivating Younger Engineers

Junior engineers must adopt a more aggressive approach towards the gaining of experience. The days of leisurely, tedious manual calculations are ending, along with the framework in which new engineers learned their profession. In this period of change, with no firmly established process for gaining experience in place, young engineers must seek out engineering knowledge and not wait for it to fall into their heads.

The new environment in consulting offices will provide less and less need for engineering "dog work," and, thus, less and less need for lazy junior engineers, or those who are content to perform such "dog work" and not rise beyond it. On the other hand, the situation provides a great opportunity for industrious young engineers to gain professional insight and make substantial contributions to the design process sooner than in the past. Managers and senior supervisors must encourage this kind of contribution, and not fall back on the old, manual procedures as a way of maintaining control of younger engineers.

Liability & Computer Use

Any change in design and construction methods makes liability a serious concern. As the use of computers has become more widespread, some engineers have had difficulty incorporating automation into their work. All sorts of improper structural designs, construction failures, and even bidding mistakes have been blamed on the machines. These engineers have concluded that the computers, and not their own ignorance, is at fault.

Likewise, as computers are relied on more and more to help train inexperienced engineers, engineers will suffer through the laments of the old timers who claim that, if only those youngsters had done it the old, "correct" way, then they would know how to do it properly. The key point here is to remember that a computer is a tool. Members of a profession are expected to be able to use the tools of their profession in a competent manner. When they do not, they can be liable for negligence. When used correctly, excellent designs and competent engineers are the result.

Summary

Computers present a special challenge to younger engineers who are at the forefront of the new automation technology.

It is ethically required of the younger engineer to contribute more to the design process sooner in his or her career. Just as senior engineers and managers can no longer have the luxury of assigning weeks of "baby-sitting" manual calculations, junior engineers can no longer sit back and enjoy the luxury of allowing design experience to "seep in." It is ethically required of younger engineers to learn their profession more quickly. It is ethically required of younger engineers to actively help redefine the way design work is done, because, with their knowledge of computers, younger engineers know better ways of getting the work done.

This type of contribution requires tremendous flexibility on the parts of both younger engineers and more senior managers. The results of this contribution would be faster, more economical and more creative solutions to design problems whether they be complex or simple. Given the current state of the engineering profession, not to make such a contribution deprives the client of the best possible engineering work, and, thus, can be seen as being unethical.

BRIAN BRENNER *graduated from the Massachusetts Institute of Technology in 1984 with the degrees of B.S. and M.S. in civil engineering. He is currently a Senior Structural Engineer for Bechtel/Parsons Brinckerhoff. He is one of the lead tunnel designers for the depressed Central Artery in Boston.*

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The Panama Canal: Uniting the World for Seventy-Six Years

The background, planning and construction of an outstanding engineering achievement presents lessons that are still worth knowing in a high-tech age.

FRANCIS E. GRIGGS, JR.

On August 15, 1914, the steamer Ancon made the first passage through the Panama Canal from the Atlantic Ocean to the Pacific Ocean. Following the ship through the Canal was Colonel George Goethals, the Chief Engineer of the Panama Canal project. The canal worked flawlessly on that day and has worked day-in and day-out for the past seventy-six years. No project built to that date, and possibly since then, has been of that magnitude and has been constructed under such unfavorable environmental conditions.

The Isthmus

The Isthmus of Panama runs primarily in an east to west orientation at a latitude of approximately 10° north (see Figure 1). The location of the canal is approximately at the same longitude as Buffalo, New York. The isthmus is as narrow as 35 miles at Darien and is approximately 50 miles wide at the canal site. The northern slopes of the isthmus are drained primarily by the Chagres River which can range between the extremes of being a docile stream to a raging torrent that can rise over 40 feet in a twenty-four hour period. The rugged Cordilleras that hug the Pacific side of the isthmus range from an elevation of 278 feet at Culebra to over 1,000 feet at other locations east and west of Culebra.

There are two seasons in Panama: rainy and dry. The dry season is concurrent with winter in the United States and has been described as being as close as anyone could ever come to paradise. The rainy season, however, is as close, for anyone who is working with soil and rock excavation, to the worst possible weather that could ever be imagined. It rains every day and at an intensity that has to be experienced in order to be appreciated. The isthmus had been called a pest hole, with diseases such as yellow fever and malaria being as common as measles and mumps were at that time in the United States.

Panama was discovered by western man in 1502 when a Spanish explorer by the name of Rodrigo de Bastidas sailed northward and

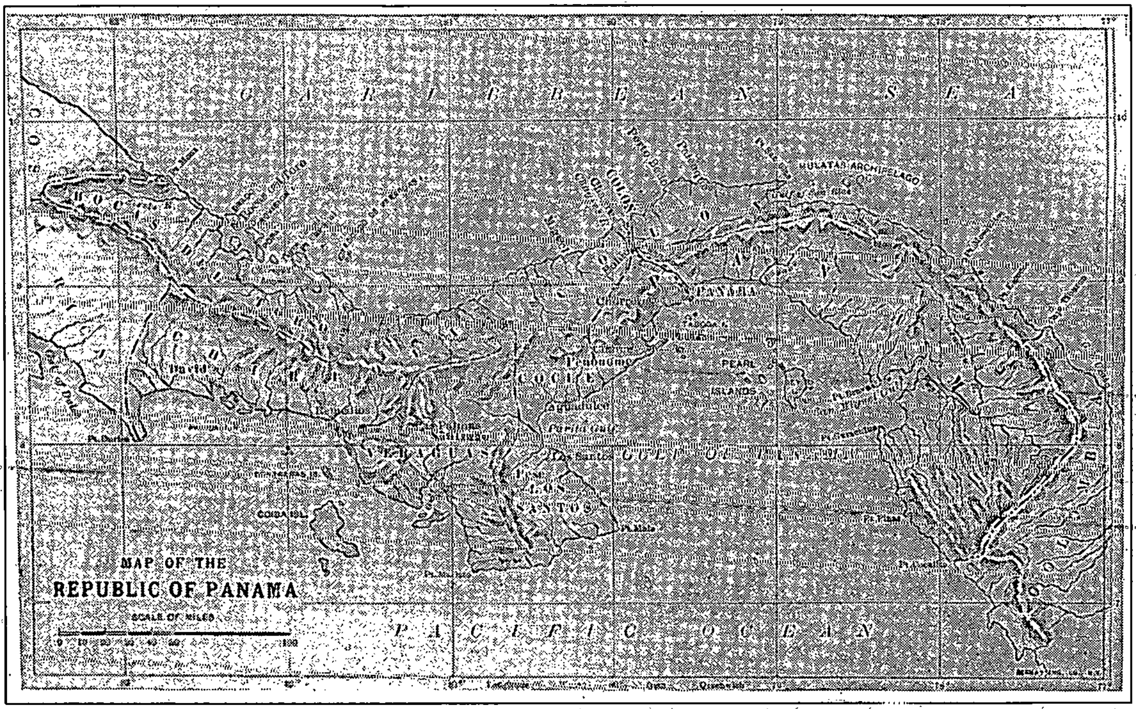

FIGURE 1. Map of Panama.

westward along the isthmus. The following year Christopher Columbus, the Admiral of the Seas, sailed southward and eastward from the Yucatan Peninsula to present day Panama. He, in fact, spent the Christmas of 1503 anchored in the Bay of Limon, the location of the northern end of the canal. This voyage, the fourth by Columbus to the new world in his search for a strait to the west, was like his others — a failure. The strait to the west would have to wait for twentieth century man.

In 1513 Balboa mounted a hill on the isthmus and saw the Pacific Ocean, what the native Indians called the "South Sea." This discovery, and subsequent pillaging and plundering expeditions by the Spanish Conquistadors such as Pizzaro and Cortez, made it necessary to find an easy way to move the rewards of their rape of the Indians back to Spain. As early as 1560 the Spaniards built a road, *El Camino Reale* (the King's Highway), across the isthmus from the area around Panama City to several different cities near the present northerly end of the canal, first Porto Bello and later Nombre de Dios, both towns named by Columbus in his 1503 trip. After the pillaging stopped, Panama went into a 200-year sleep as far as exploration and development was concerned.

Initial Plans for a Canal

A canal across the isthmus had been discussed almost from the beginning by the kings of Spain, but other than some crude mapping expeditions little was done until the middle of the nineteenth century to bring the dreams of many to reality. In 1846, the United States signed the Bidlack Treaty with Colombia, of which Panama was then a part, giving the United States the right to build and maintain a transportation system across the isthmus by any means then known or that would be known in the future in exchange for certain trading privileges. The Senate ratified the treaty and President James Polk signed it, but they had little appreciation of the future significance it would have.

All this changed in 1848 when gold was discovered at Sutter's Mill in California. The forty-niners wanted to go west by the fastest means possible before the gold was all gone and they had missed their chance to become instant millionaires. They had three routes

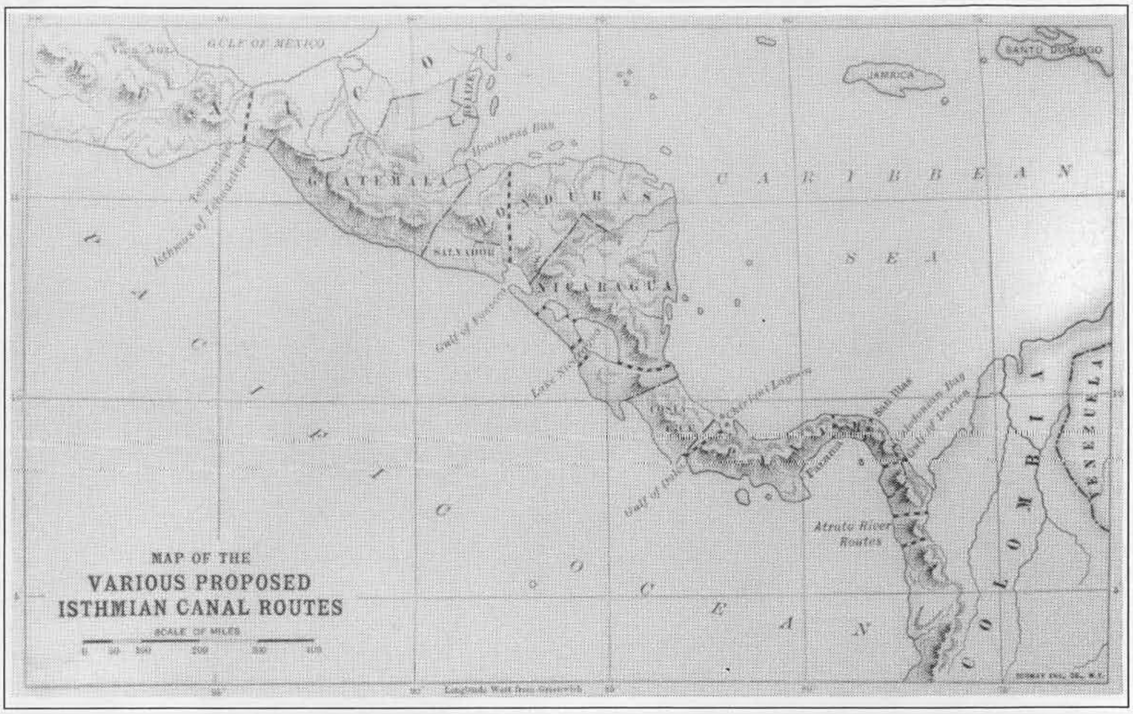

FIGURE 2. Survey of routes by the United States.

open to them at the time:

- Cross the plains and mountains of the still wild west (it took two months to travel those 3,000 miles);
- Sail or steam around Cape Horn (it took two months to travel 9,000 miles); or,
- Take a steamer to Panama, take a raft which was poled up the Chagres River by a native who would discharge the traveler at Gamboa, then be guided across the Cordilleras on foot, and arrive at Panama City to take a steamer or sailing ship to California (it took one month and covered 4,000 miles, a good deal of which would be under high risk of attack from bandits in Panama).

