SHRP-S-664

Concrete Bridge Protection and Rehabilitation: Chemical and Physical Techniques

Price and Cost Information

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Abstract

The purpose of this report is to provide cost information on chemical and physical techniques for concrete bridge protection and rehabilitation. The information provided here constitutes an essential component in the process of determining life-cycle costs for ranking of alternative protection/rehabilitation techniques.

Most of the cost data were obtained from bid tabulations provided by state highway agencies (SHAs). Fourteen SHAs and two toll road agencies, covering all major geographic regions of the country, were visited. Twelve of these provided bid tabulation data. A total of 829 tabulations were utilized.

Costs obtained from the bid tabulations were converted to mid-1991 national average values. The procedure developed to do this was derived from published cost indexes. The national average cost data for each protection/rehabilitation treatment were then subjected to detailed statistical analysis in order to develop cost models reflecting the effects of four independent variables--work quantity, number of bids, total contract cost, and cost of maintenance and protection of traffic. Eight combinations of these four variables ("factors") were developed to be the independent variables in the regression analyses. An inverse power mathematical model was used. The ultimate choice of factor in each case rested with the regression coefficient (R^2).

It was not possible to obtain sufficient bid tab data on five of the techniques. Some are new or relatively new and therefore have no to little historical data associated with them. Others are of such nature that the costs related to them are not available as definable bid items. Rather they, or their components, are embedded in the other bid items. In these instances, costs were estimated using classical engineering estimating procedures.

Executive Summary

Rational decisions regarding the choices of procedures for the protection or rehabilitation of concrete bridge members, where alternative choices exist, must be done on the basis of life-cycle costs. The input information needed to calculate life-cycle cost is defined by those elements that constitute the life-cycle cash flow for the candidate procedure. This report covers one of those cash flow elements, initial costs, relative to the range of alternatives available for protection or rehabilitation of concrete bridge members using chemical or physical techniques.

The general approach used here was to obtain historical cost data for the various techniques, and to develop statistical cost models that reflect the effects of certain factors on costs using regression analysis techniques. The cost data were obtained from bid tabulations provided by highway agencies. Fourteen state highway agencies (SHAs) and two toll road agencies were visited. Not all of the agencies visited were able to supply requested information in time to be included in the study. A total of 829 bid tabulations from the following agencies were evaluated:

- California Department of Transportation
- Florida Department of Transportation
- Illinois Department of Transportation
- Indiana Department of Transportation
- Kansas Department of Transportation
- Montana Department of Highways
- New Hampshire Department of Transportation

- Pennsylvania Department of Transportation
- Pennsylvania Turnpike Commission
- Texas State Department of Highways and Public Transportation
- Vermont Agency of Transportation
- Washington Department of Transportation

All cost data were normalized to mid-1991 national average values using factors developed from published cost indexes. The converted cost values for each protection or rehabilitation treatment were then subjected to regression analyses in order to develop a statistical cost model for that item. Four variables, known or suspected to have significant affects on bridge treatment costs, were used in eight combinations ("factors") as the independent variable. Cost data were regressed against each factor using an inverse power mathematical model. The four variables are:

- the quantity of the particular bid item in the contract
- the number of bids for the contract
- the total contract cost
- the cost for maintenance and protection of traffic during construction.

A statistical parameter, the regression effect (R^2), was used as the indicator of best fit. Costs for five of the protection or rehabilitation procedures could not be determined using the procedures described due to insufficient data in the bid tabulations. The lack of sufficient data for these items stems either from the fact that they are relatively new or that their cost components are embedded in other costs in the bids and they do not appear as unique, identifiable items. Costs for those items and the new methods developed under SHRP C-103 were determined using classical engineering estimating procedures.

It must be pointed out that the costs developed in this report for the various bridge treatment procedures are mid-1991 national average costs. They are intended to be used in life-cycle cost calculations for the purpose of broad-based policy decisions. <u>Estimates</u> for specific cases can be made by applying the geographic and time factors in this report to the cost figures. However, significant errors may occur due to the multitude of variables that can affect costs on site specific basis.

1

Introduction

Purpose

The ultimate goal of the C-100 series of SHRP projects is to develop the technology to minimize life-cycle costs of reinforced concrete bridge components. This implies the development and use of economic models that will be employed to evaluate life-cycle costs.

The mechanics of economic models for the evaluation of alternatives based on life-cycle costs are relatively simple and widely understood and accepted. The difficult part is the identification of the technically suitable alternatives and the input variables of which they are constituted. The input variables consist of costs and service lives of the definable constituents for each alternative.

The purpose of this work is to provide cost information on a number of techniques used to repair or protect bridge components. The data will be utilized in combination with the respective service lives, for determination of the life-cycle costs.

Scope

Bridge Repair/Protection Treatments

The various systems for which cost information will be developed in this report are as follows:

- Deck Patching: Patching repairs at specific locations on bridge decks
  -portland cement concrete
  -quick-set hydraulic cement materials
  -polymer mortar or concrete

- Deck Protection Systems: more widely accepted as standard than experimental which are applied to the entire deck surface at one time
  -latex-modified concrete overlays
  -membranes plus asphalt cement concrete overlay
  -low-slump, dense concrete overlays
  -sealers

- Experimental Deck Protection Systems: more widely accepted as experimental than standard which are applied to the entire deck surface at one time.
  -thin polymer overlays
  -micro-silica concrete overlays
  -polyester overlays

- Structural Patching: Patching repairs at specific locations on structural elements.
  -portland cement concrete
  -quick-set hydraulic cement materials
  -polymer mortar or concrete

- Structural Protection Systems: to entire surface areas of structural elements
  -encase with portland cement concrete
  -sealers
  -shotcrete
  -coatings

- New Deck Protection Systems: applied to the entire deck surface
  -deep polymer impregnation
  -deep corrosion inhibitor impregnation

-spray-on inhibitor, inhibitor modified concrete overlay system
-resin-modified bituminous concrete

- New Structural Patching: Patching repairs at specific locations
  -corrosion inhibitor modified patch concrete
  -spray-on inhibitor, inhibitor modified concrete patch system

Cost Components

In order to promote valid comparisons among bridge component patching/protection systems by life cycle cost analyses, it is imperative that the costs used be consistent and composed of the appropriate cost components. The potential components of cost in this sphere of activity are:

- Engineering Costs
  -design
  -preparation of plans and specifications
  -bidding
  -construction

- Installation
  -labor and supervision (including fringe benefits and overhead)
  -materials
  -equipment
  -mobilization
  -traffic maintenance and protection
  -insurance and surety bonds
  -field office
  -inspection and testing
  -contractor profit (gross-including taxes)
  -contract administration

- User Costs
  -delay
  -vehicle operation
  -safety (risk factors and consequences)
  -vehicle maintenance

- Effects on Regional Economy
- Environmental Impact

Obviously, not all costs components are applicable in all situations. Furthermore, for a given treatment, the applicable cost components will depend upon whether the work is accomplished by contract or force account. It should also be evident that some of the cost components will vary widely as functions of additional factors. Examples include traffic maintenance and protection, which is primarily dictated by traffic volume, and contractor related costs (e.g. mobilization), which are heavily influenced by work volume at the site and regional business climate.

Of necessity, these cost evaluations should be of national or broad regional scope (i.e. policy decisions). Therefore, cost components which are highly site specific, in general, should not be included in determining costs. However, a degree of judgement will be required here. If a key factor in the cost of a particular alternative involves a highly site specific cost component, it will be necessary to include it in the cost. An example might be the analysis of bridge deck rehabilitation techniques where the key advantage of some particular method lies in its ability to be accomplished without impeding traffic flow on the bridge. Obviously, traffic maintenance and protection -- a highly site specific cost component, as previously noted -- cannot be ignored in that instance.

Because of the variations in cost with time due to inflation/deflation, it is important that cost data collected have applicable dates (years) associated with them. This will permit reducing data to a common "base year" using one of the published "price indexes." Also, cost data for each applicable cost component should be collected from as wide a population (geographically and chronologically) as possible in order to establish the variability and dependability for sensitivity analyses.

Based on the aforementioned considerations, the following guidelines were used in this research to determine the appropriate values for the identified treatment systems.

- Ignore road user costs, effects on regional economy, and environmental impacts, assuming that they will be constant for all of the alternatives involved in a given classification in the study matrix.
- For each classification in the study matrix, determine whether the activity is most commonly carried out by contract or by force account.

- The cost components that should be included in contract work (whether initial or maintenance) are:
  -engineering
    *design
    *preparation of plans and specs
    *preparation of contract documents
  -contract amount, excluding traffic maintenance and protection
  -inspection and testing
  -salvage values, if applicable

- The cost components that should be included in force account work (again, whether initial or maintenance) are:
  -labor and supervision (including fringe benefits and overhead)
  -materials
  -equipment
  -inspection and testing
  -salvage values, if applicable

Notice that while maintenance and protection of traffic will not be specifically included as a cost component, it will be employed as a factor in regressing costs from bid tabs. The reason for this is the strong possibility that it may be an indicator of combined conditions that account for some of the variability in observed bid tab prices.

Approach

There are two basic approaches to acquiring the required cost information. The first involves the use of classical engineering estimating techniques. It is the most rational approach, and it provides an established and a rigorous regimen. The second approach is the empirical procedure involving the systematic examination and evaluation of archival cost data. The major problem associated with the latter approach is that there is usually insufficient documentation of details regarding the components of the cost figures. Thus, wide variations often occur between different jurisdictions because the components of the generated cost figures are not totally comparable. Likewise, it is generally not possible to find empirical data that exactly matches the sought after cost figure in terms of the desired cost components. However, the empirical approach does have the advantage of inherently incorporating subtle influences on cost figures that generally can not be accounted for using straight estimating procedures (e.g. business climate, quantity effects and productivity). The approach originally proposed for this Task was a hybrid of the rational and empirical techniques, attempting to take maximum advantage of the attributes of each methodology. Unfortunately, this becomes costly and it was for this reason that SHRP staff issued a directive to pursue the cost matter using the strictly empirical approach. Reemphasizing, the two major shortcomings involved in utilizing archival data are:

- Some specific cost activities sought will not be represented by available data.
- The components of presented cost figures in most cases will not be precisely defined causing considerable variability in the data among the reporting jurisdictions.

The expected high variability of the data is one of the factors that necessitated the compilation of an extensive data base. Two factors exacerbated the situation:

- The use of the treatment systems under evaluation varies regionally (i.e. no one jurisdiction is likely able to provide data for all treatments).
- Costs for the same activities vary due to regional economic climates.

The significance of the factors cited above should not be underestimated. Experts in the field [illegible] bridge construction and rehabilitation costs agree, for example, the regional costs for the same activity or treatment can vary by as much as a <u>factor</u> of three. Again, the point of this matter of high variability, both within jurisdictions and regionally, is that extensive data bases had to be compiled within a number of jurisdictions carefully selected from across the entire country in order that the resulting cost figures be meaningful.

2

Data Acquisition

Research Plan

The purpose of this study was to provide cost information for the five patching/protection systems previously identified, it was necessary to develop a research plan which would provide a thorough understanding of the factors which affect these costs. Due to time and financial constraints, and at SHRP's urging, an empirical method was used to develop these costs.

There are several drawbacks associated with basing costs estimates solely on the examination and evaluation of archival cost data. The primary source of this archival cost data is contract bid tabulations from State Highway Agencies (SHAs). The cost associated with a specific treatment system is reported as a unit cost on a contract document. Unfortunately for this research, the contractor is only required to reveal the unit cost, and not the components of this cost. For example, for a latex-modified overlay, the cost associated with calibrating mixers, engineering any necessary formwork, inspection and testing and salvage values are not detailed in the bid price. Without this itemized description, it is difficult to project historical costs to determine future costs due to the variability associated with these unreported components. Other problems arise when there are not sufficient historical data on which to base a cost estimate. Regional variations in cost, due to economic conditions, and frequency of applications can also be significant both within a particular SHA and among them. In order to attempt to use historical data as a basis for future costs it is necessary to establish an extensive data base of costs from carefully selected states across the country.

States Visited

The strategy used to determine which states to visit was based on geographic location, which SHAs used the systems under consideration, and the ability and willingness of the SHA to provide the needed historical data.

Preliminary decisions about which states and Canadian Provinces to visit were based on geographic location and previous knowledge of each SHAs bridge management system. Initially, there were twenty states, the Province of Ontario, the Pennsylvania Turnpike Commission and the New York Thruway Authority under consideration, as shown in Figure 2-1. The SHRP coordinator for each of these highway agencies was then contacted and asked if their SHA was interested in aiding this research effort. All state coordinators agreed to assist in any way possible. After the proper officials were identified, they were contacted, informed of the project, and agreement was obtained to provide some preliminary information. They were asked about methods and systems used by their SHA to repair concrete structures and the approximate number of applications of each.

After analysis of this information the following agencies were decided upon: Washington State DOT, California DOT, Montana DOH, Kansas DOT, Texas DOH, Indiana DOT, New York State DOT, New York State Thruway Authority, Pennsylvania DOT, Pennsylvania Turnpike Commission, North Carolina DOT, Florida DOT and Ontario Ministry of Transportation. Upon further discussion, the Ontario Ministry of Transportation was found to be unable to release information required for the research and was dropped from consideration. Visits to the remaining agencies were completed by December 13, 1991. Four additional states were visited in January and February of 1992 in order to provide additional data on low-slump dense concrete overlays and deck membrane systems. These states were: Vermont, New Hampshire, Iowa and Illinois. The total number of SHAs visited was sixteen. Figure 2-1 shows the geographic distribution of the states considered and visited.

Unfortunately, due to time constraints on the parts of the SHAs from New York and Iowa, it was not possible for them to provide information in time to be included in this report. Information from North Carolina DOT was reportedly lost in the mail and could not be replaced in time to be included.

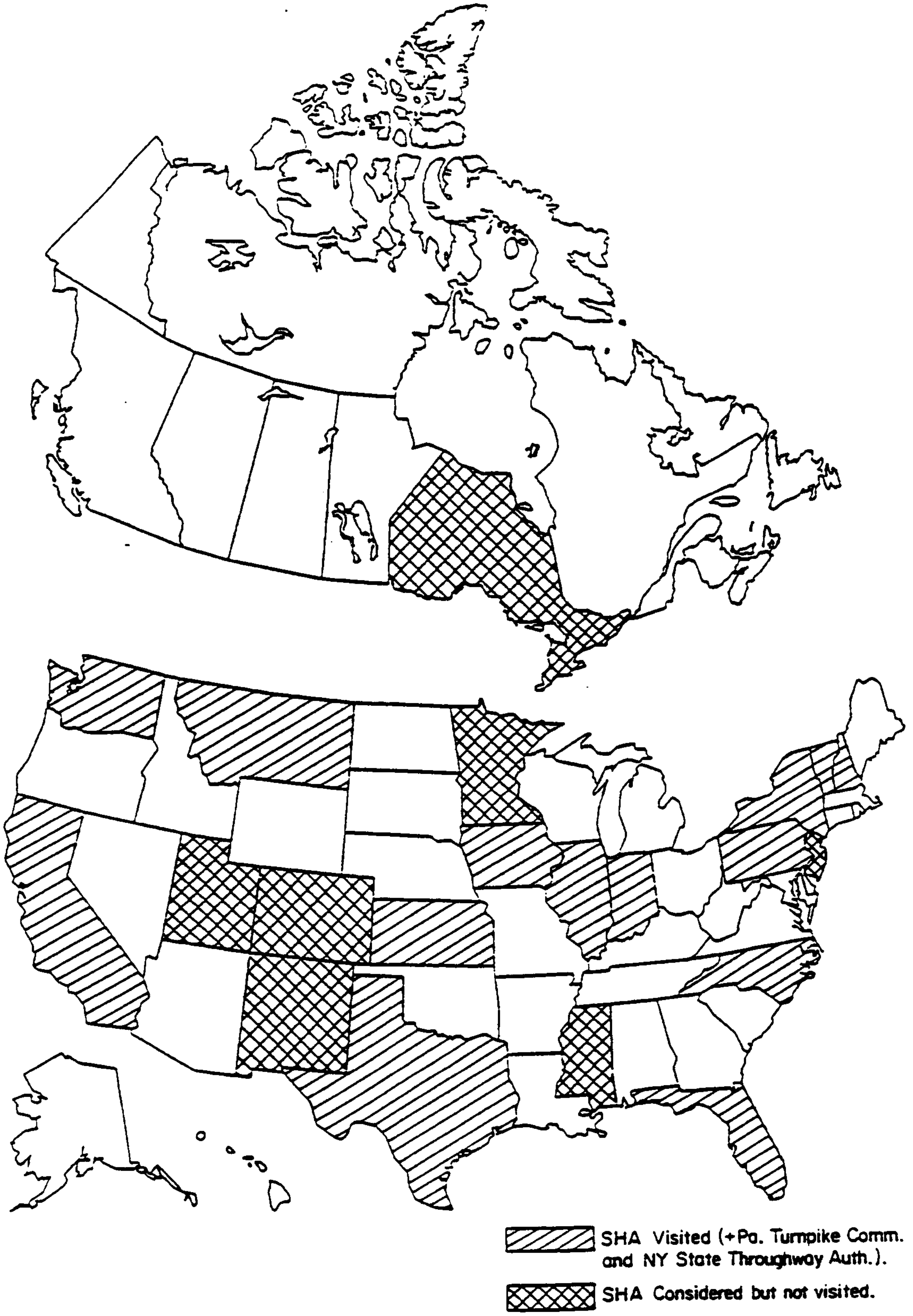


Figure 2-1. Locations of highway agencies visited.