It was just prior to this time that two Americans, George Law and William H. Aspinwall, received concessions to provide steamship and mail connections from the east coast of the United States to the mouth of the Chagres River and from the west coast to Panama City. Next, they proposed the construction of a railroad across the isthmus and contracted with two of the premier civil engineers of the time, Colonel Joseph Totten and John C. Trautwine, to undertake such a project.

Starting construction in some of the worst possible conditions in a disease-ridden country must have been a sobering experience even for men with the background of Totten and Trautwine. After five years of dealing with yellow fever, malaria, cholera and serious financial problems, sufficient progress was made and with help from the forty-niners who would pay almost anything to speed up their passage across the isthmus, they completed the railroad in 1855. It was not much of a railroad when it opened, but it did, on its single track, provide a connection between the Atlantic and Pacific Oceans, making it the first transcontinental railroad.

The United States was never very far away from planning for the construction of a canal. Almost every President from James Polk on either commissioned studies or surveys to determine the best route across the isthmus. The Senate in 1866 had a comprehensive study made of all the routes that had been considered in the past. This report, replete with beautiful

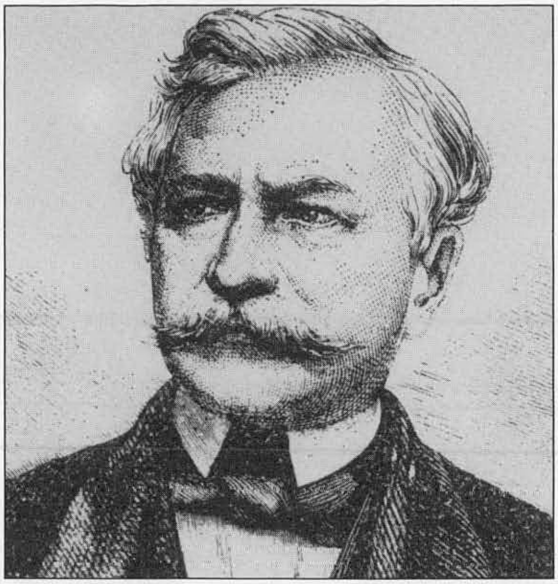

FIGURE 3. Ferdinand de Lesseps.

FIGURE 4. Lucien Napoleon Bonaparte Wyse.

maps, shaped the United States' planning for several years until President Grant restated the country's position on any future canal: any such canal would have to be under the control of the United States. He sent out many survey teams to determine, using the best surveying techniques available, the most desirable route for a canal. On the basis of these surveys, the Nicaragua Route (see Figure 2) became the United States' choice. A private company in fact did start the construction of a canal on this route in the early 1870s but ran out of funds after a very short time.

The French Plan

It was into this period of attempting to realize continually mulled dreams that Ferdinand de Lesseps (see Figure 3), the famed builder of the Suez Canal, became interested in the challenge of crossing another isthmus with a canal. After the opening of the Suez Canal in 1869 his status as an entrepreneur made him one of the most well known and respected Frenchmen of his time. Even though he was not an engineer, he was justifiably known as *Le Grand Français* due to his having succeeded in instances where most of his contemporaries were sure that he would fail, either through lack of money or through lack of technical expertise. He would, when people asked him what his business was, answer "Isthmuses."

De Lesseps commissioned, along with a group of movers and shakers interested in geography, Lucien Napoleon Bonaparte Wyse (see Figure 4) to make a trip to the Panama region and make a survey of a route or routes that could be considered for a French canal. After a minimal effort at actual surveying, Wyse made a little side trip to Colombia and received a concession from the government permitting him to build a canal anywhere east of the existing Panama Railroad. On his way home, he traveled to Washington in order to see if he could obtain copies of the American surveys that had been commissioned by Grant, but he was unsuccessful in his attempts.

Back in France, Wyse made his results known to de Lesseps and an investment-development group headed by Istvan Turr. They sent him back to Panama to do some more surveying, and then they went to work setting up an "International Symposium on an Isthmanian Canal" to be held in Paris in the spring of 1879. The purpose of this symposium was to bring together all of the experts from around the world to discuss which route across the isthmus would be most advantageous. The symposium included the involvement of engineers, entrepreneurs, politicians, shipping experts and bankers.

The Americans came fully prepared to state the case for the Nicaragua route as well as to describe some of the other routes that they had considered. Wyse presented the French plan which was really not a plan at all, since it was based more on faith than fact. When the vote on a sea level route at Panama was being taken, de Lesseps with his usual flair for the dramatic, voted yes and made a triumphal boast that he would lead the effort.

A review of the voting, however, showed that it was not the engineers who supported this route. Instead, support for the sea level canal came from individuals who were under the spell of de Lesseps. Those that were in a position to know said that the jungle, disease, and the Chagres River made it highly improbable that the kind of canal that de Lesseps wanted to build could be built. One forward-looking Frenchman, Godin DeLepinay, had instead proposed an "Artificial Nicaragua" which would be accomplished by building a lock canal with an artificial lake that would store the waters of the Chagres River, thereby making it an ally rather than an enemy in the construction and maintenance of the canal. De Lesseps, attempting to repeat his success at Suez, was blind to these suggestions and was obsessed with his ability to accomplish the impossible, just like he had done at Suez.

The story of the initial financing of the canal by de Lesseps is a fascinating one, but it would require a book to fully relate all of its details. Suffice to say that the bankers and financiers, newspaper editors and politicians, as well as the average person on the street who invested his or her life's savings, wanted to get their hands into the very large pie that de Lesseps was proposing. After a false start that raised little money, he and his son Charles went along and played the game the way the money men wanted and raised enough to start the canal. The cost of doing business in this way, however, proved to be one of the main reasons for the eventual failure of the French effort.

De Lesseps then made a symbolic journey to Panama to break ground on January 1, 1880. This trip was made during the dry season and was de Lesseps's first time in Panama. Reports of his excursion are filled with statements about his charm and vitality, even though he was in his late 70s. They portray him as a "rainmaker" type of individual who had supreme confidence in his ability and the inevitable technological fixes that would develop at the time that he needed them — just like what happened at Suez. He was not to visit Panama again until 1886 when things were falling apart for his company and then only to try and salvage his effort to raise more money through the sale of lottery bonds.

The story of the French failure that appears in most historical accounts centers around de Lesseps, money, corruption, greed, disease, earthquakes and even a revolution. From the vantage point of the typical civil engineer on the project, it was a constant struggle against bureaucracy, unrealistic expectations, insufficient funds, inflexible leadership and finally a struggle against the three natural enemies: disease, the Chagres River and the jungle.

De Lesseps originally planned to have contractors build his canal and, true to form, contracted with Couvreux Hersent, the same firm that he had used at Suez to do the job. The company prepared for the massive project during 1880 and 1881. The best civil engineers in France were ready and eager to be part of this glorious triumph and many graduates from L'Ecole Polytechnique, the premier engineering college in the country made the trip to Panama.

What these engineers found was something altogether different from what they had bargained for. Almost from the beginning Paris started calling the shots from afar, thus depriving the engineers of the necessary control. One of the first examples of this distant bureaucratic control came when Gaston Blanchet, the contractor's chief engineer, wanted to clear a path 400 feet wide across the entire isthmus for purposes of doing, for the first time, a professional survey in order to provide the engineers with a good look at actual ground conditions. The response from Paris was to cut only a 40-foot wide corridor.

The definitive plan for the canal was also under development at this time, but there was no question that it was to be a sea level canal and the engineers had to develop plans to make this type of canal work. Keep in mind that

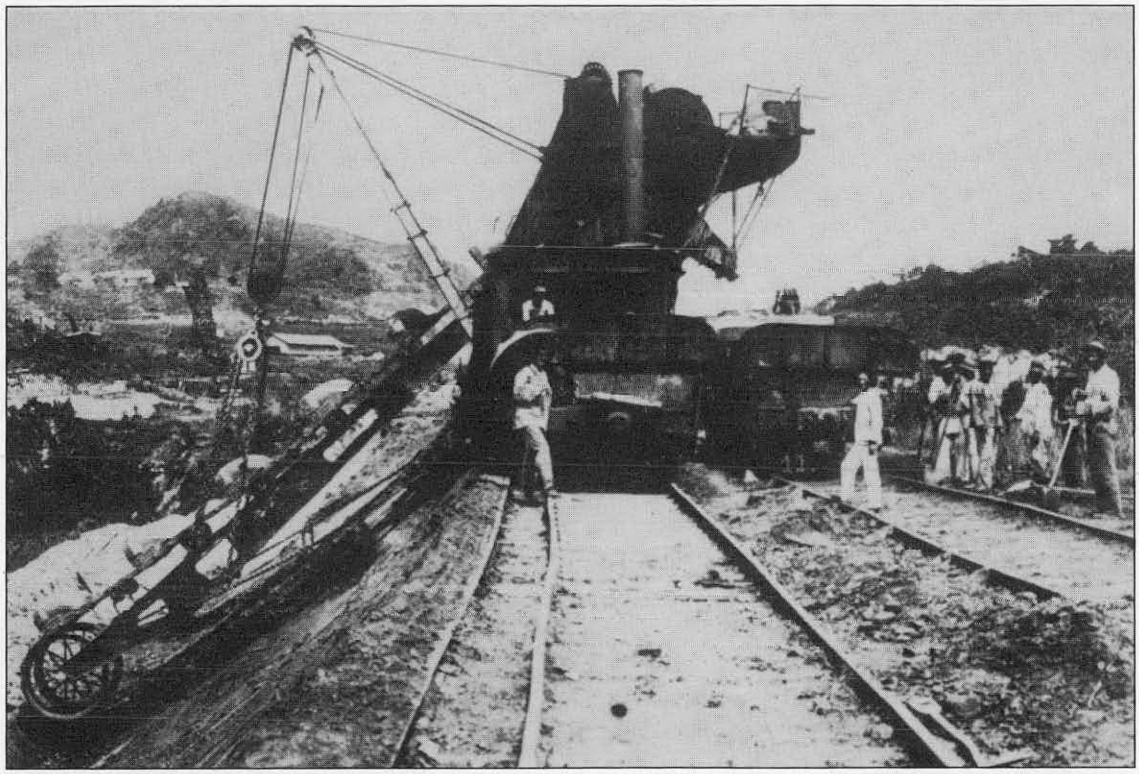

FIGURE 5. French ladder excavator.

many engineers, French and American alike, had told de Lesseps that the Chagres River would not permit the construction of a sea level canal. In spite of this knowledge, the French engineers on the site were instructed to find a way to make it work. By this time, disease (mainly yellow fever and malaria) was starting to take its toll on the visitors from Europe. The natives who were still alive were immune to yellow fever since most had survived earlier cases of the dread disease. At this time, it was commonly thought that the disease came from some mysterious germ from the swamps called *miasma*.