Data Sources

The seven systems identified for cost analysis were: patch deck treatments; conventional surface area deck treatments; experimental surface area deck treatments; patch structural treatments; and surface area structural treatments; and new surface area deck and new patch structural treatments. It was necessary to determine the components of the costs associated with each of these systems.

Several guidelines were developed to aid in the determination of these costs. Road user costs, economic effects, and environmental impact were ignored since these costs are approximately equal for all alternative methods for each system. It was necessary to determine whether a system was more likely to be performed by contract or by departmental forces because the components of cost differ between the two. For contract work components include preliminary engineering costs (design and preparation of plans, specifications and other contract documents), maintenance and protection of traffic costs, inspection, testing and construction engineering costs and salvage values. For systems applied by maintenance forces, the cost components include materials, equipment, labor and supervision (including overhead and fringe benefits), preliminary engineering, inspection, testing, construction engineering and salvage values.

Contracted Work

The information available from the highway agencies for contract work was in the form of bid tabulations, standard specifications and special provisions.

A total of 829 bid tabulations was obtained from the SHAs. Table 2-1 presents a breakdown of the number of contracts obtained from each state and the years in which they were let. The contracts obtained from the SHAs were for bridge rehabilitation projects involving the treatments and systems previously discussed. Each SHA provided access to historical data. While all contracts were generally available in an archival form (microfilm or computer tapes), only a limited number of years were in readily accessible form (paper copies). The years for which data were available was limited by available storage space, and ranged from 1981 to 1991.

During the visits to the SHAs, all available contracts were obtained and preliminary analyses were performed to determine the types of techniques applied and their applicability to the research.

Table 2-1. Number of contracts.

	YEAR											
STATE	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	TOTAL
CA					4	6	5	7	8	9	10	49
FL					10	10	7	4	3	3	4	41
IA												0*
IL									23	37	14	74
IN							47	41	25	30	40	183
KS					10	13	13	8	12	28	13	97
MT		1	1	1					1	3	1	8
NC												0*
NH				6	11	27	7	16	19	13	14	113
NY												0*
PA						17	31	20	16	26	15	125
PT						5	1	4	2	4	5	21
TX							2	2	1	2	2	9
VT					2		12	1	4	7	9	35
WA	1				2	7	16	10	11	12	15	74
TOTAL	1	1	1	7	39	85	141	113	125	174	142	829

*SHA failed to provide bid tabulations.

Copies of the contract bid tabulations were then obtained for more detailed analysis. Of critical importance to the project was the ability to use the cost information obtained from each to determine a national average cost for the specified repairs. In order to develop these national trends it is necessary to compare and analyze similar treatments. To insure that similar materials, methods and procedures were being compared, standard specifications and contract special provisions were obtained for all of the applicable treatments used by all SHAs. These documents played an important role in allowing comparisons for a given treatment among the different SHAs when the pay quantity for that treatment differed.

Maintenance Force Work

Along with contract work, consideration was also given to analyzing costs associated with repairs performed by state highway maintenance forces. When the SHAs were visited, interviews were conducted with the administrative maintenance engineers and, when time permitted, with district maintenance engineers. Any relevant data available was obtained.

Surprisingly, almost half (seven of fifteen) SHAs could not provide any information other than gross amounts spent on bridge maintenance. In those instances there were no systematic procedures to determine what repairs were performed on which structures and how much money was expended performing these repairs. Future needs were based on historical budgeting with adjustments made for inflation and the anticipation of additional work. Maintenance work was then performed until the budgeted amount was expended. Despite this apparently haphazard funding method, all maintenance engineers interviewed were aware of problems associated with these systems and they expressed regret that the systems could not or would not be improved. These engineers understand the need for cost models and effective bridge management systems but they are limited by the immense amount of work required to computerize their maintenance systems.

Eight states which were visited have operational maintenance management systems (MMS) which can provide detailed data on maintenance force repair costs. The MMS provides a breakdown of costs based on cost centers or work codes. The maintenance crews report which structures were repaired, the cost of the repair (materials, equipment and services purchased or used) and the crew size and hours worked. The MMS then uses this information to calculate total costs, productivity and unit costs.

These systems provide the maintenance engineer with a good basis to track costs and predict future needs. However, the information generated by some of these systems is inadequate for use in analyzing costs. The main reason is that the cost centers used are not specific enough to provide the required insight into the types of work performed. Four of the eight states have only two cost centers for the repair of concrete structures: deck/superstructure repair and substructure repair. These very general work descriptions do not allow for the detailed cost information required for the various patching/protection systems. The other states' MMS's have either four, five or eight cost centers for concrete repair. Although these centers provide a more narrow scope of work, they are not sufficient to represent the treatments under consideration. For example, for "concrete deck repairs," there is typically no information presented on the depth of repair, or the materials used in the repair (portland cement concrete, rapid setting concrete, epoxy concrete or asphalt).

The most commonly performed repairs by maintenance forces are the repair/replacement of expansion joints and bridge railing and the patching of deck spalls. Most maintenance forces do not overlay decks or get involved in other extensive rehabilitations because they are limited, by state law, as to the dollar amount of work performed. Another problem which arises is that overhead and administrative costs are not reported in the costs developed by the MMS.

Because the type of work or treatment system used is not specifically reported, and most of the treatments considered are not performed by maintenance forces, it is difficult to compare costs for contract and maintenance force work. For these reasons it is not possible, based on currently available information, to provide accurate costs for maintenance force repairs.

Engineering Costs

When developing life-cycle cost models for use in comparing various alternatives for bridge rehabilitation, it is necessary to include the cost of any engineering involved in the alternatives. The methods under consideration are generally accepted as being standard repair techniques. There is a great deal of effort spent in developing these standard repairs and time spent analyzing the methods and materials, but once the standard has been developed, little engineering is required. Also, while there may be considerable engineering time involved in performing detailed investigations into structure condition, once the decision is made to correct a problem, very little engineering is required for most repairs. This is especially true of deck repairs.

This assumption of little engineering cost associated with repairs may not be true for super- or sub-structure repair. These types of repairs are usually not as generic as deck repairs, and often require additional engineering to design formwork and provide necessary details. There is also a considerable amount of engineering effort expended on developing maintenance and protection of traffic (MPT) plans. This is especially true in urban areas where thousands of vehicles per day may pass through a construction site. Determining these costs, based on historical data, is difficult.

Every state visited employs some method to determine the amount of money spent on engineering since this information is required by the Federal Highway Administration (FHWA). However, the energy expended by the various SHAs in tracking the exact sources of these costs varies tremendously. The vast majority of the fifteen SHAs visited could not readily supply information on what specific engineering activities cost. They do track costs involved in preliminary engineering (design, and contract development) and construction engineering (testing and inspection), however.

The California Department of Transportation (Cal Trans) has developed a cost monitoring system which provides considerable detail on costs and their sources. This system presents information on a per contract basis for both labor costs and expenditures other than labor. There are approximately 100 activity codes used for indicating the sources of labor costs. These tasks vary from general administrative duties to very specific tasks. There are eight activity codes related to engineering design, four of which deal with structures and one with traffic control. Unfortunately, breakdown of the design costs is not fine enough to provide insight into engineering costs of repairs, but rather only a general grouping for structural design. While this system provides Cal Trans with detailed information regarding cost expenditures, it does not provide information in sufficient detail to develop engineering costs for repairs.

Had specific engineering cost information been available, more exact models would have resulted. However, not including this information will likely have little effect on comparative results. One of the guidelines developed to aid in the determination of costs was to ignore any costs which have approximately the same effect on all alternatives. MPT engineering costs are approximately the same regardless of repair treatments used, as is the engineering associated with most repair methods. While it is realized that costs may be significantly different in some specific instances, the models to be developed here are intended to be used for more general cases, resulting in little effect from engineering costs. Because there is insufficient specific data available and the costs will generally affect all treatments in about the same fashion, no further consideration will be given to engineering costs. The exception to this is the more experimental and new treatment techniques where the costs have to be estimated due to lack of empirical data. In these instances, engineering costs will be included in the cost estimates developed.

Salvage Values

The salvage value remaining when the end of service life is reached is an important factor in life-cycle cost modelling. Salvage value can effect the decision of which method to employ. The salvage value is most often thought to be a positive value, as in a trade-in allowance or resale, however, in the construction industry the salvage value can be an expense. It may be necessary to dispose of construction materials off-site, in a landfill, and the cost can be high. This cost is increased considerably if hazardous materials are salvaged.

After interviewing design engineers, estimators and construction personnel in the fifteen SHAs it was evident that little consideration was given to salvage values in either contract or maintenance force work. Only in rare cases is salvaging material ever considered on bridge rehabilitation work. When salvaging occurs, it is usually for readily reusable items such as guide rail, steel and prestressed concrete beams, and highway lighting fixtures. This occurs only rarely since storage space is limited, or the method or material has become obsolete (e.g. in the case of guide rail). In the case of added cost to dispose of material, most contracts include these costs in the bid item. The material or equipment becomes the property of the contractor and its proper disposal is required. It is expected, that if contractors wish to remain competitive, they will seek the lowest cost for disposal or the highest price for resale. This cost is then passed through to the state in the bid price.

As discussed before, maintenance work expenses are generally more difficult to track than contract repairs. In most cases only direct expenses and income are accounted for. Disposal of materials is only considered if there is a fee involved. No benefit is acknowledged if the material is reused. When maintenance work is performed, it is done to provide a safe structure to the travelling public, and any possible salvage value is considered secondary.

Because the salvage value is already considered in the contractor's bid price and maintenance force account work will not be considered here, no further effort regarding salvage value is needed in this study.

3

Data Analysis

General

Upon completion of the data acquisition phase, there were 829 contracts from 12 state highway agencies (SHAs) which were let from 1981 through 1991 that required analysis, as summarized previously in Table 2-1. In order to pool the data from different geographic regions and different years, it was necessary to develop both geographic location and inflation factors to adjust the acquired data. The data were then broken down by treatment type, entered into a data base and regression analyses were performed. When sufficient data were not available for specific methods, engineering cost estimation techniques were used to provide the needed models.

Cost Data Adjustment Factors

Introduction

Cost data obtained from the selected state highway agencies for any given bridge protection/repair/rehabilitation procedure will vary appreciably. Two of the factors that affect cost variation are time dependent economic conditions (inflation or deflation) and regional effects (a function of a number of variables ranging from local business climate to logistics and workforce demographics).

The purpose of this section is to develop the rationale and procedures to convert the cost data from the selected highway agencies to values that can be used for comparing alternatives on a national scale.

Methodology

Possible Approaches

The cost data used in this study were mandated by SHRP to consist of historical cost information from State Highway Agencies. Therefore, the general approach to cost adjustment is limited to the application of appropriate cost indexes. Of course, the cost figures for the few "experimental" or new procedures, or for others for which archival cost data do not exist with the state highway agencies, are exceptions.

Published Cost Indexes

Cost and price indexes are composite costs or prices for given quantities of specified goods or services representing defined sectors of business, trade, commerce, or industry (*1-3*). Usually, they are compiled as a function of time, and are thus indicators of the effects of inflationary or deflationary pressures within their respective spheres (*2-5*). However, they can be compiled as functions of any variables that affect costs or prices, such as geographic location (*3-4*). Because of the wide and varied range of influences on costs and prices it is not possible to compile indexes that relate uniquely to single variables. Often, these varied influences will not be readily apparent.

In the construction field, cost indexes are compiled in two different ways (*3*). One way involves pricing and totaling the cost of a defined package of components that serve as the input to a typical construction project of specified purpose and scope. The second is based on the mean total costs for the construction of facilities of specified type and scope.

There is a number of cost indexes related to construction and associated activities (*3*). The "Quarterly Cost Roundup" feature appearing four times a year in Engineering News Record (*6*) currently lists 18 of them under the subheading "Builders Indexes." The specific areas for these include general construction, general building, and industrial, commercial/ manufacturing, refinery and chemical plant construction.

Problems, Precautions, and Limitations in the Use of Cost Indexes

Cost indexes possess a number of shortcomings that necessitate caution in their use. First, it must always be remembered that cost indexes are average costs and must therefore be applied with discretion to specific cases (*1,2*). Further, cost indexes are compiled for particular purposes and the subject areas in their use must closely match the respective areas (*1,3*). It is important to recognize the geographic and demographic bases of indexes in order to apply them properly (*3*).

Cost indexes should not be used for cost projections beyond 4-5 years; accuracy falls off rapidly beyond this period (*1*). Some of the other shortcomings of cost indexes include:

- Since cost indexes are derived as reproduction costs, they do not account for technological improvements. Therefore, they have a tendency to overstate costs (*2-4*).
- Often there is a significant reporting time lag so that "current" figures may not be sufficiently accurate (*2*).
- In general, cost indexes lack sensitivity to short-term economic cycle swings.

Accuracy of Cost Indexes

The accuracy of results obtained through the use of cost indexes depends highly on the degree of attention paid to the factors described in the previous subsection. It cannot be overstressed that cost indexes must be selected based on detailed knowledge of the make up of the index and the application of sound engineering judgement. It has been reported that, properly applied, indexes can yield accuracies within 20 to 30 percent of actual costs for specific cases (*3*). For mean costs, the accuracies would be expected to be much better than this.

Cost Indexes Investigated

After a review of available cost indexes related to the subject area of this project (protection/repair/rehabilitation of concrete bridge components), the following four were selected for more detailed consideration:

- FHWA Federal-Aid Highway Construction Price Index (*7*)
- FHWA Highway Maintenance and Operating Cost Index (*7*)
- Engineering News Record Construction Cost Index (*6*)
- R.S. Means City Construction Cost Index (*8*)

The FHWA Federal-Aid Highway Construction Price Index is based on information supplied to the FHWA by the state highway agencies and is updated quarterly by the Federal-Aid Division, Office of Engineering. The composite index is a combination of three indexes covering excavation, resurfacing, and structures. The approximate weightings of the three factors used in compiling the composite value are 21%, 36%, and 43%, respectively.

The FHWA Highway Maintenance and Operating Cost Index is prepared from unit cost information submitted each year by state highway agencies. It covers both physical maintenance and traffic service items, including snow and ice control. The "Total" index is a composite of four indexes covering labor, material, equipment, and overhead. The weightings of the four factors used in compiling the total index are approximately 62%, 10%, 22%, and 6% respectively.

The Engineering News Record (ENR) Construction Cost Index is a composite price for designated quantities of certain building materials and labor. Specifically, it consists of the base mill price of 2500 lb of structural steel shapes and the 20-city average price of the following:

- 2256 lb of portland cement
- 1088 board-ft of 2 x 4, S4S lumber
- 200 hours of common labor

The ENR Construction Cost Index is updated monthly and reported in Engineering News Record (based on 1913 U.S. Average = 100) for the individual 20 cities that make up the index as well as the 20-city average.

The R.S. Means City Construction Cost Index is an integral part of the Means Construction estimating procedure. It is also one of the 18 cost indexes that Engineering News Record currently reports in the "Quarterly Cost Roundup" issues, described earlier. The Means Construction Cost Index provides cost index figures for sixteen classifications of construction activities and for up to five subclassifications of some of these as well as a weighted total average. The index values based, on a 30 major city average value of 100 as of July 1, are updated annually for 162 major U.S. and Canadian Cities. The information for each construction activity and city are presented in terms of indexes for "materials", "installation", and "total." Each index is computed from representative material and labor quantities for that activity. The Means Historical Cost Index is the 30 major city average of the weighted total average values for the various classifications of construction activities. It is currently based on a value of 100 for January 1, 1975. It is updated quarterly in Engineering News Record.

Comparison of the Selected Cost Indexes

The four cost indexes described in previous section are shown in Table 3-1 for the period covering the past three decades. In order to facilitate comparisons, all were converted to a common base year (1977 = 100). While there are general similarities among the various indexes, obvious differences are also evident. These are more evident in Figure 3-1 where the information in Table 3-1 is presented graphically for the period since 1970.

Logic would dictate that cost indexes related to the highway field should be considered first. Comparing the FHWA Highway Construction Price Index with the FHWA Highway Maintenance and Operations Cost Index reveals a wide disparity between them, especially during the past ten years. Furthermore, the FHWA Highway Construction Price Index agrees reasonably well with the two general construction cost indexes presented (ENR and Means). The reason for the divergent behavior of the FHWA M&O Index is not clearly evident. However, as noted in the earlier discussion of that index, it includes traffic service items such as snow and ice control, which not only may account for the behavioral differences, but also raises the question of its relevance to the application at hand. Detailed evaluation of the components of the FHWA M&O Cost Index since 1979 reveals that only material costs increased at about the same rate as the FHWA Construction Cost Index. Labor, equipment, and overhead components of the M&O Cost Index increased at rates 3, 4,

Table 3-1. Cost indexes examined.

	Cost Indexes*			
Year	FHWA Federal-Aid Highway Construction Price Index (Composite)(7)	FHWA Highway Maintenance & Operations Cost Index (Total)(7)	ENR 20-City Construction Cost Index(6)	R.S. Means 162-City Historical Construction Cost Index(8)
1960	37.0	38.61	32	39.7
1965	41.7	44.18	38	43.9
1970	58.0	57.55	54	58.1
1971	60.8	60.46	61	64.5
1972	64.2	64.89	68	70.3
1973	70.8	69.86	74	76.2
1974	96.3	78.18	78	83.4
1975	96.7	85.24	86	90.6
1976	93.4	92.69	93	94.7
1977	100.0	100.00	100	100.0
1978	119.4	107.83	108	108.0
1979	142.6	118.17	117	116.8
1980	163.0	134.58	126	127.1
1981	156.7	146.29	137	141.4
1982	146.8	160.04	148	153.8
1983	146.5	166.28	158	162.0
1984	155.0	173.83	161	165.6
1985	172.1	184.37	163	166.9
1986	171.6	193.71	167	170.2
1987	172.0	202.53	171	177.1
1988	184.7	210.77	175	181.6
1989	184.2	219.09	179	186.1
1990	184.9	228.23	184	190.6
1991			187	195.6

*All indexes converted to 1977 Base Year = 100

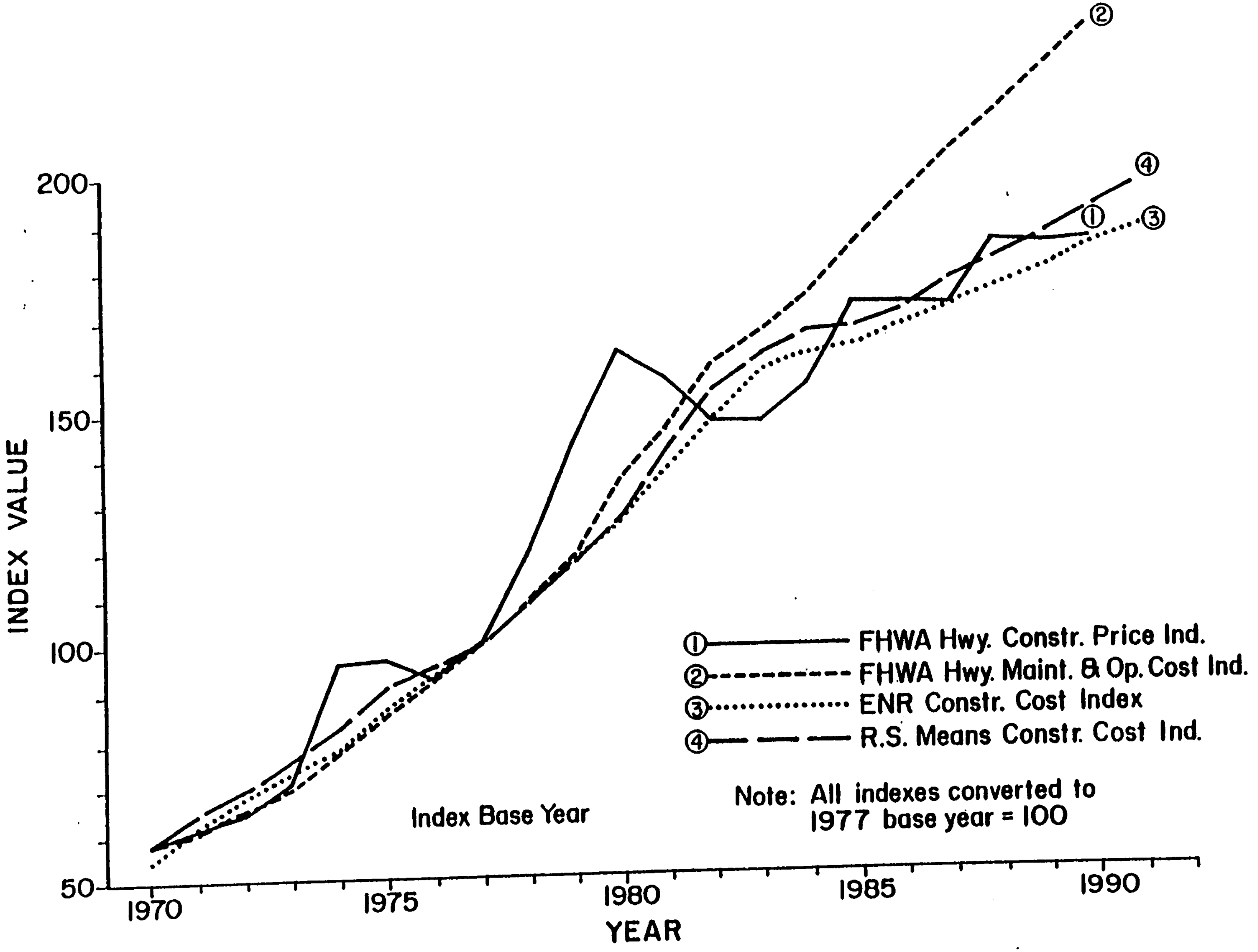


Figure 3-1. Plots of the cost indexes versus time.

and 5 times, respectively, than the FHWA Construction Cost Index. This clearly indicates a totally different set of activities than those found in the construction scene. It might be argued that the types of activities that are under consideration here are, in fact, significantly different from ordinary construction activities. However, it is the judgement of the researchers that the magnitudes of the differences are too great to accept that argument as total explanation of the anomalous behavior. Accordingly, the FHWA M&O Cost Index is judged to be too highly influenced by activities outside the scope of bridge protection/repair/rehabilitation to warrant further consideration.

The inclination at this point leans heavily toward the FHWA Construction Price Index. This is reinforced by the availability of a geographical breakdown of cost indexes by State, which are published annually by Engineering News Record (*6*) in the 2nd "Quarterly Cost Roundup" issues. However, for many of the states there are large, irrational variations in the index values from year to year that suggest random changes in the index bases or reporting procedures. This point is illustrated in Table 3-2. The obvious question at this point is whether or not there exist systematic geographical variations in cost of sufficient significance to require consideration. If not, the matter of geographic effects on cost becomes a moot point. To evaluate this question the mean values for the State index data shown in Table 3-2 were assumed to be normally distributed about a calculated overall mean value of 173.5. The standard deviation is 26.7. The Z-value dividing the data into thirds by frequency is 0.43, giving breakpoints of approximately 162 and 185. In other words, if the data are statistically normally distributed, one-third, i.e. seventeen, of the highway agencies "average" values in the last column of Table 3-2 should be less than 162, and equal numbers should be greater than 185 and between 162 and 185. The results are shown on Figure 3-2. If there were no regional geographic effects on costs, then the three levels of cost index should be randomly distributed among the states. Obviously, this is <u>not</u> the case. Large contiguous groupings of states in the same cost index categories are evident. Notice that this occurs in spite of the obviously high degree of variability of the individual yearly index values in Table 3-2. This, of course, is aided by the mitigating central-limit-theory-effect of using the means of the annual values.

It is established, then, that geographical effects on highway construction costs are significant. Further, since the FHWA Highway Construction Cost Index has a significant deficiency in this matter (high year-to-year variations--as discussed previously), it is prudent to consider using a different index.

The two remaining indexes under study here are the Engineering News Record Construction Cost Index and the R.S. Means City Construction Cost Index. Referring to the earlier descriptions of these two indexes, it is clear that the Means Construction Cost Index is the

Table 3-2. State Highway Construction Cost Indexes–Federal-Aid Highway Construction (*6*).

	1981	1982	1983	1984	1985	1986	1987	1988	1989	Avg.
NEW ENGLAND										
Connecticut	129.6	169.2	143.4	147.5	170.2	216.5	255.4	221.1	209.3	184.7
Maine	165.4	168.6	145.7	173.9	201.1	229.5	209.0	209.4	222.8	191.7
Massachusetts	154.8	156.2	141.0	174.9	178.1	177.1	347.7	403.3	299.3	225.8
New Hampshire	155.7	149.1	148.7	166.0	174.7	165.3	167.1	178.1	190.9	166.2
Rhode Island	134.1	144.2	133.4	217.8	187.2	179.4	210.7	252.9	215.5	186.1
Vermont	130.8	144.4	234.6	147.1	232.1	230.8	216.1	191.9	347.8	208.4
MID-ATLANTIC										
Delaware	130.0	393.6	148.5	185.7	257.7	170.4	137.7	153.4	403.1	220.0
District of Columbia	159.3	109.5	106.1	119.5	174.7	164.5	196.6	181.7	178.3	154.5
Maryland	193.2	159.5	166.5	154.9	181.5	210.2	232.7	201.6	208.8	189.9
New Jersey	188.5	158.4	130.8	145.4	167.3	215.8	264.7	230.7	227.6	192.1
New York	220.7	214.1	192.3	240.2	225.4	286.4	286.0	425.2	342.2	270.3
Pennsylvania	169.1	175.0	149.9	146.2	189.6	172.8	204.7	221.5	189.7	179.8
SOUTH										
Alabama	135.8	130.6	148.8	154.7	177.9	162.2	176.8	157.3	184.3	158.7
Florida	151.2	149.7	135.2	155.6	163.2	181.0	176.9	180.9	176.9	163.4
Georgia	179.9	166.4	166.3	211.7	252.1	233.0	216.6	218.6	202.4	205.2
Kentucky	160.0	131.1	131.4	147.5	171.2	158.5	170.8	168.9	201.7	160.1
Louisiana	147.9	138.7	119.4	131.2	133.7	145.3	129.2	133.3	142.1	135.6
Mississippi	164.3	159.4	157.9	140.6	173.8	153.6	162.1	159.0	179.9	161.2
North Carolina	158.4	135.3	140.1	148.8	180.0	187.5	175.0	191.3	186.9	167.0
South Carolina	178.8	147.1	177.2	181.5	196.3	169.5	232.4	202.4	145.8	181.2
Tennessee	143.2	134.6	131.4	124.2	144.6	153.2	152.2	144.2	153.4	142.3
Virginia	172.4	128.0	127.3	126.7	147.5	156.7	173.2	185.2	178.4	155.0
West Virginia	154.0	106.9	103.1	96.2	120.9	116.7	191.1	141.7	153.2	131.5

(continued)

Table 3-2. State Highway Construction Cost Indexes–Federal-Aid Highway Construction (*6*).

	1981	1982	1983	1984	1985	1986	1987	1988	1989	Avg.
MIDWEST										
Illinois	143.5	134.9	119.4	143.2	159.7	161.6	165.6	158.2	154.3	148.9
Indiana	160.8	151.3	147.6	186.4	186.6	175.5	154.8	169.2	170.1	166.9
Michigan	138.4	143.2	135.6	128.4	153.7	174.4	168.1	176.9	158.5	153.0
Ohio	159.1	146.9	168.7	180.2	177.5	182.6	229.3	287.7	235.6	196.4
Wisconsin	130.5	148.1	151.7	161.2	168.5	150.7	170.7	157.9	163.2	155.8
MISSISSIPPI TO ROCKIES										
Arkansas	149.7	123.9	126.3	149.8	156.3	158.1	157.6	153.3	141.5	146.3
Colorado	157.9	167.0	168.6	198.0	191.0	171.4	164.1	177.1	178.5	174.8
Iowa	142.3	150.7	158.0	182.1	170.7	164.2	162.9	172.0	160.9	162.6
Kansas	163.2	161.4	178.7	170.2	196.3	179.2	190.1	204.5	176.9	180.1
Minnesota	152.4	141.2	150.1	156.6	152.3	177.7	179.2	171.2	183.1	162.6
Missouri	149.6	145.9	141.4	167.8	180.8	179.1	157.6	154.8	16[illegible]7	160.3
Montana	192.6	177.0	156.7	213.0	194.7	198.9	160.6	219.1	187.7	188.9
Nebraska	130.8	128.9	135.0	151.9	149.9	139.9	133.0	149.4	142.5	140.1
New Mexico	153.5	149.1	171.0	181.9	180.9	199.5	192.8	159.9	160.2	172.1
North Dakota	196.7	163.0	162.9	158.7	167.1	154.1	151.7	180.3	136.3	163.4
Oklahoma	153.8	150.0	134.4	150.5	159.2	148.5	156.5	144.3	142.5	148.9
South Dakota	156.5	150.8	146.8	167.0	184.7	175.7	148.9	148.1	157.4	159.5
Texas	138.0	125.7	113.1	127.4	134.8	155.5	135.6	124.2	127.1	131.3
Wyoming	147.3	141.1	172.8	169.9	183.6	143.7	134.8	125.4	125.1	149.3
FAR WEST										
Alaska	279.3	na	266.4	163.1	122.9	118.2	na	na	112.5	177.1
Arizona	195.6	172.3	202.2	190.9	210.3	221.6	208.1	201.1	170.7	197.0
California	200.3	184.3	190.2	189.9	182.6	205.1	211.6	236.4	236.1	204.1
Hawaii	162.5	163.9	144.7	177.7	226.8	317.6	198.5	282.1	270.3	216.0

(*continued*)

Table 3-2. State Highway Construction Cost Indexes--Federal-Aid Highway Construction (*6*).