Excavating soil and rock during the rainy season proved extremely difficult. Under pressure to show some progress while they were working on a plan to harness the Chagres River, the engineers started dredging from both oceans inland using primarily American-built dredges. Progress for this type of excavation was good; in fact, if they were building a 100-foot wide canal, their efforts would have been of value. The French equipment, however, was unable to discharge the excavated material far enough away from the banks to prevent much of the excavated materials from sliding back into the already excavated canal. The ladder dredges (see Figure 5), despite excellent workmanship, were just too small to do the job. The railroad rolling stock that was employed was the best available in the early 1880s, but it was insufficient for the job.

What the engineers did not seem to realize, based on the evidence, is that the task of excavation was only a relatively minor part of the overall challenge. The main difficulty was how to transport the excavated materials from the Culebra Cut to the spoil areas and, once there, how to quickly unload the soil and rock in order to get the cars back to the excavators. The French constantly found that their dirt trains got bogged down in their own previously dumped material. In short, they never had a system in place that could guarantee that the excavators would always be excavating and not sitting around waiting for the dirt trains to return.

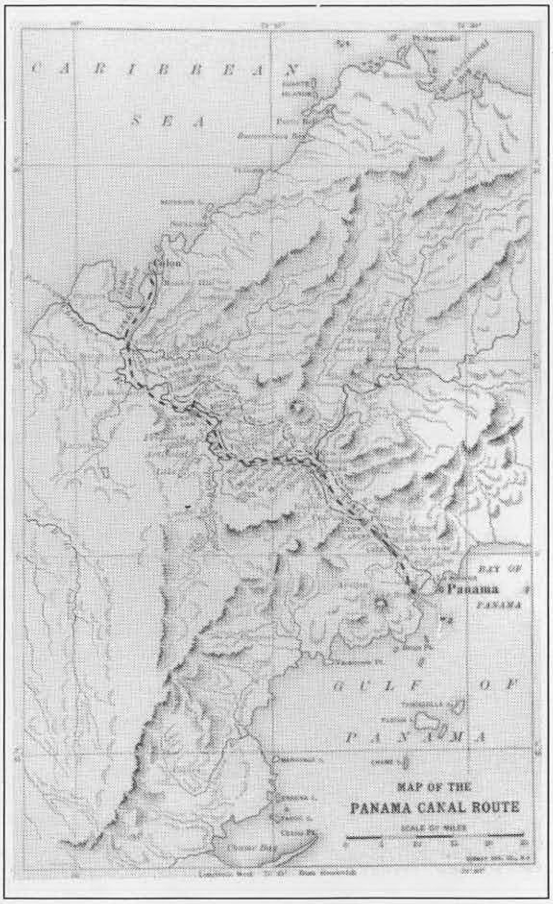

FIGURE 6. Map of the proposed canal route.

Failure of the Sea Level Design

The major problem, however, regarding what to do with the Chagres River remained unsolved by the French, perhaps because it virtually precluded any solution. The elevation of the Chagres River at the point where it was to make its first contact, near Gamboa, with the line of the sea level canal was approximately 45 feet above sea level and about 32 miles from the Atlantic Ocean (see Figure 6). The Chagres River drains a large and steep watershed and, as a result, is subject to rapid transition from stream to raging torrent. To prevent it from flooding the excavation, the French proposed to dam it upstream and dig a diversion channel in order to separate the river waters from the ocean waters. This project, however, required a major effort in and of itself, and it was for this reason that it was finally deemed to be totally impractical.

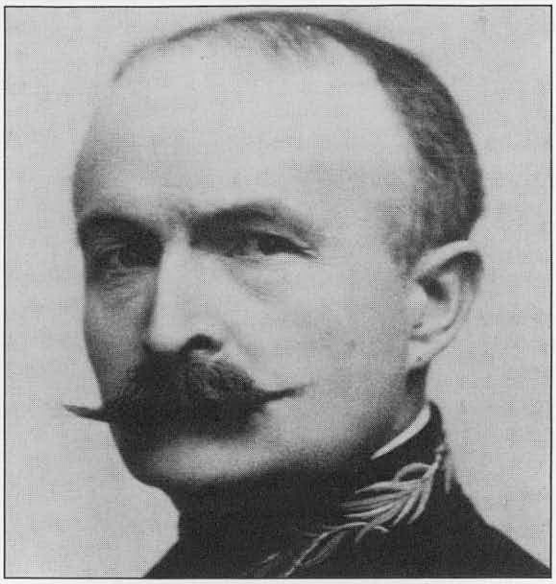

FIGURE 7. Phillippe Bunau-Varilla.

One French engineer, however, distinguished himself for his vision in trying to solve many of the problems mentioned above. He was Phillippe Bunau-Varilla (see Figure 7), a graduate of L'Ecole Polytechnique, and a believer in de Lesseps and the ability of French technology to accomplish the task. He came to the isthmus to work for the company after the contractors were excused from their contract, and was given a responsible position immediately working for Jules Dingler, Director General and a well-known French engineer. At this time, yellow fever was rampant and even though the French built the best hospitals and provided excellent nursing care, the chances of surviving the fever were exceedingly small. Dingler's wife and children died of the disease as did many other Frenchmen. Bunau-Varilla himself was infected, but he was one of the few who managed to survive.

After Dingler left the isthmus in late 1885, Bunau-Varilla found himself at the age of twenty-seven in charge as Director General of the largest construction project in the history of man until such time as another, more senior engineer could be sent over from France. During his stay as Director General, he made many recommendations that, if followed, might have saved the day for de Lesseps.

If de Lesseps had been more directly involved with the project, he would have realized that the technological fix he always counted on resided in the mind and abilities of Bunau-Varilla. The young engineer had proposed, among other things, that all excavation for the canal be performed in the wet by creating artificial lakes with locks at either end of the lakes. This construction method would enable the canal to be used as a lock canal during the excavation process. Thus, within this system, excavation could be continued in order to deepen the lakes until such time as it would be possible to remove the lock gates of the highest lake so that the highest level lake would now be at the level of the lower lake. In time, the canal could eventually become a sea level canal, with the tolls collected in the meantime applied to the cost of completing the canal, thus minimizing the amount of capital that had to be raised by selling bonds. He also proposed and implemented erecting large wooden railroad trestles in the dump areas in order to eliminate the problems of the dirt trains being bogged down in the mud.

In 1886 Bunau-Varilla resigned as an employee of the project development company and went into partnership with others and became a contractor on the canal. By this time, however, money was running out and word was getting back to France that all was not well and that one of the greatest financial disasters in history was about to occur. De Lesseps had gone back to the citizens of France on several occasions for more support, always with glowing reports about the progress being made on the canal. He was able to obtain more money to carry on, but at progressively higher rates of interest which is usually the case when lenders question the safety and quality of their loans.

The government, in order to check the exact extent of the progress being made on the canal, sent an investigator, Armand Rousseau, to obtain first-hand information and to report back on his findings. De Lesseps realized that his last chance to salvage the canal was at hand, and made his second trip to Panama to urge on his workers in late 1885, during the dry season of course. Based on what he saw during this trip, he decided to change the design of the canal (the conclusion reached by Bunau-Varilla, Armand Rousseau and his own new Director General Leon Boyer) to a lock canal and to bring into the project leading French civil engineers such as Gustave Eiffel.

After making these changes in 1887, de Lesseps again asked for authorization from the national Chamber of Deputies for the sale of lottery bonds. The Chamber of Deputies finally approved the sale of the bonds in June of 1888, but de Lesseps, despite frantic appeals to the French people, failed in raising the amount needed. It was shortly after this failed attempt to raise new monies that the company he headed was placed into receivership. Not too long after that, in February 1889, a liquidator was appointed to salvage what he could for the original shareholders.

Restructuring for a Second Try

The New Panama Canal Company was formed by the liquidator in 1894. Many financiers and contractors who had made small fortunes through their original involvement with de Lesseps on the canal, including Bunau-Varilla, were forced to invest in the new company under threat of prosecution and jail. Their primary task was to see that work proceeded on the canal at such a rate that the concession with Colombia could be maintained and extended. The real purpose of the new company was, in the opinion of many, to keep the company going long enough in order to sell its assets to someone else, most probably the United States.

Investigations conducted in 1893 into the de Lesseps company revealed that fraud, bribery and greed were prevalent in the financial circles and newspapers of France. Much of the money raised through the sale of bonds had gone into the pockets of individuals who did not contribute to the construction of the canal.

It should not be forgotten, however, that the French engineers made significant progress on the construction of the canal. They excavated over 50,000,000 cubic yards of soil and rock; they built hospitals, villages, harbors and piers; and they left vast amounts of equipment that could be used by anyone who wanted to come in to pick up the pieces and translate de Lesseps' dream into reality.

The fact that they had spent in excess of

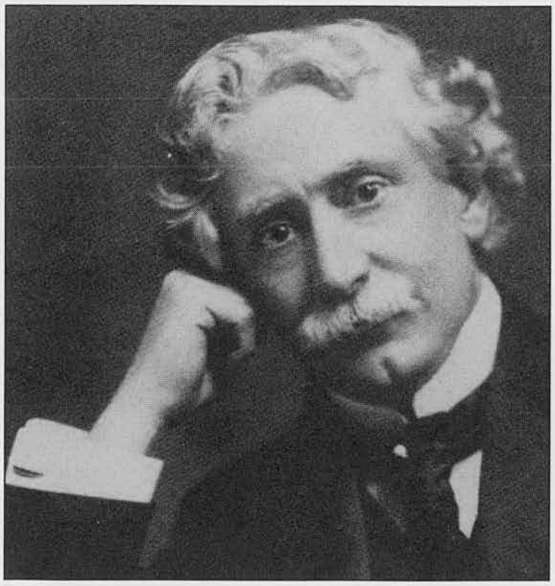

FIGURE 8. William Nelson Cromwell.

FIGURE 9. Theodore Roosevelt.