	1981	1982	1983	1984	1985	1986	1987	1988	1989	Avg.
Idaho	150.7	146.6	158.9	163.3	156.4	153.7	173.3	172.5	152.3	158.6
Nevada	165.5	149.0	174.5	187.9	178.7	184.3	201.9	184.9	236.7	184.8
Oregon	180.5	164.1	160.7	181.4	201.0	192.5	215.5	230.0	234.9	195.6
Utah	163.1	153.2	143.5	166.8	163.7	170.4	149.5	177.4	168.1	161.6
Washington	179.4	168.9	153.8	149.5	166.8	156.2	145.6	171.1	159.6	161.2

Base Year 1977 = 100.

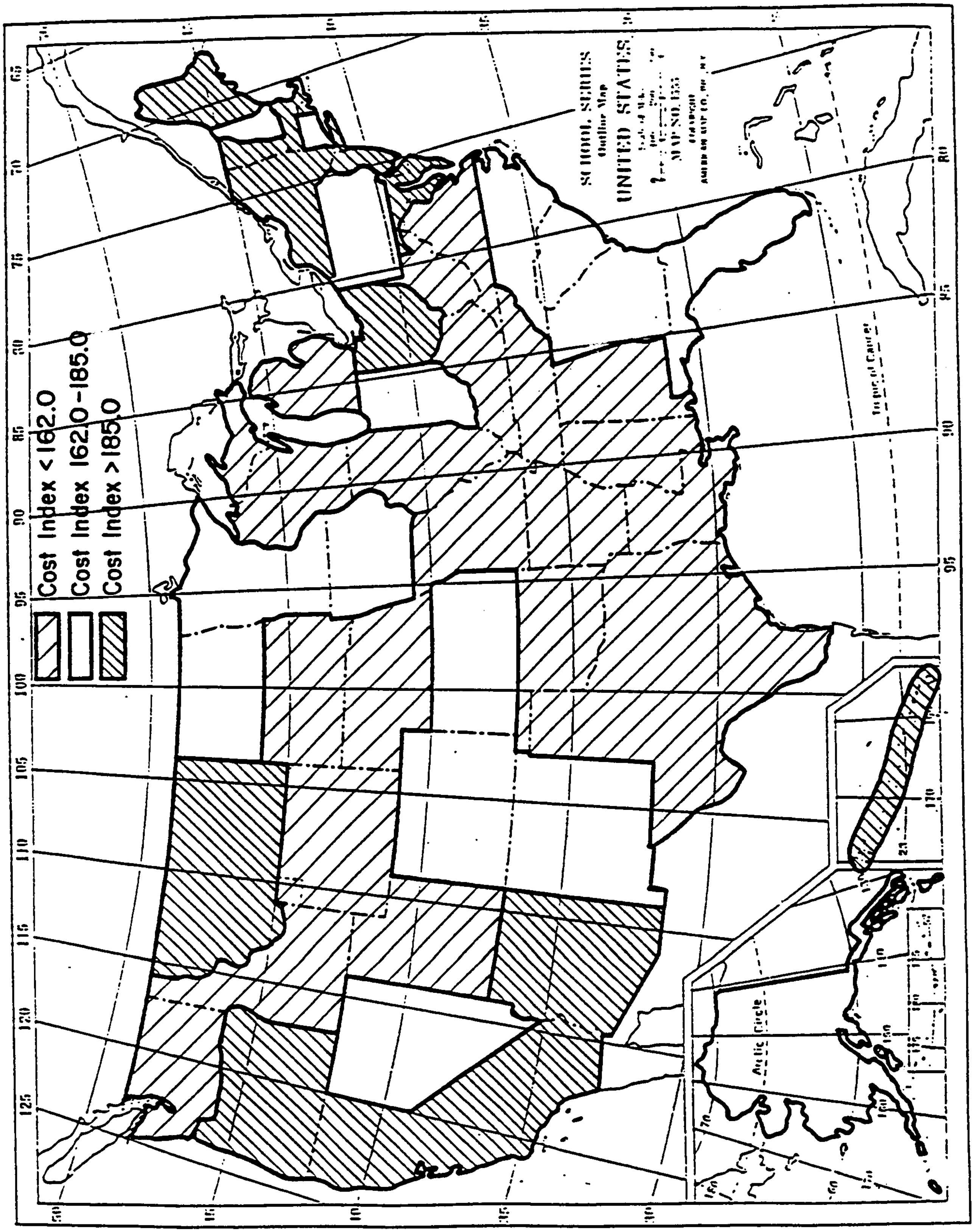


Figure 3-2. Distribution by states of FHWA Highway Construction Cost Index.

more suitable. First, it is much more comprehensive and detailed than the ENR index. This permits the selection of a more specific subarea index to more nearly match the nature of the construction activities covered by this research. There is only <u>one</u> combined index available with the ENR Index. Notice that in this regard, the Means Construction Cost Index also has the same advantage over the FHWA Construction Cost Index. Second, it is based on a larger geographical data base than the ENR Construction Cost Index.

Thus, the Means Construction Cost Index presents clear advantages over the other indexes evaluated here. However, the FHWA construction Cost Index is still the only one of the four indexes studied that has an obvious and direct link to the subject of this research, <u>viz</u>, construction costs on highway structures. Therefore, it is necessary to demonstrate that any other index under consideration correlates with the FHWA Construction Cost Index before it can be used.

Table 3-3 presents the average cost indexes for the States covered by the R.S. Means City Cost Construction Index for the subarea of concrete construction. These are the "total" index values; that is, the combination of materials and installation costs. A statistical correlation analysis between these data and the average FHWA State Highway Construction Cost Indexes (Table 3-2) shows that a correlation exists at better than the 99.9% confidence level. Of course it has already been demonstrated on Figure 3-1 that good agreement exists between the overall FHWA Highway Construction Cost Index and the Overall Means Construction Cost Index. Finally, the distribution by state of the R. S. Means Construction Cost Index in Table 3-3, using the same technique and criteria used for the FHWA Construction Cost Index in Figure 3-2, is shown on Figure 3-3. The obvious similarity between Figures 3-2 and 3-3 further indicates the existence of a relationship between the Means Cost Index and highway construction costs. Accordingly the R.S. Means City Construction Cost Index will be used to prepare procedures and factors for adjusting archival cost data from a state highway agencies for geographical and time effects. An important extra benefit results from this decision. The Means Construction Cost Index is an integral part of the Means cost estimating system. This leads naturally to procedures that will be used to provide engineering estimates for those activities for which insufficient cost data exist and for "experimental and new" procedures that have little or no prior history.

Table 3-3. Cost indexes for concrete construction (Total)--State averages based on R. S. Means City Cost Indexes.(8)

COST INDEX	STATE(s)
80.6	South Dakota
80.9	South Carolina
82.9	Mississippi
83.1	Tennessee
83.7	Louisiana
85.5	Alabama
85.6	North Carolina
86.4	Arkansas
86.5	Oklahoma
86.9	Nebraska
87.0	Kansas
87.1	Georgia; Virginia
87.5	Wyoming
87.6	Texas
88.0	Florida
88.5	Kentucky
89.6	Utah
90.6	New Hampshire
92.8	Maine
93.6	Montana
93.8	District of Columbia
94.0	Iowa
94.1	Vermont
94.8	Colorado
95.0	New Mexico

(continued)

Table 3-3. Cost indexes for concrete construction (Total)--State averages based on R. S. Means City Cost Indexes.(8)

COST INDEX	STATE(s)
95.1	Arizona, Missouri
96.8	Wisconsin
97.6	Minnesota
97.7	Idaho
97.9	Indiana
98.1	Illinois
99.1	Connecticut
99.2	Michigan; Ohio
101.0	Maryland
101.9	Washington
102.2	Pennsylvania
103.6	West Virginia
105.2	Nevada; Rhode Island
105.5	New York
106.7	Delaware
107.3	New Jersey
107.5	Oregon
110.8	Massachusetts
113.6	California
117.7	Hawaii
141.9	Alaska

Note: National Average (7/1/91) = 100.0.

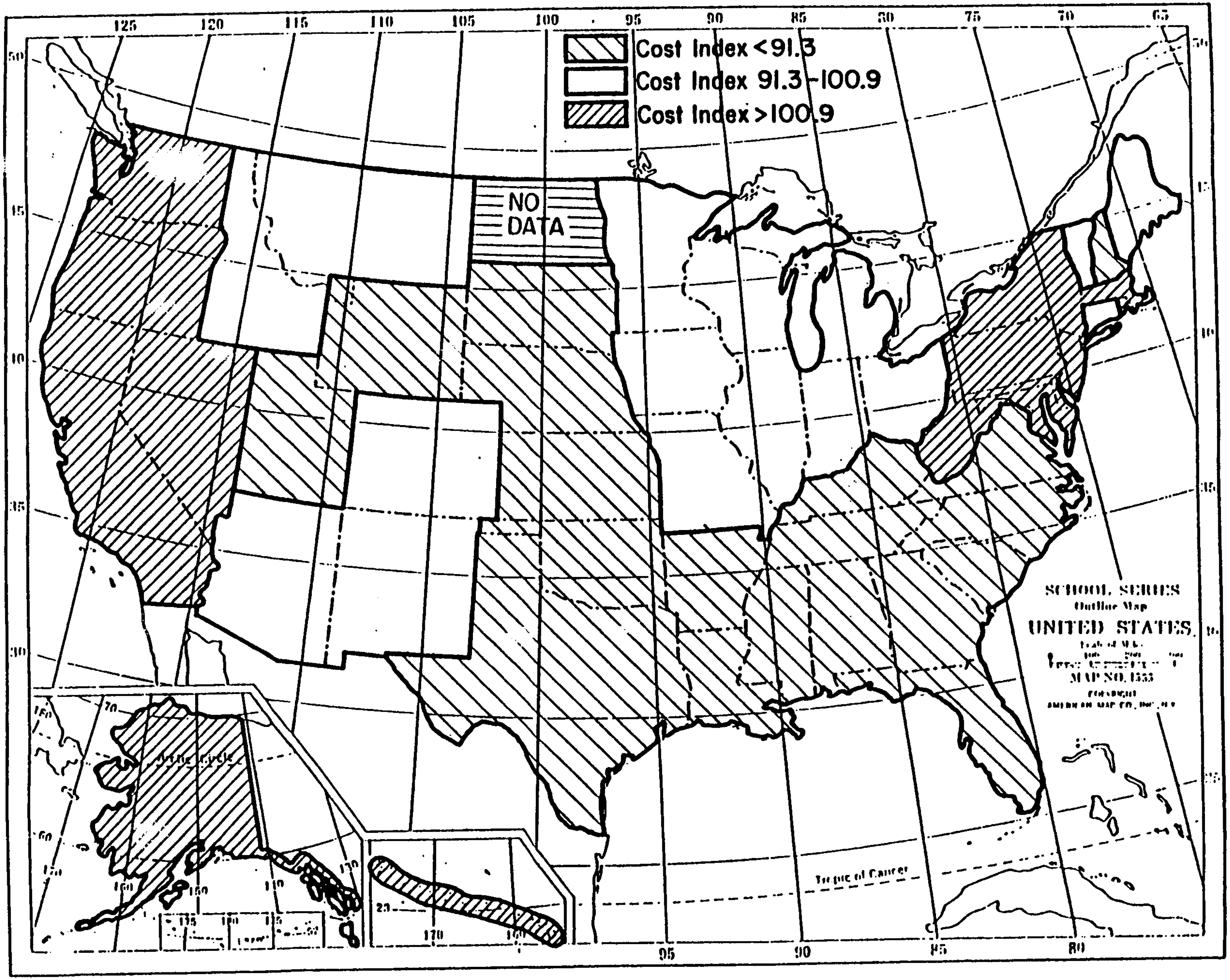


Figure 3-3. Distribution by states of Means Construction Cost Index.

Procedures

General

Following the rationale developed in the preceding sections of this chapter, the R.S. Means City Construction Cost Index will be used as the basis for developing a system to convert archival cost data from local jurisdictions into current (mid-1991) national average values. The purpose is to produce cost figures with defined basis in order to permit valid economic analysis comparisons of alternatives for the protection/repair/rehabilitation of concrete bridge components. The collateral capability of the developed system to provide estimates of cost for a specific activity at a given geographic location and time using archival data from a different time and place for the same activity will also be demonstrated.

The Functional Relationships

The functional relationships upon which the developed system is based are presented in algebraic form below.

Nomenclature:

N = national average cost
C = cost in a particular city (or state)
L = geographical conversion factor for particular city (or state)
T = time conversion factor to convert to mid-1991 value
$_{a,b}$ = particular cities (or states)
$_{m,n}$ = particular years

The general relationship for determining national average cost values is:

$$N_n = C_{a,m} \times L_a \times \left(\frac{T_m}{T_n}\right) \tag{3-1}$$

For the usual case that represents the primary purpose of this effort (converting local archival costs to 1991 national average costs), notice that $T_n = 1.000$ and equation 3-1 becomes:

$$N = C_{a,m} \times L_a \times T_m \tag{3-2}$$

where N = the 1991 national average cost

If the national average cost for 1991 is known or has been calculated from equation 3-2, the present (1991) cost in a particular city (or state), C_a, can be calculated from equation 3-3 because $T_m = 1.000$.

$$C_a = \frac{N}{L_a} \tag{3-3}$$

The general equation for estimating the cost in a particular city (or state) in a given year, $C_{a,m}$, from cost data for another city (or state) in a different year, $C_{b,n}$, is:

$$C_{a,m} = C_{b,n} \times \left(\frac{L_b}{L_a}\right) \times \left(\frac{T_n}{T_m}\right) \tag{3-4}$$

If the national average cost in 1991, N, is known, the cost in a particular city (or state) in a given year, $C_{a,m}$, can be estimated from:

$$C_{a,m} = \frac{N}{L_a \times T_m} \tag{3-5}$$

Location and Time Factors

The L and T (location and time factors) in equations 3-1 through 3-5 are derived from the R.S. Means "City" and "Historical" Cost Indexes, respectively, as presented in the 1992 Means Concrete Cost Data (8). The location (L) factors were calculated from the Means Index Values using the following relationship:

$$L = \frac{100}{I_c} \tag{3-6}$$

where I_c is the Means City Index Value. State L values were computed as the arithmetic means of the calculated city L values for each state. Only Division 3 (concrete construction) index values were used, as discussed earlier. The calculated L values covering the "materials," "installation," and "total" aspects of concrete construction are presented for each city and state in Table 3-4.

The time (T) factors were calculated using the "Historical Cost Index" from the 1992 Means Concrete Cost Data (*8*) and the following relationship:

$$T = \frac{221.6}{I_T} \tag{3-7}$$

where I_T is the Means Historical Cost Index Value for year T. The resulting time factors are tabulated in Table 3-5.

Future Costs

Though not relevant to the specific needs for this project, it is worthwhile to make note of the fact that the formulas and factors developed here can be used to estimate costs after July 1, 1991 in the following manner:

In equation 3-1, substitute $T_n = \frac{221.6}{j}$, giving:

$$N_n = \frac{C_{a,m} \times L_a \times T_m \times j}{221.6} \tag{3-8}$$

where

j = R.S. Means Quarterly City Cost Index (based on 1975 = 100) available in the "Builders Indexes" section of Engineering News Record's Quarterly Cost Reports (*6*).

If national average costs (1991) are available, equation 3-8 reduces to:

$$N_n = \frac{N \times j}{221.6} \tag{3-9}$$

Table 3-4. Factors to convert costs to National Average Values based on R.S. Means City Cost Indexes for Concrete Construction.[8]

State	City	Factors					
		Materials		Installation		Total	
		City	State Average	City	State Average	City	State Average
AL	Birmingham	1.087	1.028	1.250	1.270	1.186	1.169
	Huntsville	0.992		1.284		1.160	
	Mobile	1.026		1.239		1.152	
	Montgomery	1.007		1.305		1.179	
AK	Anchorage	0.552	0.552	0.835	0.835	0.705	0.705
AZ	Phoenix	0.934	0.948	1.136	1.121	1.054	1.052
	Tucson	0.962		1.106		1.050	
AR	Fort Smith	0.978	0.971	1.319	1.299	1.172	1.158
	Little Rock	0.964		1.279		1.144	
CA	Anaheim	0.942	0.953	0.845	0.846	0.878	0.881
	Bakersfield	0.943		0.845		0.878	
	Fresno	1.006		0.867		0.912	
	Los Angeles	1.027		0.833		0.894	
	Oxnard	0.991		0.842		0.890	
	Riverside	0.912		0.844		0.867	
	Sacramento	0.901		0.876		0.885	
	San Diego	0.957		0.885		0.909	
	San Francisco	0.939		0.803		0.847	
	Santa Barbara	0.850		0.803		0.819	
	Stockton	1.007		0.870		0.914	
	Vallejo	0.960		0.837		0.877	
CO	Colorado Springs	0.928	0.904	1.168	1.167	1.068	1.056
	Denver	0.8[illegible]		1.166		1.043	

(continued)

Table 3-4. Factors to convert costs to National Average Values based on R.S. Means City Cost Indexes for Concrete Construction.(8)

State	City	Factors					
		Materials		Installation		Total	
		City	State Average	City	State Average	City	State Average
CT	Bridgeport	0.917	0.913	1.075	1.073	1.013	1.009
	Hartford	0.941		1.064		1.021	
	New Haven	0.978		1.072		1.036	
	Stamford	0.837		1.085		0.980	
	Waterbury	0.890		1.068		0.997	
DE	Wilmington	0.968	0.968	0.921	0.921	0.937	0.937
DC	Washington	0.955	0.955	1.142	1.142	1.066	1.066
FL	Fort Lauderdale	1.035	1.031	1.241	1.209	1.159	1.138
	Jacksonville	1.038		1.266		1.174	
	Miami	1.050		1.205		1.144	
	Orlando	1.026		1.233		1.149	
	Tampa	1.005		1.098		1.063	
GA	Atlanta	1.148	1.033	1.174	1.235	1.164	1.149
	Columbus	0.951		1.372		1.183	
	Macon	1.020		1.214		1.136	
	Savannah	1.012		1.178		1.112	
HI	Honolulu	0.845	0.845	0.853	0.853	0.850	0.850
ID	Boise	0.961	0.961	1.063	1.063	1.024	1.024
IL	Chicago	1.016	0.992	0.940	1.043	0.966	1.023
	Peoria	1.013		1.172		1.110	
	Rockford	0.940		0.992		0.973	
	Springfield	0.998		1.068		1.042	

(continued)

Table 3-4. Factors to convert costs to National Average Values based on R.S. Means City Cost Indexes for Concrete Construction.[8]

		Factors					
		Materials		Installation		Total	
State	City	City	State Average	City	State Average	City	State Average
IN	Evansville	0.930	1.009	1.085	1.034	1.024	1.023
	Fort Wayne	1.025		1.070		1.053	
	Gary	1.002		0.911		0.942	
	Indianapolis	1.047		1.032		1.[illegible]	
	South Bend	1.027		1.032		1.[illegible]	
	Terre Haute	1.024		1.071		1.054	
IA	Davenport	1.047	0.971	1.081	1.133	1.068	1.064
	Des Moines	0.894		1.185		1.060	
KS	Topeka	1.078	1.069	1.211	1.201	1.159	1.150
	Wichita	1.059		1.190		1.140	
KY	Lexington	1.082	1.088	1.215	1.158	1.163	1.031
	Louisville	1.094		1.101		1.099	
LA	Baton Rouge	0.971	1.045	1.325	1.302	1.171	1.195
	New Orleans	1.087		1.235		1.178	
	Shreveport	1.078		1.346		1.236	
ME	Lewiston	0.987	0.987	1.138	1.137	1.079	.078
	Portland	0.987		1.135		1.076	
MD	Baltimore	0.856	0.856	1.086	1.086	0.990	0.990
MA	Boston	0.879	0.922	0.806	0.895	0.831	0.905
	Lawrence	0.908		0.911		0.910	
	Lowell	0.903		0.903		0.903	
	Springfield	0.979		0.935		0.951	
	Worcester	0.942		0.921		0.929	

(continued)

Table 3-4. Factors to convert costs to National Average Values based on R.S. Means City Cost Indexes for Concrete Construction.(8)

State	City	Factors					
		Materials		Installation		Total	
		City	State Average	City	State Average	City	State Average
MI	Ann Arbor	1.024	0.971	0.907	1.045	0.946	1.013
	Detroit	0.973		0.869		0.903	
	Flint	0.936		0.973		0.960	
	Grand Rapids	0.943		1.171		1.078	
	Kalamazoo	0.943		1.186		1.086	
	Lansing	0.958		1.104		1.046	
	Saginaw	1.017		1.103		1.071	
MN	Duluth	0.972	1.003	1.075	1.039	1.035	1.025
	Minneapolis	1.033		1.003		1.014	
MS	Jackson	1.004	1.004	1.361	1.361	1.206	1.206
MO	Kansas City	1.085	1.135	1.067	1.015	1.072	1.053
	St. Louis	1.185		0.963		1.033	
MT	Billings	0.947	0.903	1.195	1.195	1.092	1.070
	Great Falls	0.858		1.195		1.047	
NE	Lincoln	0.929	0.985	1.318	1.278	1.145	1.151
	Omaha	1.040		1.238		1.157	
NV	Las Vegas	0.943	0.961	0.929	0.946	0.935	0.952
	Reno	0.979		0.962		0.968	
NH	Manchester	0.974	0.956	1.255	1.213	1.136	1.105
	Nashua	0.937		1.170		1.074	
NJ	Jersey City	0.960	0.953	0.923	0.923	0.935	0.933
	Newark	0.908		0.871		0.884	
	Patterson	0.951		0.923		0.934	
	Trenton	0.993		0.974		0.980	
NM	Albuquerque	0.907	0.907	1.156	1.156	1.053	1.053

(continued)

Table 3-4 Factors to convert costs to National Average Values based on R.S. Means City Cost Indexes for Concrete Construction.(8)

		Factors					
		Materials		Installation		Total	
State	City	City	State Average	City	State Average	City	State Average
NY	Albany	1.160	0.961	1.003	0.980	1.055	0.969
	Binghamton	1.078		1.129		1.110	
	Buffalo	0.921		0.934		0.929	
	New York	0.755		0.704		0.722	
	Rochester	0.844		1.014		0.946	
	Syrcuse	0.950		1.130		1.057	
	Utica	1.053		1.174		1.127	
	Yonkers	0.925		0.751		0.806	
NC	Charlotte	0.949	0.986	1.309	1.306	1.152	1.169
	Greensboro	1.045		1.326		1.209	
	Raleigh	0.964		1.284		1.147	
OH	Akron	1.042	1.023	0.978	1.002	1.000	1.009
	Canton	1.045		1.040		1.042	
	Cincinnati	1.063		1.021		1.036	
	Cleveland	1.031		0.892		0.937	
	Columbus	0.977		1.038		1.015	
	Dayton	0.936		1.015		0.985	
	Lorain	1.009		1.025		1.019	
	Toledo	1.012		1.001		1.005	
	Youngstown	1.096		1.011		1.041	
OK	Oklahoma City	0.978	1.008	1.285	1.262	1.155	1.156
	Tulsa	1.037		1.238		1.157	
OR	Eugene	0.953	0.913	0.887	0.945	0.910	0.931
	Portland	0.873		1.003		0.952	

(continued)

Table 3-4. Factors to convert costs to National Average Values based on R.S. Means City Cost Indexes for Concrete Construction.(8)

State	City	Materials City	Materials State Average	Installation City	Installation State Average	Total City	Total State Average
PA	Allentown	0.933	0.995	0.928	0.977	0.929	0.980
	Erie	1.081		1.044		1.057	
	Harrisburg	0.921		1.022		0.983	
	Philadlephia	1.106		0.885		0.953	
	Pittsburgh	0.971		1.017		1.000	
	Reading	0.958		1.050		1.015	
	Scranton	0.996		0.891		0.926	
RI	Providence	0.999	0.999	0.925	0.925	0.951	0.951
SC	Charleston	0.996	1.086	1.385	1.349	1.214	1.237
	Columbia	1.175		1.312		1.259	
SD	Sioux Falls	0.987	0.987	1.451	1.451	1.241	1.241
TN	Chattanooga	1.107	1.099	1.261	1.272	1.200	1.203
	Knoxville	1.078		1.314		1.218	
	Memphis	1.076		1.238		1.174	
	Nashville	1.134		1.274		1.221	
TX	Amarillo	0.903	0.990	1.280	1.261	1.112	1.144
	Austin	1.010		1.227		1.139	
	Beaumont	1.962		1.135		1.066	
	Corpus Christi	0.945		1.350		1.170	
	Dallas	1.059		1.222		1.159	
	El Paso	0.993		1.488		1.263	
	Fort Worth	0.946		1.232		1.111	
	Houston	0.912		1.225		1.091	
	Lubbock	0.973		1.294		1.157	
	San Antonio	1.195		1.161		1.172	

(continued)

Table 3-4. Factors to convert costs to National Average Values based on R.S. Means City Cost Indexes for Concrete Construction.(8)

State	City	Factors					
		Materials		Installation		Total	
		City	State Average	City	State Average	City	State Average
UT	Salt Lake City	0.969	0.969	1.221	1.221	1.116	1.116
VT	Burlington	0.940	0.940	1.145	1.145	1.063	1.063
VA	Newport News	0.912	0.925	1.344	1.330	1.149	1.149
	Norfolk	0.916		1.325		1.142	
	Richmond	0.955		1.282		1.142	
	Roanoke	0.917		1.368		1.163	
WA	Seattle	1.032	0.973	0.946	0.989	0.975	0.982
	Spokane	0.918		1.034		0.989	
	Tacoma	0.970		0.987		0.981	
WV	Charleston	0.844	0.870	1.047	1.030	0.964	0.966
	Huntington	0.895		1.012		0.967	
WI	Madison	0.969	1.035	1.070	1.036	1.031	1.033
	Milwaukee	1.101		1.002		1.035	
WY	Cheyenne	0.981	0.981	1.258	1.258	1.143	1.143

Table 3-5. Factors to convert costs to 1991 values based on R.S. Means Historical Cost Index.[8]

YEAR	FACTOR
1960	4.924
1961	4.881
1962	4.797
1963	4.685
1964	4.560
1965	4.459
1966	4.270
1967	4.111
1968	3.895
1969	3.597
1970	3.368
1971	3.015
1972	2.780
1973	2.568
1974	2.340
1975	2.160
1976	2.065
1977	1.956
1978	1.810
1979	1.675
1980	1.539
1981	1.383
1982	1.271
1983	1.208
1984	1.181
1985	1.172
1986	1.149
1987	1.104
1988	1.077
1989	1.051
1990	1.026
1991	1.000

If it is desired to project estimated costs into the future, this can be done using an escalation (inflation) factor. However, the further that the time extends beyond the base year (1991), the greater the potential error. It is recommended that the time extension not exceed five years (*1*). The escalation factor can be estimated from the Means Historical Construction Cost Index values. Inflation is generally assumed to follow a geometric progression in which the individual terms may be expressed as follows:

$$A_y = B(1 + f)^{(y - y')} \qquad (3\text{-}10)$$

where

A_y = the cost index in year y
B = the cost index in the first year, y′, of the progression
f = the inflation rate

This can be converted to linear form by logarithmic transformation:

$$\log (A_y) = \log (B) + (y - y') \log (1 + f) \qquad (3\text{-}11)$$

and linear regression analysis can be performed on the Means Historical Cost Index values (A_y) versus time (y -y′). The result using the cost index values from the 1992 Means Concrete Cost Data (*8*) is:

$$A_y = 18.44\ (1.0531)^{(y-1942)} \qquad (3\text{-}12)$$

The Means Index data and the regression curve are shown on Figure 3-4. Rather than use equation 3-12, however, it is recommended that index values be calculated on the basis of the actual cost index value of 221.6 on July 1, 1991 and the average inflation rate. Since (1 - f) = 1.0531, the average inflation rate, f, = 0.0531 (5.31%) over the period of 1942-1991.

Therefore, the Estimated cost indexes for years subsequent to 1991 (P_h) can be calculated from:

$$P_h = 221.6\ (1.0531)^{(h - 1991)} \qquad (3\text{-}13)$$

And, the national average cost in year h, N_h, can be estimated from:

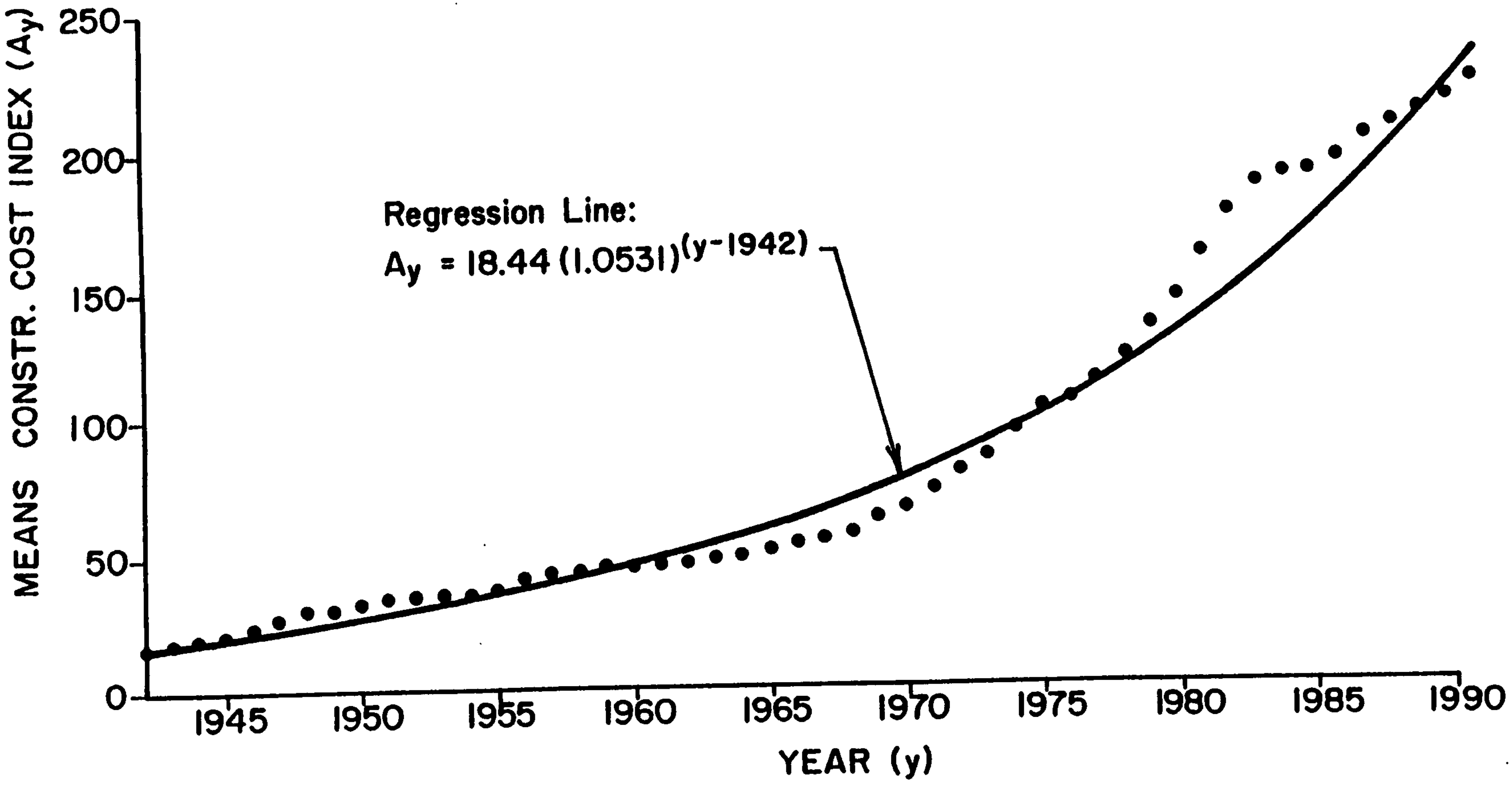


Figure 3-4. Means Historical Cost Index versus time.

$$N_h = \frac{N \times P_h}{221.6} \tag{3-14}$$

where N is the national average cost in 1991. Then, the estimated cost in any city, a, in year h can be estimated from

$$C_{a,h} = \frac{N_h}{L_a} \tag{3-15}$$

Examples

To illustrate the procedures developed in this chapter, the following examples are presented.