$287,000,000 would, however, detract from the work the French engineers had performed and leave the impression in the minds of many that they had not accomplished anything.

From an engineering standpoint, the French engineers had made excellent surveys, measured the flow in the streams and rivers and had begun to develop a plan to perform the excavation of Culebra by following some of the suggestions of Bunau-Varilla. They also proved that western man could come into the tropics and build an isthmanian canal thousands of miles away from civilization. If the French had started the canal twenty years later when equipment of much larger size and capacity was available, and the source of yellow fever and malaria was known, there is not much doubt that, even with corruption on the home front, they could have built a lock canal at Panama.

The Panama Canal

How the United States got involved in the construction of a canal at Panama is told in great detail in *The Path Between the Seas*, by David McCullough,[1] and by Phillippe Bunau-Varilla in his fascinating book, *Panama: The Creation, Destruction, and Resurrection.*[2] The United States from 1899 to 1902 was strong in its belief that when a canal was built it would be built by the United States and it would be a lock canal through Nicaragua. Largely through the efforts of Bunau-Varilla, William Nelson Cromwell (see Figure 8), lawyer for the New Panama Canal Company, George Morison, a civil engineer and member of the Isthmanian Canal Commission, Senator Mark Hanna and finally Theodore Roosevelt (see Figure 9), the new President of the United States, this sentiment was changed to Panama. As a result of their efforts, the Spooner Act was passed by Congress which gave the President the authority to negotiate with both Colombia and the New Panama Canal Company for the purpose of arriving at a treaty with Colombia and at an acceptable purchase price for the French company. If these negotiations were unsuccessful, the President was authorized to initiate the process required to construct a canal through Nicaragua.

The Senate ratified the Hay-Herran Treaty with Colombia and all was apparently set for a smooth beginning of construction by the United States. All, that is, except for ratification of the treaty by Colombia. After some bitter words back and forth between the United States and Colombia, the treaty was rejected by Colombia. The Colombians apparently wanted more than the $10,000,000 the United States was offering them and felt that the some of the

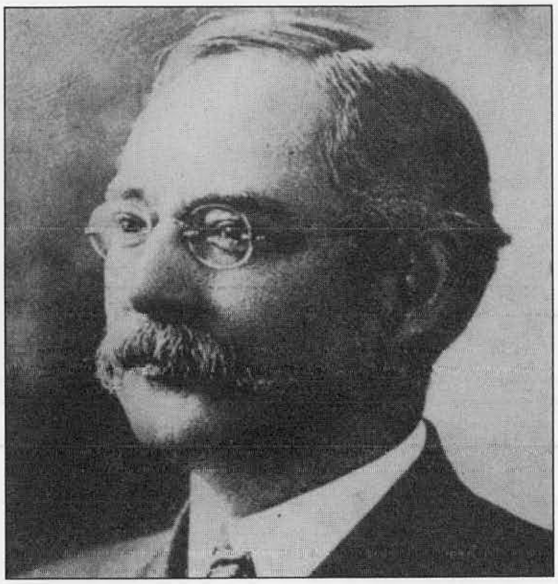

FIGURE 10. John Finley Wallace, first Chief Engineer.

$40,000,000 that was to be paid to the New Panama Canal Company should come to them. They also had some concerns about sovereignty over the land on which the canal was to be built. To say that Theodore Roosevelt was unhappy with what he referred to as those "Bandits in Bogota" or "that Bogota lot of jack rabbits" would be vastly understating the case.

In November of 1903, a group of Panamanian locals unhappy with Colombia's rejection of the treaty revolted and took control of what is now Panama. This uprising was planned in part by Bunau-Varilla, William Nelson Cromwell and a handful of Panamanians. In order to ensure its success, the revolution needed and, from a Colombian viewpoint, was granted the support of the United States and its gunboats.

What happened behind closed doors in Washington is not entirely known. Some say that Theodore Roosevelt was fully aware of everything going on and that he approved of the dispatch of gunboats to Panama and the subsequent actions of United States forces taken to protect passage on the Panama Railroad. However involved Washington was involved with the "revolution," Roosevelt recognized the new country of Panama two days after the revolution, which was fast even by his own standards. Roosevelt was to state later in his autobiography that his foreign policy was based on:

> "the exercise of intelligent forethought and of decisive actions sufficiently far in advance of any likely crisis."

He further stated that:

> "From the beginning to the end our course was straight-forward and in absolute accord with the highest standards of international morality. Criticism of it can come only from misinformation, or else from a sentimentality which represents both; mental weakness and a moral twist."

So, in Roosevelt's mind, what he did was a measured response to the situation that he faced and one in which he had predetermined all of his possible courses of action under a variety of eventualities.

As noted, we may never know the exact story behind the uprising. On November 18, 1903, two weeks after the revolution, Secretary of State, John Hay, signed a treaty with Panama that had been drafted by none other than Phillippe Bunau-Varilla, Envoy Extraordinary and Minister Plenipotentiary to the government of the United States of America. The Senate viewed this new treaty as an improvement over the Hay-Herran Treaty and it was ratified on December 2, 1903. The Hay-Bunau-Varilla Treaty was somewhat reluctantly ratified by the Panamanians on February 23, 1904, as the first order of business of the new government. On November 4, 1904, the United States flag flew over the newly acquired territory — the Canal Zone — for which it was, by treaty, to act as if it were sovereign in perpetuity.

At that moment the dreams of Americans from Bidlack to Roosevelt seemed about to come true, but no less perhaps than the man with the greatest commitment to the canal in terms of time and passion — Phillippe Bunau-Varilla — would realize his dreams as well. He had been involved with the Canal since 1884, a period of over twenty years. Bunau-Varilla was to write in his book:

> "I have fulfilled my mission . . . I had

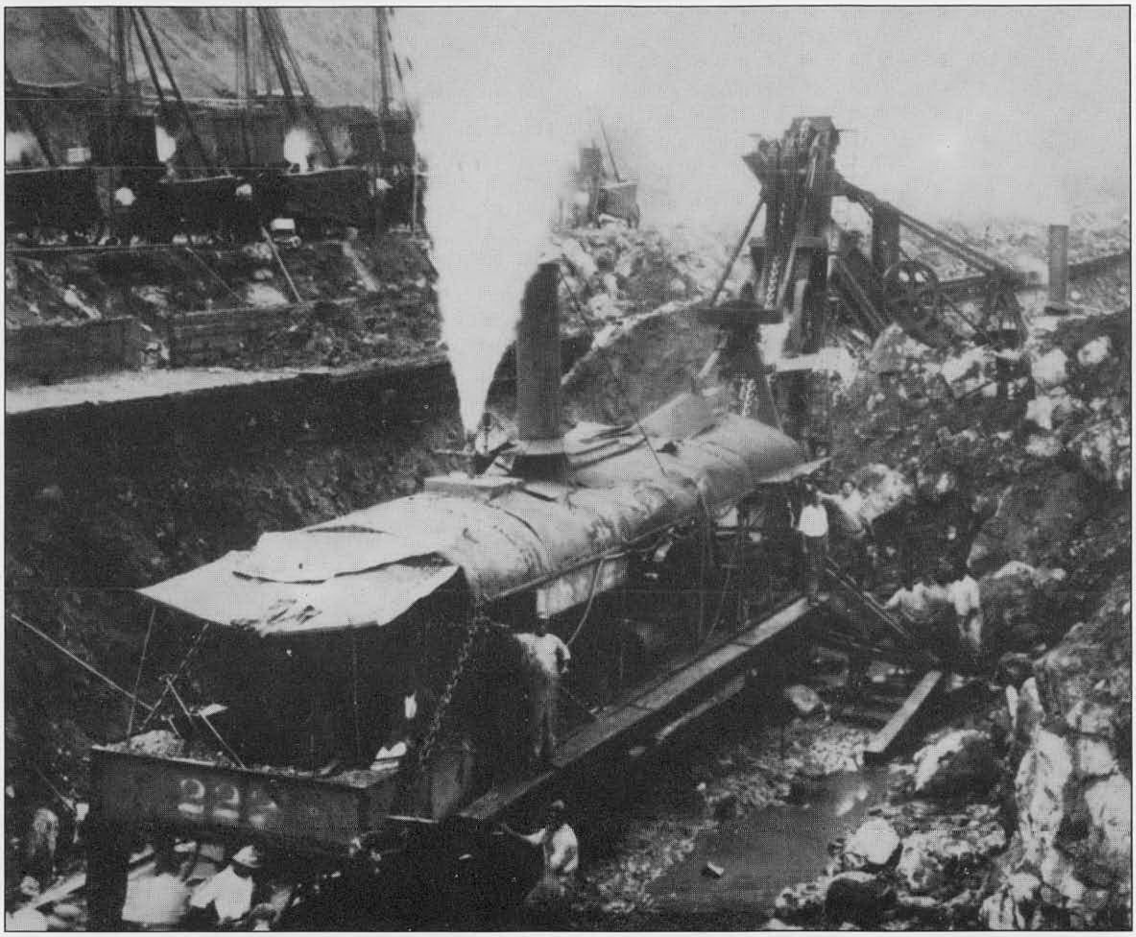

FIGURE 11. Bucyrus steam shovel.

safeguarded the work of the French genius, I had avenged its honor: I had served France."

He might have gone on to say that his company was to receive $453,200 of the $40,000,000 paid to the New Panama Canal Company. Perhaps he did what he did for the glory of France and French genius; or, perhaps he did what he did in order to salvage a bad investment. The actual motivations for his actions will never be known, but this may be one situation where the interpretation that puts him in the best light might be the most accurate one.

It was now time for the United States to go in and pick up the pieces left by France and show the French how American know-how and determination would make the "dirt fly." Such was not the case, however, since the first year of the American effort made the French actually look good. The problem was not a lack of money but a lack of leadership and a circuitous decision-making organization.

John Finley Wallace (see Figure 10), one of the top construction engineers in the United States and President of the American Society of Civil Engineers (ASCE) in 1900, was selected by President Roosevelt to be Chief Engineer. Unfortunately, the Spooner Act prescribed that the project be overseen by a seven-man Isthmanian Canal Commission without explicitly defining what were the lines of authority within the project. In addition, most of the commission was located in Washington, D.C., far away from the work. Given the failure of the French, there was substantial pressure on the chief engineer to produce results quickly. Wallace succumbed to this pressure and was seemingly obsessed

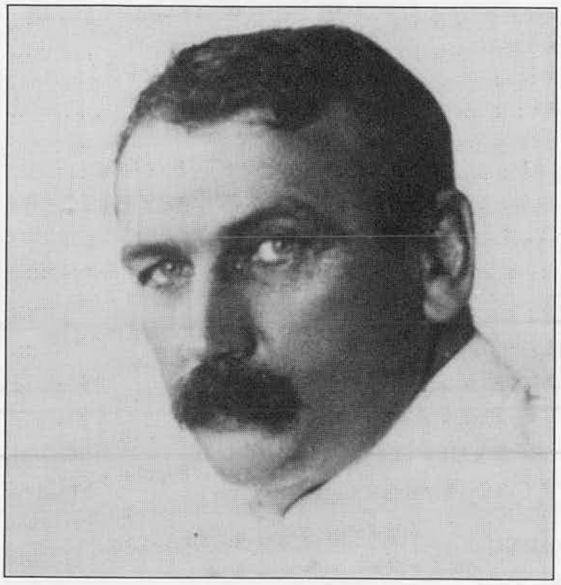

FIGURE 12. John Stevens, second Chief Engineer.

with making the "dirt fly" and, as a result, never really was able to share his plan, if he had one, with his men.