Archival data reveal that it costs \$5.00/sq ft (\$53.80/m^2) to overlay bridge decks with latex-modified concrete in Boston in 1986 (total cost).

(a) What is the estimated national average cost for 1991?

From equation 3-2:

$$N = C_{a,m} \times L_a \times T_m$$

where

$C_{a,m}$ = \$5.00/sq ft (given)
L_a = 0.831 (table 3-4)
T_m = 1.149 (table 3-5)

$$N = (5.00)(0.831)(1.149) = \underline{\$4.77/\text{sq ft}}\ (\$51.33/\text{m}^2)$$

(Note: The 1986 Cost in Boston is greater than the 1991 National Average Cost because costs in Boston are much higher than the national average--about 20% higher).

(b) What is the estimated cost in Pittsburgh, PA in 1989?

From equation 3-4:

$$C_{a,m} = C_{b,n} \times \left(\frac{L_b}{L_a}\right) \times \left(\frac{T_n}{T_m}\right)$$

where

$C_{a,m}$ = \$5.00/sq ft (given)
L_a = 0.831 (table 3-4)
L_b = 1.000 (table 3-4)
T_m = 1.149 (table 3-5)
T_n = 1.051 (table 3-5)

$$5.00 = C_{b,n} \times \left(\frac{1.000}{0.831}\right) \times \left(\frac{1.051}{1.149}\right)$$

$$C_{b,n} = \underline{\$4.54/\text{sq ft}}\ (\$48.85/\text{m}^2)$$

Notice that since the national average cost for 1991 (N) was calculated in example (a), equation 3-5 could have been used, as follows:

$$C_{b,n} = \frac{N}{L_b \times T_n} = \frac{4.77}{(1.000)(1.051)} = \underline{\$4.54/\text{sq ft}}\ (\$48.85/\text{m}^2)$$

(c) What is the national average cost in October 1991?

From equation 3-8:

$$N_a = \frac{C_{a,m} \times L_a \times T_m \times j}{221.6}$$

where

$C_{a,m}$ = \$5.00/sq ft (given)
L_a = 0.831 (table 3-4)
T_m = 1.149 (table 3-5)
j = 222.80 (ENR, vol. 227, no. 25, Dec. 23, 1991, p. 32)

$$N_n = \frac{(5.00)(0.831)(1.149)(222.80)}{221.6} = \underline{\$4.80/\text{sq ft}}\ (\$51.65/\text{m}^2)$$

Or, since the July 1, 1991 national average cost has already been calculated [Example (a)], equation 3-9 gives:

$$N_n = \frac{N \text{ x } j}{221.6} = \frac{(4.77)\ (222.80)}{(221.6)} = \underline{\$4.80/\text{sq ft}}\ (\$51.65/\text{m}^2)$$

(d) What is the estimated National Average Cost for July 1, 1996?

From equation 3-13:

$$P_h = (221.6)(1.0531)^{(1996-1991)} = 287.0$$

and from equation 3-14:

$$N_h = \frac{N \text{ x } P_h}{221.6}$$

where:

N = $4.77/sq ft [from example (a)]
P_h = 287.0 [from equation 3-13]

$$N_h = \frac{(4.77)\ (287.0)}{221.6} = \underline{\$6.18/\text{sq ft}}\ (\$66.50/\text{m}^2)$$

(e) What is the estimated cost in Cleveland, OH on July 1, 1996?

From equation 3-15:

$$C_{a,h} = \frac{N_h}{L_a} \text{x, membranes and}$$

where

N_h =\$6.18/sq ft [example (d)]
L_a =0.937 (table 3-4)

or

$$C_{a,h} = \frac{6.18}{0.937} = \underline{\underline{\$6.60/sq\ ft}}\ (\$71.02/m^2)$$

Data Set Development

Items

There were seven systems for which cost data were obtained. These systems are as follows:

- Deck Patching: consists of patching repairs at specific locations on bridge decks. May use portland cement concrete, quick-set hydraulic mortars or concrete or polymer mortars or concrete.

- Conventional Deck Protection Systems: these are systems which are applied over the entire bridge deck surface at one time. They may include latex-modified concrete overlays, membranes and asphalt concrete overlay, low-slump dense concrete overlays, and sealers.

- Experimental Deck Protection Systems: these are systems generally accepted as experimental or those that have not yet gained significant usage. They are applied to the entire bridge deck surface at one time. They may include thin polymer overlays, micro-silica overlays, and polyester overlays.

- Structural Patching: these are patching repairs at specific locations on structural members (non-deck). They may use portland cement concrete, quick-set hydraulic mortar or concrete, or polymer mortar or concrete.

- Structural Protection Systems: these are applied to the entire surface areas of structural elements. These repairs may involve encasement with portland cement concrete, sealers, shotcrete and coatings.

- New Deck Protection Systems: these are newly developed under SHRP C-103. They are applied to the entire deck surface and include deep impregnation and spray-on treatments.

- New Structural Patching: these are newly developed under SHRP C-103. They are applied to specific locations of the substructure/substructure and include spray-on inhibitor and/or inhibitor concrete patches.

In order to better analyze the data which was to be collected, a literature search and interviews with SHA maintenance engineers were performed to develop a more detailed list of work items. For example, it was determined that all SHAs have two types of deck repairs: a full depth and a partial depth repair. So these were incorporated into the patch deck treatments. Similarly, for patch structural treatments, there are shallow and deep repairs.

The types of sealers and coatings used for surface area deck and structural treatments was expanded to include boiled linseed oil, silane, siloxane and high molecular weight methacrylate for decks and boiled linseed oil, silane, siloxane, epoxy and other coatings for substructures.

Preparation for surface area deck treatments often includes removal of a portion of the existing deck's surface. For asphalt covered decks, it was necessary to include the removal of asphalt, as well. The deck scarification is usually performed by milling machines, but recently hydrodemolition has become popular. These three work items were added to those for conventional surface area deck treatments.

The addition of these items results in forty-four treatment items for which cost models will be determined. These treatment items are listed in Table 3-6 and will be more fully described in Chapter 4.

Data Observations

Each of the 829 contract bid tabulations obtained from the SHAs was analyzed to obtain information regarding any of the subject treatment items used. Bid tabulations list all work items in the contract for each bidder on the project. The number of bidders any given

Table 3-6. Specific treatment items to be costed for the identified treatment areas.

100 Topical Deck Treatments
  110 Portland Cement Concrete Patches
    111 Partial Depth Repairs (square yard)
    112 Full Depth Repairs (square yard)
  120 Quick-Set Hydraulic Mortar/Concrete Patches
    121 Partial Depth Repairs (square yard)
    122 Full Depth Repairs (square yard)
  130 Polymer Mortar/Concrete Repairs
    131 Partial Depth Repairs (square yard)
    132 Full Depth Repairs (square yard)

200 Conventional Areal Deck Treatments
  210 Latex Modified Concrete Overlay (square yard)
  220 Membrane and Asphalt Cement Concrete Overlay (square yard)
  230 Low Slump Densified Concrete Overlay (square yard)
  240 Sealers
    241 Boiled linseed oil (square yard)
    242 Silane, Siloxane (square yard)
    243 High Molecular Weight Methacrylate Deck Sealer (square yard)
  250 Scarification of Concrete Deck Surface
    251 Milling or Unspecified Method (square yard)
    252 Hydrodemolition (square yard)
  260 Removal of Asphalt from Deck Surface (square yard)

300 Experimental Deck Treatments
  310 Thin Polymer Overlay (square yard)
  320 Micro-Silica Concrete Overlay (square yard)
  330 Polyester Overlay (square yard)

400 Topical Structural Treatments
  410 Portland Cement Concrete Patches
    411 Shallow Repairs (square yard)
    412 Deep Repairs (square yard)
  420 Quick-Set Hydraulic Mortar/Concrete Patches
    421 Shallow Repairs (square yard)
    422 Deep Repairs (square yard)
  430 Polymer Mortar/Concrete Repairs
    431 Shallow Repairs (square yard)
    432 Deep Repairs (square yard)

500 Areal Structural Treatments
  510 Encase with Portland Cement Concrete (square yard)
  520 Sealers
    521 Boiled Linseed Oil (square yard)
    522 Silane, Siloxane (square yard)
  530 Shotcrete (cubic yard)
  540 Coatings
    541 Epoxy (square yard)
    542 Others (square yard)

600 New Areal Deck Treatments
  610 Deep Impregnation, Grooving Technique
    611 Monomer, Methyl Methacrylate
    612 Corrosion Inhibitor, Postrite
    613 Corrosion Inhibitor, Cortec 2020
  620 Spray-on Corrosion Inhibitor, Inhibitor Modified Overlay System
    621 Non-Dried, Postrite
    622 Non-Dried, Cortec 2020
    623 Non-Dried, Alox 901
    624 Dried, Postrite
    625 Dried, Cortec 2020
    626 Dried, Alox 910

700 New Topical Structural Treatments
  710 Type I Concrete Removal, Patch with Corrosion Inhibitor Concrete
    711 DCI
    712 Cortec 2000
  720 Type II Concrete Removal, Spray-On Inhibitor, Patch with Corrosion Inhibitor Concrete
    721 Postrite, DCI Concrete
    722 Cortec 2020, Cortec 2000 Concrete
    723 Alox 901, PCC

Table 3-7. Number of observations.

	YEAR											
STATE	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	TOTAL
CA					54	57	32	53	62	98	106	462
FL					18	18	16	5	3	7	7	74
IA												0*
IL									145	468	247	860
IN							691	758	440	481	715	3,085
KS					166	206	308	239	311	788	405	2,423
MT		3	12	18					5	20	12	70
NC												0*
NH				66	119	291	78	176	186	142	222	1,280
NY												0*
PA						147	282	219	147	207	100	1,102
PT						199	32	64	42	94	109	540
TX							13	12	4	27	11	67
VT					21		206	24	87	60	105	503
WA	3				6	23	63	41	66	71	81	354
TOTAL	3	3	12	84	384	941	1,721	1,591	1,498	2,463	2,120	10,820

*SHA failed to provide bid tabulations.

project ranged from one to as many as fifteen. For each treatment item used in the contract, the quantity and each contractor's bid price were recorded. This resulted in a series of data observations for each item. The total number of data observations for all techniques is 10,820. Table 3-7 summarizes the number of data observations per state per year. Each observation represents one bid price on a treatment item from one contract by one bidder.

It should be noted that some states provided more data than other states. The Indiana Department of Transportation was responsible for supplying 3,085 data observations, approximately thirty percent of the total. Normally, one state supplying such a significant amount of data would cause concern about influencing the model. However since each observation was adjusted using the previously discussed location and time factors, any influence from geographical distribution of the data should be appreciably diminished.

As can be seen in Table 3-7, most states were able to produce contracts back to 1986. Not surprisingly, the snow belt states had the most rehabilitation contracts, and most of them dealt with deck repair. The southern states and California were chosen since they have large coastlines and rehabilitation projects comprised mostly of superstructure and substructure repairs brought on by marine atmospheric corrosion conditions.

The ages of the transportation systems played a large part in determining the number of contracts obtained. The northeastern states, those with the oldest systems and harshest environmental influences, displayed the largest amount of rehabilitation work during the early to mid-1980s. Unfortunately complete contracts were not readily available for all years. The midwest and west coast states are now involved in large numbers of rehabilitation projects, as can be seen in Tables 2-1 and 3-7 for Indiana, Illinois, Kansas and Washington. California, with a combination of good weather and a relatively young system, has, to date, had fewer rehabilitations than might be expected.

Another factor in the number of contracts obtained is the rehabilitation strategy of the states surveyed. Some states, notably Pennsylvania and Kansas, let contracts that include rehabilitations to several structures. However, Kansas tabulates the items for each bridge thus having many more observations per contract than Pennsylvania. Pennsylvania, as well as other states, list only one item for each treatment but have large quantities for that item.

The data obtained from each state were sorted by item numbers and merged with the other states resulting in individual data bases for each item. Table 3-8 summarizes these data bases showing the distribution by state. This table gives an indication of which states are using which technique. Since the items were normalized by modifying the pay units to be

Table 3-8. Number of observations by state and item.

ITEM #	CA	FL	IL	IN	IA	KS	MT	NH	N Y	NC	PA	PA TPK	TX	VT	WA	TOTAL
111	25	0	100	808		600	22	63			141	20	5	120	0	1,904
112	12	2	153	405		431	3	49			91	25	11	8	0	1,190
121	64	0	0	0		0	0	3			0	0	0	6	41	114
122	0	0	0	0		0	0	0			0	0	0	0	0	0
131	6	0	15	0		0	0	0			12	0	0	0	34	67
132	0	0	0	0		0	0	0			0	0	0	0	0	0
210	0	0	30	799		11	11	0			93	121	0	0	138	1,203
220	12	0	45	0		3	0	309			20	9	0	95	11	504
230	0	0	29	0		600	11	3			0	0	0	0	0	643
241	0	0	127	0		0	11	198			182	42	4	0	3	567
242	26	0	0	0		26	3	283			6	0	0	0	0	344
243	142	1	0	0		0	4	0			70	0	0	0	3	220
251	63	0	90	788		588	0	52			122	41	0	48	16	1,808
252	0	0	2	0		15	0	0			0	0	0	0	0	17
260	18	0	40	215		102	0	0			2	0	0	55	14	446
310	0	0	0	0		0	0	0			3	0	0	0	47	50
320	2	0	31	0		3	0	0			0	0	0	0	28	64
330	54	0	0	0		0	0	0			3	0	0	0	16	73
411	6	0	106	0		7	0	45			92	15	0	58	0	329

Table 3-8. Number of observations by state and item.