Wallace's staff was also graced with the addition of the noted physician, Dr. William Gorgas, to control the effects of disease on the project staff and workers. Gorgas had been selected for his post because of his experience in clearing Havana of yellow fever in a very short period of time. What he had learned and accomplished there, Gorgas had been assigned to repeat in Panama. However, Wallace did not believe that mosquitoes spread yellow fever and malaria, and, as a result, did not support Gorgas's efforts.

The layout of the area to be cleared of the *Stegomyia* and *Anopheles* mosquitoes was different from Havana, but the procedures to be followed were the same. Gorgas knew that *Stegomyia*, the yellow fever mosquito, would be easiest to eradicate, since he knew their breeding habits, places where they laid their eggs, their range of movement and life cycle. He also knew the importance of keeping these mosquitoes away from infected people. The *Anopheles* mosquito, the carrier of malaria, posed a much greater problem, but at least he knew how to attack them and minimize their effect.

Wallace and the poor organizational structure, however, did not supply Gorgas with the men and materials needed to accomplish his task. As a result, yellow fever returned to the isthmus. Even though the outbreak of the disease was much less severe than in the time of the French efforts, panic set in and many Americans abandoned the project. Morale was poor, output was poor, planning was not evident, corruption flourished, and all Wallace did was keep on digging with the equipment the French had left behind.

Observers would later say that Wallace never had his heart in the job and feared for his life. This evaluation may very well have been true, and the Canal Commission might have been partly to blame for the dismal state of affairs in Panama, but the man at the top must have a vision for a project of this magnitude to succeed in this type of inhospitable environment. The project director must be able to instill confidence and enthusiasm for the task in those engineers that work for him.

Wallace surely should have been up to this challenge considering his background in the United States. The fact that his salary of $25,000 was higher than that of any government official except the President was an indication of how much was thought of him and how much was expected of him. As is often the case when a project is floundering, the man in charge does not measure up to the task.

Wallace's inability to lead was covered up by his constant complaining to the Secretary of War, William Howard Taft, about his problems in getting the supplies he needed. He also brought up again for discussion the old issue of whether the United States should be building a sea level canal or the lock canal that had been recommended by the Canal Commission.

Perhaps his greatest contribution to the canal project was the decision to use the Bucyrus 95-ton steam shovel as the primary excavation machine (see Figure 11). Realizing the sad state of organizational affairs, he asked for more authority and was about to get it when he suddenly resigned (or was fired depending on whose account is to be believed) in June of 1905, less than one year after he accepted the leadership of the greatest construction project ever attempted by the United States. In his own words written ten years later he stated:

"The foundations of all great structures are hidden from sight, and only the architectural effect of an imposing building resting thereon appreciated. Nevertheless without the foundations the final structure could not be erected, and without any expectation of public appreciation either at present or in the future, I felt in my own conscience that my compensation would consist in the personal feeling that during the strenuous period of preparation at least a foundation of ideas in organization and plans had been made, and that the misunderstandings which I may have had with the administration and those above me at least made the way easier for my successors."[3]

It is hard to find anyone connected with the enterprise who agreed with Wallace's appraisal of the foundation that he believed that he had placed or of the plans he had developed. John Stevens (see Figure 12), the second Chief Engineer for the project and Wallace's successor, revealed:

"When I reached the zone, conditions could have been worse, but they were bad enough. No real start at any effective work on the canal project had been made, no organization worthy of the name had been effected, sanitary reforms were really just beginning, little new plant had been provided, and little that was absolutely needed had been ordered . . . In such organization as existed, no cooperation was apparent — exactly the opposite — and no systematic plan, as far as could be discovered, had been formulated toward carrying out the work along lines promising any degree of success."[4]

Stevens also remarked that Wallace had what appeared to be a "thorough case of fright." He was also to note shortly after he began to work that:

"[T]here are three diseases in Panama, they are yellow fever, malaria, and cold feet and the greatest of these is cold feet."

Stevens, a railroad builder of national reputation, was a self-made man who made his career on the frontier working for James Hill in the layout and construction of the Great Northern Railroad. He was a "can-do" man who believed that hard work was the key to success in any venture. When he arrived at Panama in the summer of 1905, he found that the place, as noted above, was in as bad shape as President Roosevelt led him to believe it was. He saw at once that there was no coordination between groups that should have been cooperating, and that the Panama Railroad, which was the key to success, was in terrible condition. He also observed that the men were not being properly fed, housed and cared for. He found that:

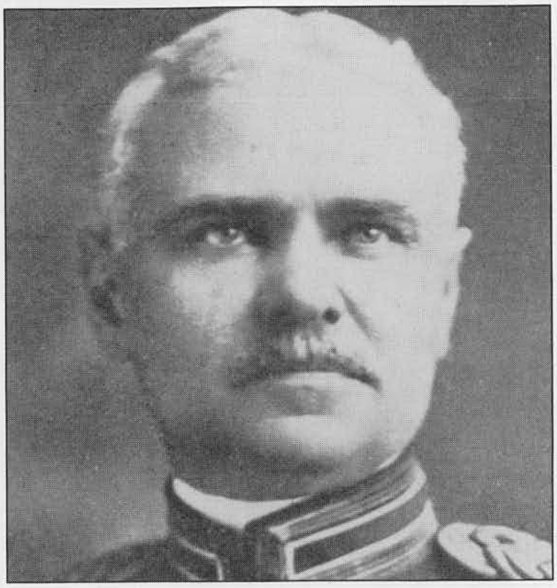
FIGURE 13. George Washington Goethals, third Chief Engineer.

"[W]orse than all, over and above in the diseased imaginations of the disjointed force of white employees, hovered the Angel of Death in the shape of yellow fever."[4]

His first major decision was to suspend all digging until he had determined that the project was in such a state that digging could be efficiently and wisely undertaken. As part of these preparations, he furnished Gorgas with all the resources he needed under the proviso that Gorgas control outbreaks of yellow fever on the isthmus in four months.

While the disease eradication efforts were going on Stevens had additional housing constructed; he arranged to have recreational facilities erected; he brought in food and ice; and he built bakeries for the workers. He then ordered the latest and highest capacity locomotives and dirt cars, upgraded the track, and employing the Bucyrus shovels, which had been ordered by Wallace, laid out a railroad network that would move the dirt efficiently from Culebra and other cuts to the spoil areas. He was everywhere along the route and the workers finally could see that they had a leader who shared with them his vision, enthusiasm and plan. In short, he was everything that Wallace was not.

Stevens also requested more authority than had been given to Wallace. Roosevelt modified the commission to give him what Wallace had requested. This level of authority later proved to be insufficient. Nevertheless, in less than six months Stevens had turned the entire project around and was ready to begin digging.

One of the main problems Stevens faced was that some of the engineers still thought the United States should be building a sea level canal. Wallace had urged Taft and Roosevelt to build a sea level canal before he was replaced. In fact, a commission formed by President Roosevelt with well-known civil engineers making up most of the membership, recommended by a majority vote that a sea level canal 150 feet wide should be constructed. A Senate committee also voted in favor of a sea level canal. On the other hand, Stevens overwhelmingly supported a lock canal. This canal's primary design feature was a major dam at Gatun to store the waters of the Chagres River. The canal as proposed was in fact very much like that described by Godin DeLepinay in 1879 in Paris. Roosevelt, however, listened to Stevens who had seen the Chagres River in flood and decided to approve the lock canal design as supported by Stevens. With that issue finally out of the way, excavation began in earnest and the United States embarked on the years of work necessary to accomplish the task.

Stevens had fabricated a well-oiled machine that offered the promise of success. Things were looking so good that President Roosevelt made a trip to Panama to see for himself what was going on. In one way, his visit was reminiscent of de Lesseps's trips, since he seemed to be everywhere and seeing everything. However, unlike de Lesseps, he came in the rainy season and the workers were amazed to see the President of the United States slogging through the mud. He was to report back to Congress that the "Army of Panama" was at work on this project, the most important construction job in the history of the country.

Suddenly, early in 1907, Stevens began to disturb Roosevelt and Taft with the tenor of some of his statements and attitudes. Shortly thereafter Stevens either resigned, or was fired, once again depending on a subjective interpretation of the events and personalities involved. So, less than two years after he began as chief engineer, he left his post in a most curious manner. In three years the project had had two chief officers. However, the main difference this time from Wallace's vacating the post was that conditions on the isthmus were in far better shape. Stevens later reflected that:

> "We handed over to the army engineers a well-planned and built machine, one that was running fairly smoothly, with perhaps a squeak or a hot bearing here and there, as is always inevitable with new machinery. Improvements in detail could be made, as would have been the case no matter who had been the engineer. But the fact remains that no radical change was made in any of its component parts, and that it proved such a success was no surprise whatever to me."[4]

Roosevelt was beside himself and decided that:

> "[T]he only way to carry forward the great project was to put at the head of the organization a man who would be compelled, under the rigor of military law, to remain at his post of duty."

This man turned out to be Major George Washington Goethals of the U.S. Army Corps of Engineers (see Figure 13). Goethals was the son of Belgian immigrants who settled in Brooklyn in 1848, the year that gold was discovered in Sutter's Creek in California. He attended the

City College of New York for almost four years but did not graduate since he had received an appointment to the United States Military Academy at West Point in April of 1876, the year of the Centennial of the Nation. Graduating in 1880 near the top of his class, he was commissioned as a Second Lieutenant in the Engineers Corps on June 12th.

His assignments prior to his service on the canal included several years of teaching at the Engineer School of Application and at the Academy. He also worked for Colonel William Merrill on the construction of locks and dams on the Ohio River, and as assistant in the design of locks and dams on the Cumberland and Tennessee Rivers. For that project, he had major responsibility for maintaining the river in navigable condition while keeping in operation the Mussel Shoals Canal.

It was on this particular assignment that he rounded out the experience that he would need to succeed at Panama, since he built and operated a 14-mile long railroad that served as a supplement for the construction and operation of the canal. Later, he was to design and build locks at Colbert Shoals that had a vertical lift of 26 feet. This lock represented a remarkable achievement, since up until that time a lift of 14 feet was considered to be a large lift.