ITEM #	CA	FL	IL	IN	IA	KS	MT	NH	N Y	NC	PA	PA TPK	TX	VT	WA	TOTAL
412	5	25	40	0		30	0	81			119	78	47	17	0	442
421	0	0	0	0		0	0	3			1	0	0	0	0	4
422	0	0	0	0		0	0	0			0	0	0	0	0	0
431	0	0	11	0		0	0	0			0	9	0	0	0	20
432	0	8	0	0		0	0	0			0	0	0	0	0	8
510	0	0	0	0		0	0	0			0	0	0	0	0	0
521	0	0	27	0		0	0	0			0	0	0	96	0	123
522	18	24	0	0		0	5	0			24	0	0	0	0	71
530	9	13	0	70		0	0	0			42	30	0	0	3	167
541	0	1	14	0		7	0	126			79	150	0	0	0	377
542	0	0	0	0		0	0	65			0	0	0	0	0	65
TOTAL	462	74	860	3,085	*	2,423	70	1,280	*	*	1,102	540	67	503	354	10,820

consistent and adjusting the unit costs for inflation and location, it was possible to merge all like treatment items. These are the data which will be analyzed to produce the cost models.

Each observation makes up one record in the data base. Along with the item number and unit cost as-bid, there are several other pieces of information maintained for each record. This information includes:

- The state from which the data was obtained
- The highway district from within that state
- A project number and project description
- The date on which the contract was let
- The number of bidders on the job and the place in which the bidder finished in the bid order
- The total contract bid amount
- The total amount bid for maintenance and protection of traffic
- The item number
- The adjusted national price.

The state, district and letting date are used to calculate the adjusted national price using previously discussed procedures. The project number and description were maintained as identification so that if questions arose, the original bid tabulations could be consulted. The quantity, adjusted national price, number of bidders, contract amount, and maintenance and protection of traffic amount were used to develop the model.

In statistical modeling it is necessary to have a sufficiently large data set so that the resulting models provide significant estimations. Neter, Wasserman and Kutner suggest that the number of observations should be at least six to ten times the number of the variables in the independent variable pool (*9*). There were four independent variables (quantity, number of bidders, contract amount and maintenance and protection of traffic amount), with the adjusted national price being the dependent variable. Therefore, the model building data sets should contain between 24 and 40 observations. If this criterion is used for the data in Table

3-8 there appears to be insufficient data for the following items and of course the newly developed treatments (#600 and #700's):

#122	Full depth quick-set hydraulic mortar deck patches (0 observations)
#132	Full depth polymer mortar deck patches (0 observations)
#252	Hydrodemolition (17 observations)
#421	Shallow quick-set hydraulic mortar structure patches (4 observations)
#422	Deep quick-set hydraulic mortar structure patches (0 observations)
#431	Shallow polymer mortar structure patches (20 observations)
#432	Deep polymer mortar structure patches (8 observations)
#510	Encase structure with portland cement concrete (0 observations)

Since there is insufficient data for these items, other methods must be used to determine a cost model.

Since quick-set and polymer mortars are very expensive when compared with portland cement the benefit in their use comes from being able to quickly return the structure to service after the repairs have been made. If a deck requires full depth patching, it can be assumed that the structure requires a great deal other rehabilitation work as well. In this case there is little or no benefit from using the rapid hardening materials for the patch. Also, since there were no observations in over 800 contracts, it was decided to drop these two items (# 122 and #132) from further consideration.

While there is no benefit to be gained from using rapid setting materials for full depth slab repairs, as evidenced by the list above, there is some benefit for their use in structural repairs. Therefore, items #421, #422, #431 and #432 remained in consideration. However since there were so few observations, classical engineering cost estimating techniques were used to develop the cost models for these.

Most states surveyed have used hydrodemolition as a technique to remove concrete deck surfaces. However, in order to keep bid prices as low as possible, most SHAs use a generic scarification specification which allows for either hydrodemolition, or the more common milling. Since a significant amount of effort has been expended in investigating hydrodemolition in another Task in the C-103 project (including costs), this method (#252) will be dropped from further consideration. The data from item #252 was merged into the more generic scarification item (#250) since this item allows for the use of hydrodemolition.

Encasement of heavily deteriorated substructure elements with portland cement concrete is often performed by SHAs. But, as can be seen in Table 3-8, there were no reported observations for item #510. Conversations with SHA engineers revealed that this procedure is generally not bid in this manner. More commonly, the concrete and reinforcing steel quantities are added to generic structural class concrete and reinforcing steel quantities. Therefore, since encasement is a commonly used repair technique, engineering cost estimation was used to determine the cost for this item.

The bid tab data are summarized in Appendix A in the form of plots of unit cost (contract median cost) versus contract quantity. One plot is presented for each treatment item for which sufficient data exist. All costs are adjusted to mid-1991 national average values.

Since SHA would not have any experience with the 14 items listed in Table 3.6 items #600 and #700, engineering cost estimation was also used to determine the cost of these newly developed SHRP C-103 items.

Computer Models

Scope of Models

In general the extensive amount of data obtained from the various SHAs provided a sufficient number of observations with which to develop statistical models. There are several problems which may result from only the use of observational or historical data. The primary concern is that historical data does not result from a controlled experiment. Therefore the data may not provide adequate information on cause and effect. Without a carefully controlled experiment, all of the controlling independent variables may not be observed. Another aspect of this problem is that although an apparent statistical relationship is found to exist, this does not necessarily indicate that there is a causal relationship. If there is a causal relationship at the present or in the past, there is no guarantee that this relationship will hold in the future.

Caution must be used when applying derived models. Doubt about the accuracy of models outside of the regressed limits exists, and care should be used when the model is used outside these limits. The accuracy of the model is based on the assumption that all independent variables are known and are used in the model. If, in actuality, this is not the case, the shape of the curve outside the regressed limits may be in doubt.

Factor Description

After the data were obtained and processed into subsets containing similar work items from each state, model development procedures were instigated. Preliminary work was initiated into determining possible factors which would affect the model. As previously described, the only variables available from the bid tabulations which might have an affect on the adjusted national cost were quantity of work, the number of bids, the total contract cost and the maintenance and protection of traffic cost. No other factors were available without extensive research of the project contract documents, which was infeasible for the over 800 contracts utilized in the study in the time allotted.

With only these four variables to use in the model, it was necessary to develop an understanding of how these variables effect the bid price. It was determined during interviews with estimators that most SHAs predict their costs simply on the quantity of work performed. This is based on there being two components of cost - a fixed cost and a variable cost. The fixed cost represents costs which will be realized regardless of the quantity. An example of this is materials; the price is generally fixed at a certain unit price. In the simplest form, this may true. However, there may be discounts for large quantities and premium prices for small quantities. Labor and equipment requirements also vary with size. A larger quantity will require either more labor and equipment or a longer time span to complete the work. Productivity rates also must be considered when comparing the cost of large or small repair. When all of these factors are considered it is evident that there is a relationship between quantity and cost--as quantity increases, the unit cost decreases. This relationship is evident in Figure 3-5 which shows a plot of cost versus quantity for item 210 - latex modified concrete overlays. This plot shows that there is a tremendous reduction in price as the quantity increases. At very small quantities, the cost was doubled and in some six times the cost for large quantities. As can be seen in Figure 3-5, this cost reduction changes rather rapidly, and at approximately 2000 square yards (1674 m^2) the cost becomes almost constant for this particular item.

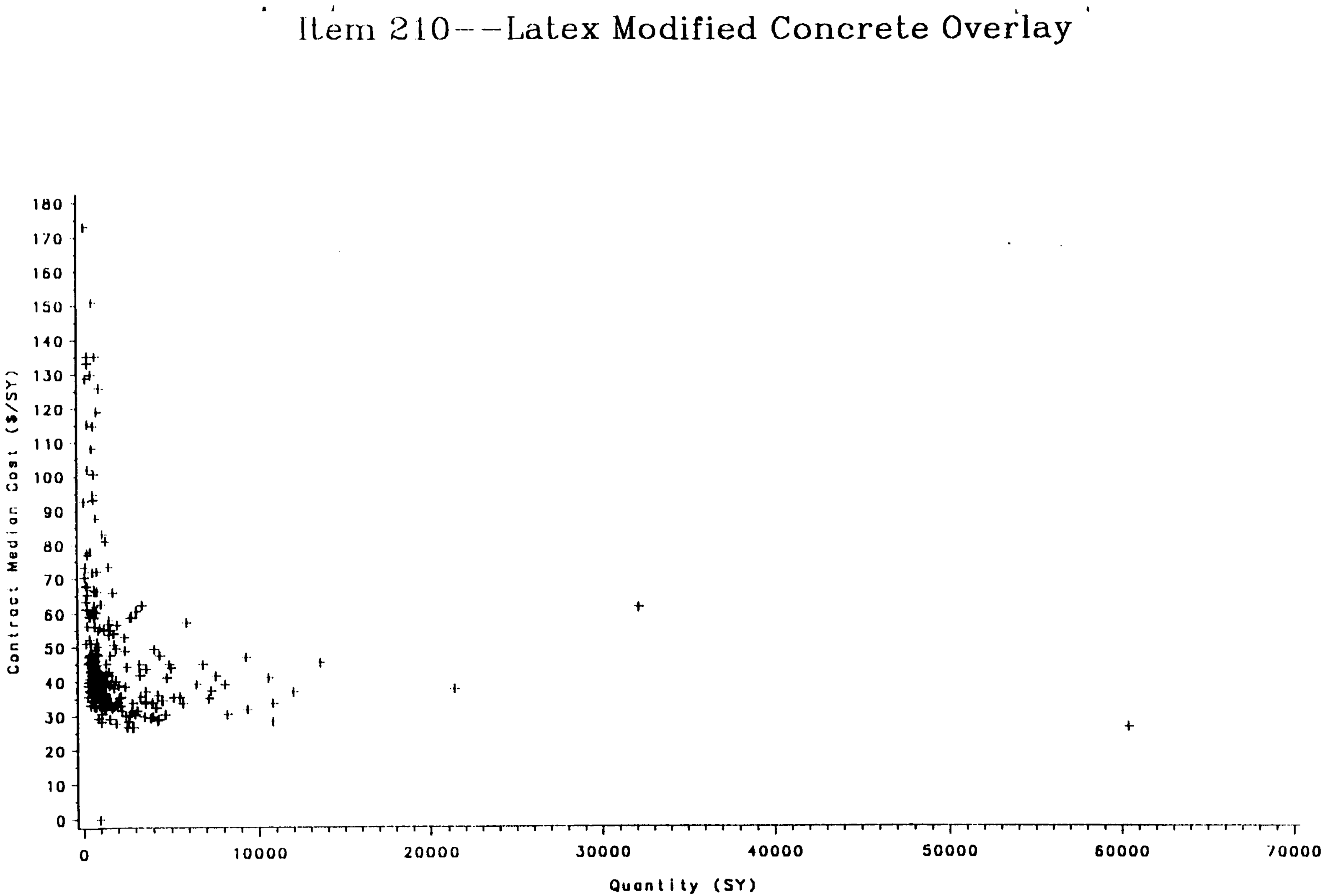


Figure 3-5. Cost versus quantity for Item 210--latex modified concrete overlays.

Similar quantitative relationships can be developed for the other variables in the data bases. The state of the economy plays a major role in determining costs of repairs. Construction activity is a commonly used activity for gauging the economic climate. As the economy worsens more contractors begin to rely on public projects, and the number of bidders on the projects increase. Knowing that competition has increased, the contractors must cut costs to a minimum to be competitive. By reducing profit margins and overhead rates, as well as labor costs, the contractor's bid prices drop. While simply observing the number of bidders on a specific contract may be a crude indicator, it may provide additional insight and improve the model.

Another factor which has an effect on cost is the difficulty of the work. This difficulty may be the result of poor access to the repair area, remote location of the jobsite, etc. Again, without additional in-depth research into the contracts, it is not easy to determine the complexity of the work. One variable available on the bid tabulations that may provide some information regarding the difficulties on the construction site is the cost of the maintenance and protection of traffic (MPT) item. Even more is revealed if the ratio of MPT costs to total contract cost is observed. As this ratio increases, it indicates more effort being expended on job site activities rather than actual rehabilitation work. There are many reasons to have an increased MPT budget. In urban areas work may be limited to non-rush hours, so that traffic safety equipment must be removed to open the highway. This causes a shift in the work hours on the project, resulting in increased costs for labor, equipment and even materials, since overtime or premium hours are being worked. In rural areas MPT costs are generally lower since traffic levels are much lower and entire structures may be closed for long periods of time for rehabilitation. By closing the structures and not forcing workers to be exposed to traffic, productivity increases and overhead rates are reduced, leading to lower bid prices at the expense of the user costs (not used in the model).

The total construction cost should also be considered as a possible factor influencing costs. As the size of a contract increases it allows the contractor to spread overhead and profit over more items and quantities. While the savings in this case may not be as significant as with other factors, there may be some savings realized and this will be considered in the model.

The relationships between the four variables and unit cost can be simplified as follows:

- As quantity increases, cost decreases
- As the ratio of MPT cost to total contract amount increases, cost increases
- As the number of bids increases, the cost decreases

- As the total contracts amount increases, the cost decreases

It is desired to combine these variables into a series of factors which can be modeled to provide cost information. Since the quantity of work is probably the best indicator of cost, it was decided that this variable should be present in all factors. This results in the following eight factors:

Factor 1 = quantity

Factor 2 = (quantity * contract amount)/MPT amount

Factor 3 = quantity * contract amount

Factor 4 = quantity * number of bidders

Factor 5 = ((quantity) * (contract amount)^2)/MPT amount

Factor 6 = (quantity * number of bidders * contract amount)/MPT amount

Factor 7 = quantity * contract amount * number of bidders

Factor 8 = (quantity * number of bidders)/MPT amount

Typical plots of adjusted national cost versus each factor are shown in Figures 3-6 through 3-13, for Item 111--partial depth p.c.c. deck patch. As can be seen in these eight plots, there appears to be a relationship between the adjusted national cost and each factor. However, it does appear that there is more noise or scatter in some plots when they are compared. For example, Figures 3-6 and 3-7 both show trends that as the independent variable (Factor 1 and Factor 2, respectively) increases, there is a rapid decrease in cost. As the independent variable continues to increase the rate of change of the cost decreases and the cost levels out at some asymptotic value. Similar trends are shown in Figures 3-8 thorough 3-13. Some of these trends, however, are less defined than others due to the scatter in the data. Some factors, such as Factor 7 in Figure 3-12 seem to have a great deal of scatter and will not produce a proper model. Factors for any items which appear to have little or no correlation with the adjusted national cost were dropped from further consideration. This will be discussed more fully in Chapter 4.

It should be noted that there is a great variation in the magnitude of the independent variables between the factors. This is particularly significant for Factors 3, 5, and 7, and to a lesser extent in Factors 2 and 6. The reason for this is the presence of the contract amount in these terms. The effect is less in Factors 2 and 6 since the term is divided by the MPT amount. Factor 5, although divided by the MPT amount, has the contract amount squared in the numerator, thereby reducing the effect of the MPT term in the denominator. Factors 3 and 7 do not have the MPT amount in the denominator, and therefore have large magnitudes. It should be noted that the magnitudes of these variables will not have adverse effects on the models. They will, however, have an impact on the magnitude of the regression coefficients.

Model Description

Based on the shape of the curves in Figures 3-6 through 3-13 it was decided that a nonlinear decay model should be used to fit the data. There were four models that were proposed;

- an exponential decay model

$$y = b_1x + b_2 \exp(-x/b_3) \tag{3-16}$$

- an inverse power model

$$y = b_1 + b_2x + b_3/x^{b_4} \tag{3-17}$$

- an hyperbolic model

$$y = b_1x + (b_2 + b_3x)/(1 + b_4x) \tag{3-18}$$

- a logarithmic model

$$y = b_1 + b_2 x - b_3 \log_{10}(x) \tag{3-19}$$

These four models are capable of fitting the types of curves shown Figures 3-6 through 3-13, and will be discussed in the following sections

Exponential Decay Model

The exponential decay model has been used successfully to develop nonlinear models for data similar to that shown in Figures 3-5 through 3-13. In this regression equation, the b_2 parameter is the y - intercept when x is equal to zero.