After a stint as Assistant to the Chief of Engineers in the Spanish-American War, he returned to teach at West Point. He was subsequently appointed to the National Coast Defense Board, which was also called the Taft Fortification Board. It was in this capacity that he came into close contact with William Howard Taft, Secretary of War to President Roosevelt. He toured extensively with Secretary Taft and made a visit to Panama with him in 1905 during Wallace's year as Chief Engineer. Taft later urged John Stevens to appoint Goethals as Assistant Engineer. Stevens declined this recommendation, since he was looking for a "railroad man" and not a specialist in locks.

With Stevens's resignation, Goethals's time had arrived. It was as if his entire career had pointed him toward this moment and project. He had experience with the design and construction of locks, railroads, and major excavation projects. He also had experience in the management of large numbers of men and demonstrated an ability to work with the bureaucracy and Congress. In addition, he had the support of Secretary Taft and, therefore, of President Roosevelt.

On February 26, 1907, Goethals was appointed Chief Engineer and arrived in Panama in March to take over from John Stevens. Realizing that the civilians at work on the canal were apprehensive about working for a military man who would have other military personnel as his assistants, Goethals stated early on that:

> "I am no longer a commander in the United States Army. I am commanding the Army of Panama, the enemy is Culebra Cut and the locks and dam."

He further told them that the organization would be no more military than in the past, except in the precision of its work, and that no person who did his duty, whatever the person's rank or station, need have any fear of the incoming administration.[5]

Goethals, upon his appointment, possessed complete control of everything that occurred at Panama since Roosevelt had found another way to get around the Spooner Act. The President simply made all of Goethals's assistant engineers members of the canal commission that was called for in the act. In addition, the engineers would all reside on the isthmus and report directly to Goethals. Roosevelt had supposedly informed the new members of the commission that:

> "[I]f at any time you do not agree with his [Goethals's] policies, do not bother to tell me about it — your disagreement with him will constitute your resignation."[5]

The commission consisted of George Goethals, William Gorgas, William Sibert, David Gaillard, Harry Rousseau, Joseph Blackburn and Harry Hodges. All of them were military men except for Blackburn who was a former Senator from Kentucky and who had little responsibility and no authority.

So when Goethals took the reins, the organizational problems were over, a lock canal had been decided on with a dam at Gatun, the

FIGURE 14. Gatun Locks.

railroad had been upgraded and a system for transporting the spoil had been put into place by Stevens. Gorgas had rid the zone of yellow fever and was working on malaria. Housing, food supplies and recreational facilities were provided for the workers and their families. In short, the United States was sparing no expense in order to provide everything needed to ensure the project's success.

Many people who have written about the canal have implied that all Goethals had to do was to oversee the continued functioning of the system that had been established by Stevens. Nothing could be further from the truth:

- Nothing had been done on Gatun Dam other than the taking of borings;
- Nothing had been done on the detailed design of the locks;
- Final plans for harnessing the Chagres River had not been drafted; and,
- No one had developed a plan to stop or minimize landslides.

While evidently not an inspirational leader like Stevens, Goethals gave the impression that he was "one of the guys," and he did gain the respect and admiration of the workers. According to the workers, Stevens was referred to as "Big Smoke," while Goethals was referred to as the "white haired Colonel," the "old man" or "the Colonel." Most, if not all, of the workers on the isthmus would speak highly of Goethals years after the completion of the canal. He always praised the workers and their dedication to the task. He was, however, quick to send home anyone whom he felt was not doing his job.

As an engineer, he completed the plans for the Gatun Dam, the largest earth fill dam ever built. The dam was built in spite of some bad press back in the United States that held that it would never be safe due to excess settlement or that it would never hold water due to "underground rivers."

Goethals also modified the arrangement of the locks on the Pacific side by moving one set of locks back from Sosa Hill to Miraflores because of poor soil conditions encountered at the original site. This solution was also justified from a military standpoint, since Miraflores

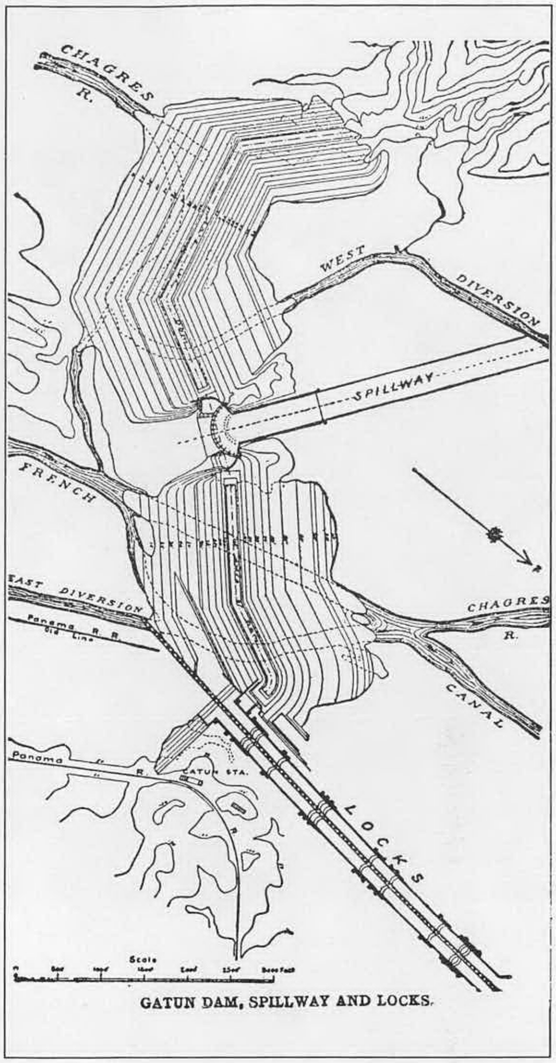

FIGURE 15. Gatun Dam.

was safer from bombardment by ships lying off the southerly end of the canal.

The construction of the dam and locks at Gatun was placed in the hands of Colonel Sibert who had worked on the famous Poe Lock on the Soo Canal and had other experience in building locks and dams around Pittsburgh (see Figures 14 and 15). His relations with Goethals were strained, but they never reached the breaking point. He did, however, get his licks in when he collaborated with John Stevens in a book entitled, *The Construction of the Panama Canal*,[6] in 1915.

The design of the gates for the locks and the maze of tunnels with their huge gate valves

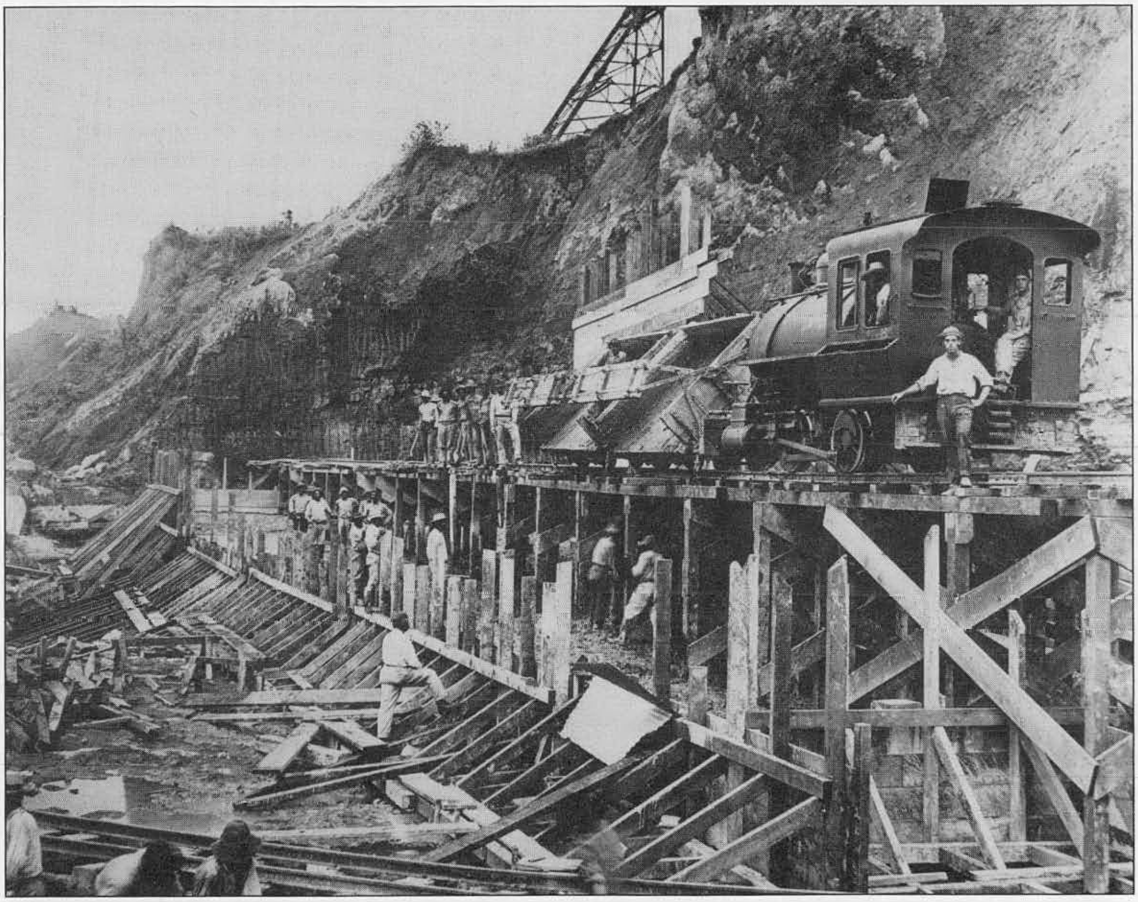

FIGURE 16. Concrete work on the locks.

went to Colonel Harry Hodges. Construction of the locks began in 1907 and was completed in 1913 (see Figure 16). A total of over 5,000,000 cubic yards of concrete was used for the project, with all of the cement and sand having to be shipped to the isthmus. Never had such a quantity of concrete been placed on one project before.

Efficiency was the order of the day and the cost accounting system set up by Goethals was able to track costs accurately and, in many cases, able to challenge the workers to perform better.

But all of these tasks, major though they were, could not measure up in magnitude to the excavation required at Culebra that Goethals had assigned to Colonel Gaillard. When Goethals took over, he estimated that he would have to excavate approximately 54,000,000 cubic yards from the Culebra Cut. Before this part of the project was completed, a total of more than 100,000,000 cubic yards had been excavated. Part of this increase was due to the fact that Goethals had widened the canal to a minimum of 300 feet, but most of it resulted from slides that had began in 1907 and continued throughout the construction of the canal and for many years after it opened. It is hard for an engineer even today to appreciate the fact that slides containing over 7,000,000 cubic yards of material do occur, but that is exactly what happened time and time again. Names like the Cucaracha (famous for its slides) became almost like household words on the pages of *Engineering News Record* and still are found in the soil mechanics books of today.

All Goethals could do when these slides occurred was to tell Gaillard to dig them out. He knew that eventually the slides would stop and the slopes would stabilize. Before the Culebra

Cut was completed, the top width of the cut had increased from a planned width of 670 feet to over 1,800 feet. In many places, the slopes were as flat as 1 to 5. Goethals's system of drill, blast, dig, haul and do it over again day after day, week after week and year after year had apparently succeeded. When he directed that work begin to pull all of the tracks out of the cut in 1913, another Cucaracha slide filled the bottom of the excavation once again. After attempting to dig the slide material out in the dry, he decided to pull up all of the track, flood the excavation and dig using dredges.

Since everything was being completed on schedule and under budget, it became clear to every one connected with the canal that it would be opened in the summer of 1914. Morale was high and, as a result, production was also at a high level. George Goethals was the man of the hour. He had proved himself worthy of the trust that Secretary Taft, President Roosevelt and finally President Woodrow Wilson had placed in him. This military man, this engineer, had become an inspirational leader by example. He became judge and father confessor out of necessity. He was an early efficiency expert in his approach to cutting costs, and even played psychologist by including in the *Canal Record,* the weekly publication of the Canal Commission, details of the production of each shovel crew. This type of recognition created a spirit of competition between shovel crews that resulted in ever increasing volumes being excavated each period.

The canal, when completed, had cost over \$630,000,000 with the United States's share being \$352,000,000. A total of over 260,000,000 cubic yards of materials had been removed and over 5,000,000 cubic yards of concrete were poured. The world's largest earth fill dam had been constructed that impounded the world's largest man-made lake (see Figure 17) and a land that was considered to be a pest hole was now developed and free from the fear of disease. Cities had been built and made habitable, the railroad had been upgraded and Panama was an independent country with a canal.

When President Roosevelt visited the isthmus in 1906, he addressed the workers:

> "You, here, who do your work well in bringing to completion this great enterprise, will stand exactly as the soldiers of a few, and only a few of the most famous armies in all the nations stand in history. This is one of the great works of the world."

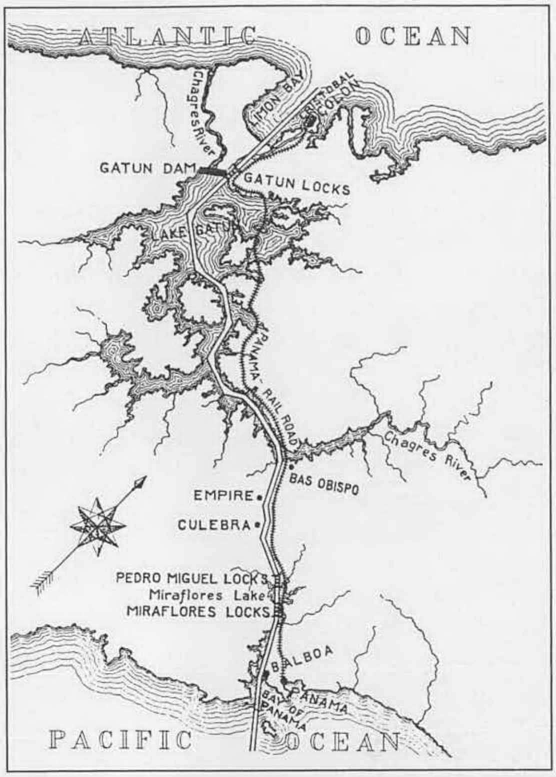

FIGURE 17. Plan of the completed canal and Gatun Lake.

The "Army of Panama" had done its job and they had earned the right to be going home.

Epilogue

De Lesseps died in 1894 a broken man who had been convicted of fraud and mismanagement. Bunau-Varilla returned to victoriously sail through the canal in order to preserve some measure France's honor and contribution to the canal's construction. He was later to lose his leg in the battle of Verdun in World War I. John Wallace would have a very successful career. John Stevens also returned to a very successful practice in civil engineering and ultimately became President of ASCE in 1927. George Goethals would be promoted to Major General and remain as Governor of the Canal Zone until

World War I when he was appointed Head of the Quartermaster Department. Theodore Roosevelt, after running for President again and losing in 1912, would always consider the canal as one of the major accomplishments of his administration. He never saw the completed canal. Eventually, William Howard Taft would become Professor of Law at Yale University after losing in his bid for a second term as President and later be appointed Chief Justice of the United States Supreme Court. Colonel Gaillard would die in 1913 shortly before the completion of the canal. Colonel Gorgas would become Surgeon General and be recognized the world over as the man who, as much as anyone, made the canal possible.

All of these persons in varying degrees, had accomplished what most had thought was impossible — they had *divided the land and united the world.* From that August day over seventy-five years ago, the canal has done what it was designed to do — move ships between two oceans. It is, undeniably, one of the marvels of the twentieth century.

The canal that the "Army of Panama" had built would be enlarged to a minimum width of 500 feet over the years. The Madden Dam would be built on the Chagres River further upstream from Gatun Lake to impound more water in order to meet the needs of traffic during the dry months. This dam, completed in 1936, ensures that the 12,000 transits a year will not deplete the waters in Gatun Lake and will permit a minimum navigable depth in the canal of 38 feet. The small locomotives used to haul the ships through the locks were changed in 1964 after a fifty-year life.

Other than the modifications listed above and some improvements to the canal's lighting and general maintenance systems, the canal was able, fifty years after its opening, to handle all but 103 ships. At an age of more than 75 years, it is still able to handle 93 percent of the ships currently in use. The super tankers, as a class of ship, are all too large to fit into the 110-foot by 1,000-foot locks.

In 1977, President Carter signed a treaty with Panama that resulted in the United States surrendering all rights it gained in the Hay-Bunau-Varilla Treaty of 1903 signed with the newly emerged state of Panama. The Senate, after much debate, ratified this new treaty in 1978. The treaty provides a twenty-year transitional period over which the management of the canal would gradually shift from an American operation to a fully Panamanian operation in 1999.

NOTE — *This article was based on a presentation at a meeting of the BSCES Committee on Younger Members at Merrimack College in November, 1989.*

FRANCIS E. GRIGGS, JR. *is Professor of Civil Engineering at Merrimack College in North Andover, Massachusetts. A member of the Committee on the History and Heritage of American Civil Engineering, he is presently editor of Volume 11 of the* ***Biographical Dictionary of American Civil Engineers.*** *He is interested in nineteenth century civil engineering, particularly bridge engineering with special focus on iron bridges and their builders.*

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The Engineering Center: One Walnut Street, Boston

The new home of the Engineering Center incorporates a rich history and culture to serve as a living monument embodying the best of the past, present and future.

H. HOBART HOLLY

The engineering profession has a proud heritage that can serve as a guide and inspiration for the present and the future. It is therefore most appropriate that the Engineering Center should have as its home a building that is a monument to the past — a constant reminder of our engineering heritage and of our national heritage of which we both are a part.

The heritage that a building represents is the people associated with it, people that will now include the membership and staff of the three sponsoring engineering societies that constitute the Engineering Center: the Boston Society of Civil Engineers Section/ASCE, the Massachusetts Association of Land Surveyors and Civil Engineers, and the American Consulting Engineers Council of New England.

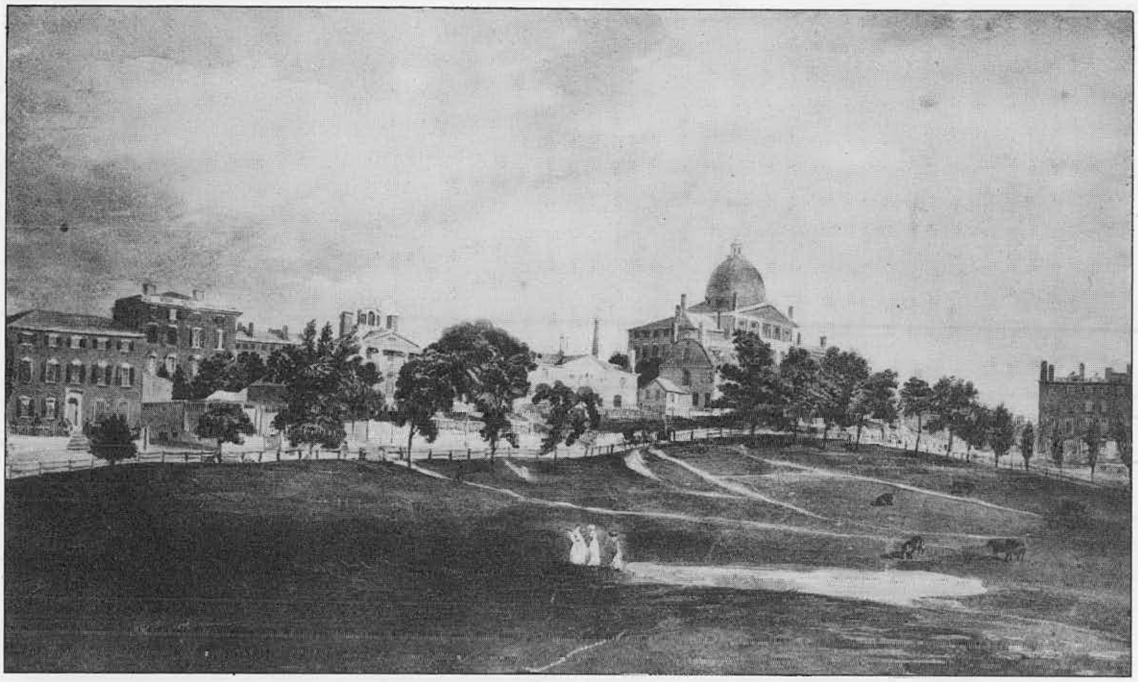
The building at One Walnut Street was the product of Charles Bulfinch, the leading architect of his time. While Bulfinch was engaged as the architect for this building as well as for the Massachusetts State House and many other historic buildings, Loammi Baldwin was serving as engineer for the historic Middlesex Canal, and Simeon Borden was establishing the Borden Base Line. Thus, One Walnut Street stands as a tribute to these pioneers in their respective related fields and to all of those who have made contributions to the Commonwealth of Massachusetts and the nation through the professions they represent.

It is also appropriate that the Boston Society of Civil Engineers Section/ASCE, as the oldest technical society in the United States (established in 1848), should have its headquarters in a building that reflects heritage and prestige.

Henceforth, a visit to the Engineering Center will provide an experience that links the endeavors of the present with a past in which the engineers of today can take pride and inspiration.

Early History

One of Charles Bulfinch's most noted achievements was the design of many outstanding homes on Beacon Hill that established a style of elegance that has made the area on the hill



In the 1809 watercolor by J.R. Smith, the Phillips House is shown at the left with the entrance on Beacon Street. Courtesy of the Bostonian Society/Old State House.

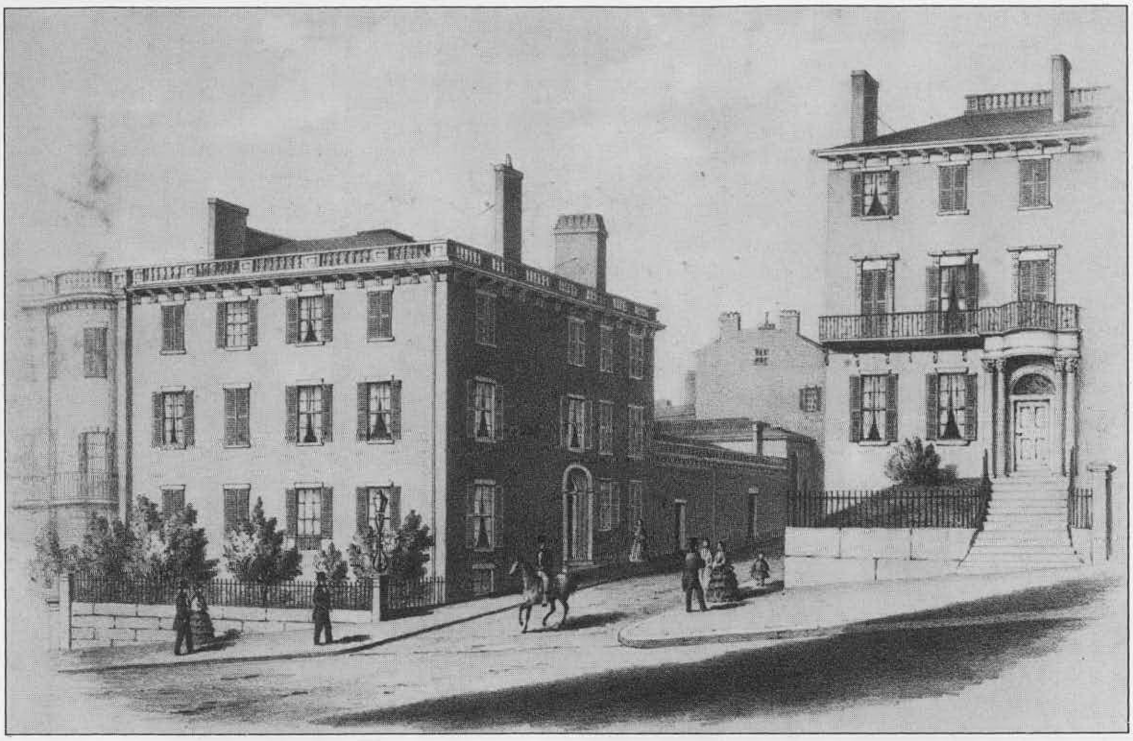
famous. The new home of the Engineering Center was built on the corner of Beacon Street and what is now Walnut Street, with its original entrance on Beacon Street. According to the original development, Walnut Street was laid out as a way in 1799 and did not become an accepted street until some years later. Built in 1804 in the "square style" for which Bulfinch was noted, it was one of the earliest, and most probably the first, brick house on Beacon Street on which it was later numbered 38.

The builder and first resident of the house, John Phillips (1770-1823), was one of Boston's most prominent citizens. From 1804, the year the house was built, until his death he was a member of the Massachusetts State Senate, serving as presiding officer for the last ten years. When Boston became a city, Phillips was elected the first mayor in 1822. He served for one year and declined re-election for reasons of health. Born in the house was his son Wendell Phillips, the famous orator for anti-slavery and other causes.

Of particular interest, the land deed from the developer, Jonathan Mason, to John Phillips contains the restriction that no building in the development shall be over three stories in height, exclusive of cellar and roof, for a period of thirty years. During the Phillips ownership of nineteen years, there is no record of significant changes having been made to the house.

Two years after John Phillips died in 1823, his heirs sold the house to Thomas Lindall Winthrop, who was also a very prominent Bostonian. He served in the State Senate and as Lieutenant Governor of Massachusetts from 1826 to 1832 while he resided at the house. He was highly esteemed especially for his work on behalf of public schools. He served as president of both the Massachusetts Historical Society and the American Antiquarian Society.

To accommodate his large family, Winthrop moved the entrance to the Walnut Street side and altered the Beacon Street facade. It appears that he raised the upper story and made the third-story windows higher, thus enlarging the living space while remaining within the three-story restriction. The ells were added in Winthrop's time and changes were made to the staircase and the interior. Since Bulfinch was still living at this time, it is possible that he



This 1843 view shows the Phillips-Winthrop House with the entrance on Walnut Street. Courtesy of the Bostonian Society/Old State House.

might have had a hand in the alterations.

On Winthrop's death in 1841, the house was sold at public auction to Thomas Dixon. Thomas Dixon brought international fame with him. He was born in London but served the Dutch government as Consul General at Boston and abroad. He was made a Knight of the Netherlands for his services.

During the time of Dixon's ownership, the Boston Society of Civil Engineers was founded not too far away at the United States Hotel in Boston on April 26, 1848. A few months later, on July 3rd, the first regular meeting of the society was held and a room for meetings was found in Joy's Building on Washington Street just a short walk away from the house.

Dixon's family owned the house until 1858 when they sold it to Nathan Matthews. Since Matthews also owned buildings at Nos. 3 and 5 Walnut Street, he made some changes to the house on the side that faced his other properties. Matthews was a self-made businessman who was noted for his philanthropies. He donated Matthews Hall and several scholarships to Harvard.

Matthews lived in the house only two years and then sold it to John Chipman Gray who owned it for but one year. Gray was a prominent lawyer. He served as Judge Advocate, and for five years was a lecturer at Harvard Law School.

Robert M. Mason purchased the house in 1861 but appears not to have taken up residence there until 1866. Mason was a successful Boston businessman whose principal philanthropic interest was the Massachusetts Soldiers Fund. Mason's daughters, Ida M. and Ellen F. Mason, inherited the house in 1879 and lived there together for about fifty years. The sisters were prominent socially in Boston and at summer places in Newport, Rhode Island, and Dublin, New Hampshire. It was Mason who added the building's mansard roof, effectively making it a four-story building, the three-story limitation having long expired. Also added were some Italianate features that may have reflected the Mason family's residence abroad for some years.

The Engineering Center, One Walnut Street, at the present time.

Recent History

In 1931 Mrs. James J. Storrow purchased One Walnut Street from the Mason Estate, and in 1939 donated it to the Judge Baker Foundation as its headquarters. The work performed to transform the former private residence to accommodate institutional functions removed some of Bulfinch's and other later architectural features from the interior, but made it adaptable to the uses of the Engineering Center without requiring extensive alterations. Under this ownership a number of charitable and service organizations had activities in the building, but by far the most important were the Judge Baker Guidance Center and the Boston Children's Services Association.

In 1976 the building was acquired by the Phillips-Winthrop House Trust to serve as the law offices of Mahoney, Hawkes & Goldings. Some interior changes were effected in order to suit its new, more modern function. In 1978 an exterior restoration was accomplished that removed many decorative features that had been added over the years. Most noticeable was the removal of its exterior gray paint in order to expose once more the old red brick. On June 7, 1990, the Phillips-Winthrop House Trust sold One Walnut Street to the Engineering Center Education Trust.

Heritage

The building at One Walnut Street that one views today is an historic building that contributes to, and is part of, historic Beacon Hill. The mansard roof is certainly not Bulfinch, but even with this later addition the Bulfinch lines and features are still in evidence. The changed features that remain reflect the history of Beacon Hill and Boston over the nearly two centuries since the house was built. The interior arrangement is much altered except in the staircase and fireplaces. The proportions of the rooms and much of the original woodwork has been retained, preserving an atmosphere of substance and elegance culled from the past. In this building, engineers can be reminded of their rich heritage on which they base their present and future.

As the Engineering Center, history will be made at One Walnut Street by the engineers associated with it. As these engineers will now become part of the history of the house, their actions will merge into the lives and dreams of the past residents of the house who are the heritage that we inherit.

One Walnut Street represents a proud past. It will be a fitting reminder to those of the engineering societies that constitute the Engineering Center of the great heritage that they represent as they make history today and in the future.

H. HOBART HOLLY *is Chairman of the History and Heritage Committee of the Boston Society of Civil Engineers Section/ASCE.*

Discussion

Applying Orthotropic Deck Design to a Vertical Lift Bridge by W.J. Gaddis and P.W. Clark, Vol. 4, No. 2, Fall 1989, pp. 65-68

ALI TOURAN

The authors of the article "Applying Orthotropic Deck Design to a Vertical Lift Bridge," W.J. Gaddis and P.W. Clark, should be commended for their attempt to bring to greater attention the merits of using orthotropic deck design under special circumstances. The authors have noted, however, that orthotropic steel decks have been used in the United States in only five or six occasions. They have also provided two examples of major orthotropic bridges (the San Mateo Bridge in California and the Poplar Street Bridge in St. Louis).

It is worth noting that more than twenty orthotropic bridge decks have been constructed in the United States *and* Canada in the past three decades. Table 1 provides a listing of some of these bridges, their date of completion and length.

Orthotropic steel decks are an attractive design alternative because they last longer than concrete. They can also be used as a replacement deck for deteriorated concrete decks in congested urban areas without causing major disruption in traffic. The two most recent deck replacement projects using orthotropic decks involved the Golden Gate Bridge in San Francisco (completed in 1985) and the Benjamin

TABLE 1
Orthotropic Bridges in the United States

Bridge Name & Location	Year Completed	Length (ft.)
Humphrey's Creek Bridge, Sparrows Pt., Maryland	1965	112
Dublin Bridge, Hwy. 680, Livermore, California	1965	320
San Mateo-Hayward Bridge, Hayward, California	1967	5,542 of Orthotropic Spans
Poplar Street Bridge, St. Louis, Missouri	1968	2,165
Creyt's Rd. Bridge, I-496 near Lansing, Michigan	1968	192
San Diego/Coronado Bridge, California	1969	1,870 of Orthotropic Spans
Queensway Bridge, Long Beach, California	1969	1,200
Fremont Bridge, Portland, Oregon	1973	2,159
Yukon River Bridge, Alaska	1975	2,300
George Washington Bridge,* New York	1978	4,760
Throgs Neck Bridge,* New York	1984	13,410
Golden Gate Bridge,* San Francisco	1985	8,981
Benjamin Franklin Bridge,* Philadelphia	1987	7,412

* Deck replacement only.

Franklin Bridge in Philadelphia (completed in 1987). In both of these projects, concrete decks were replaced with steel deck modules while keeping all travel lanes open during peak hours of traffic flow.

ALI TOURAN *is an Assistant Professor of Civil Engineering at Northeastern University. He holds M.S. and Ph.D. degrees in civil engineering with an emphasis on construction*

management and engineering from Stanford. His areas of expertise are construction cost and productivity analysis, simulation modeling, and heavy construction equipment and methods. He has performed research in concrete productivity, simulation and tunneling, material handling and bridge deck construction. He has lectured on construction process simulation, and data collection and analysis.

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