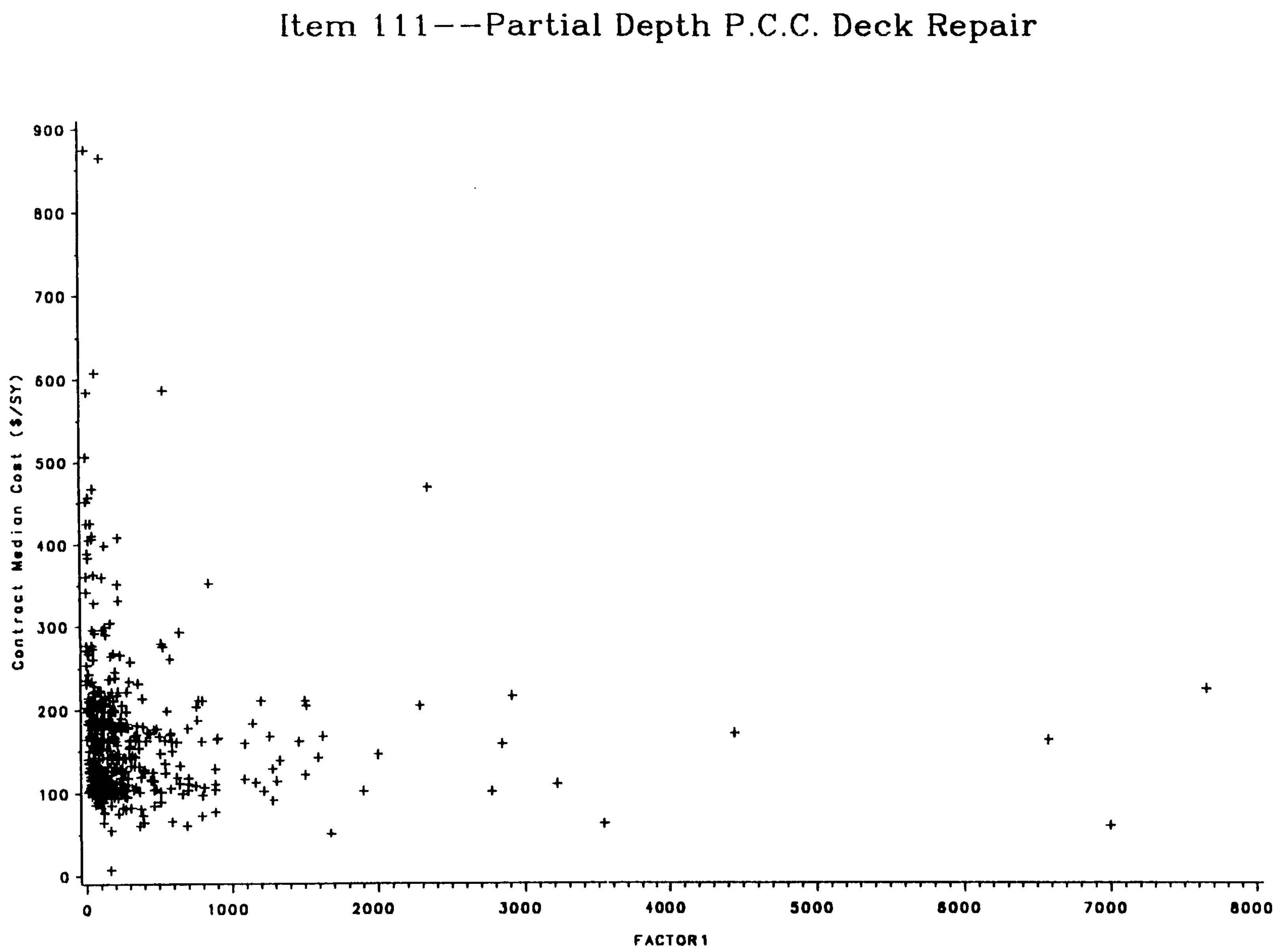


Figure 3-6. Adjusted national cost versus factor 1 for Item 111--partial depth p.c.c. deck patch.

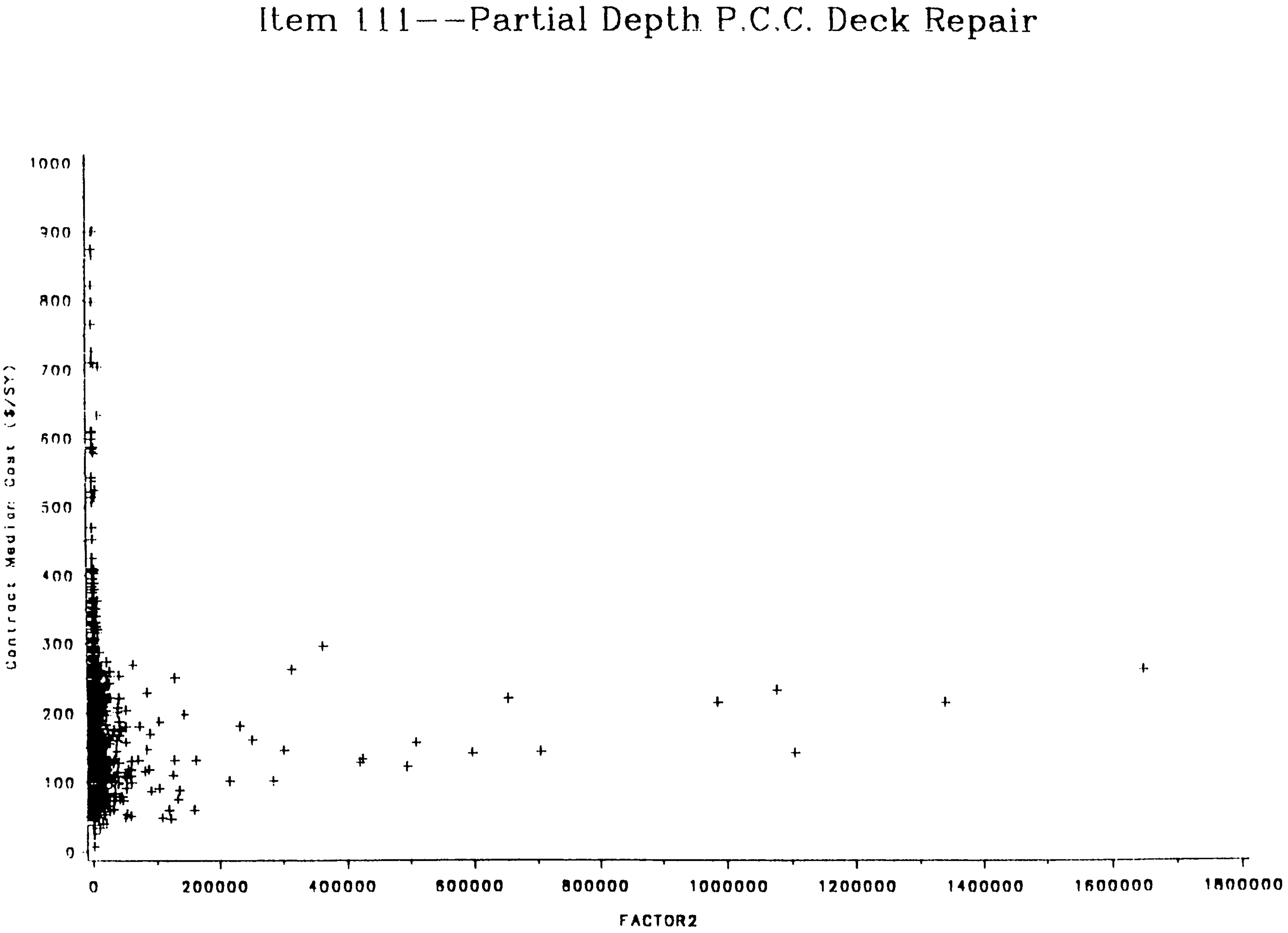


Figure 3-7. Adjusted national cost versus factor 2 for Item 111--partial depth p.c.c. deck patch.

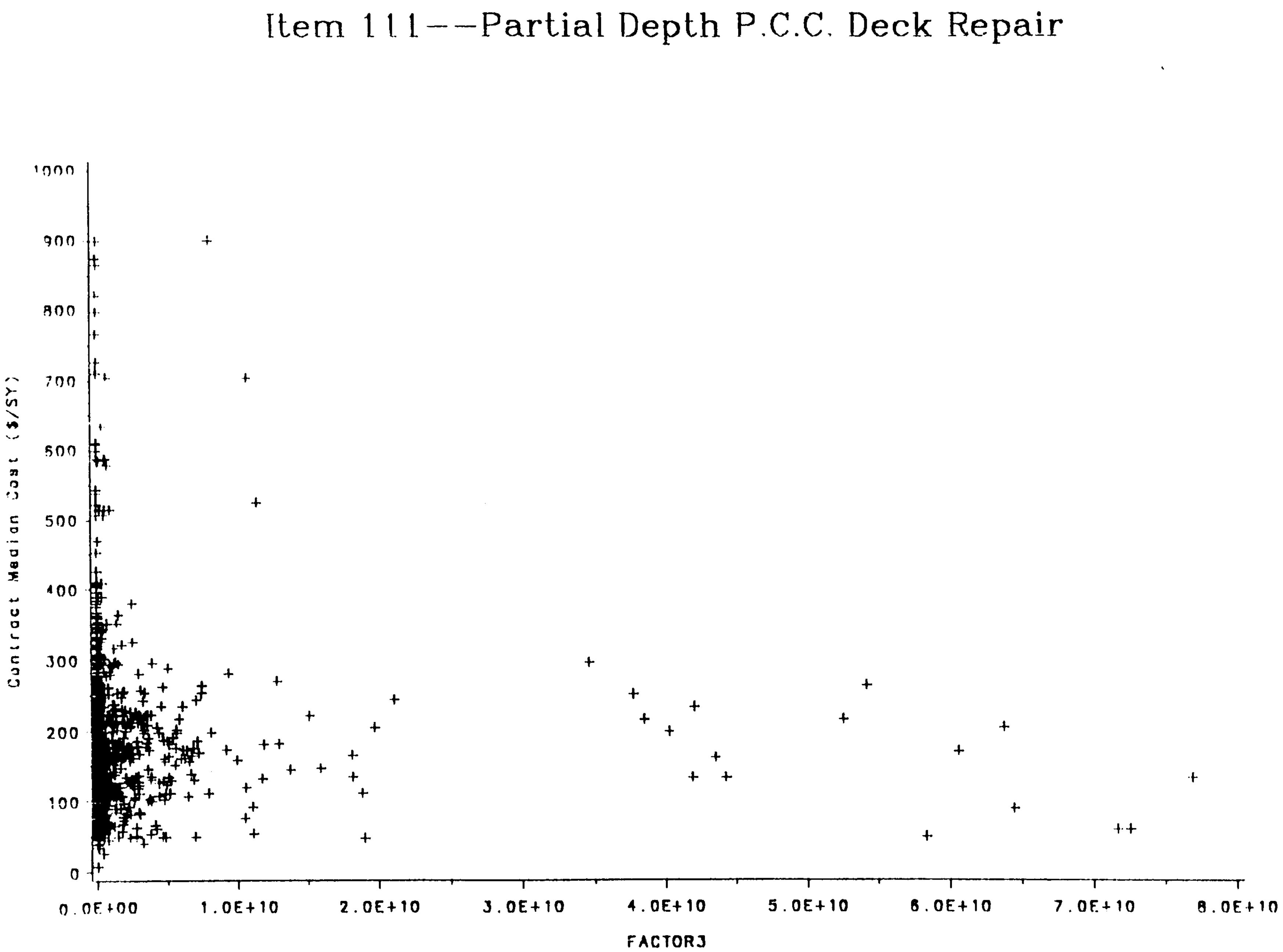


Figure 3-8. Adjusted national cost versus factor 3 for Item 111--partial depth p.c.c. deck patch.

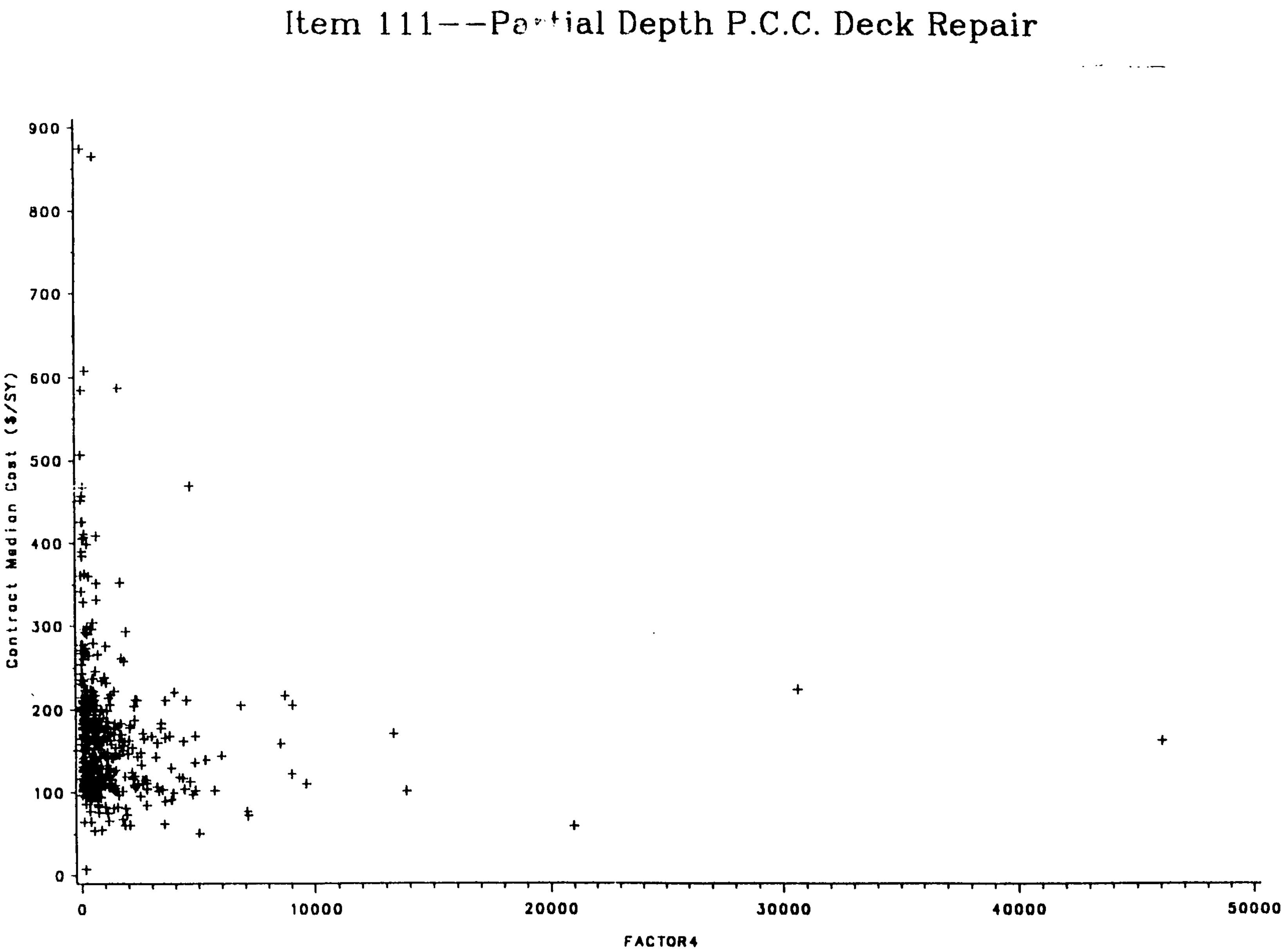


Figure 3-9. Adjusted national cost versus factor 4 for Item 111--partial depth p.c.c. deck patch.

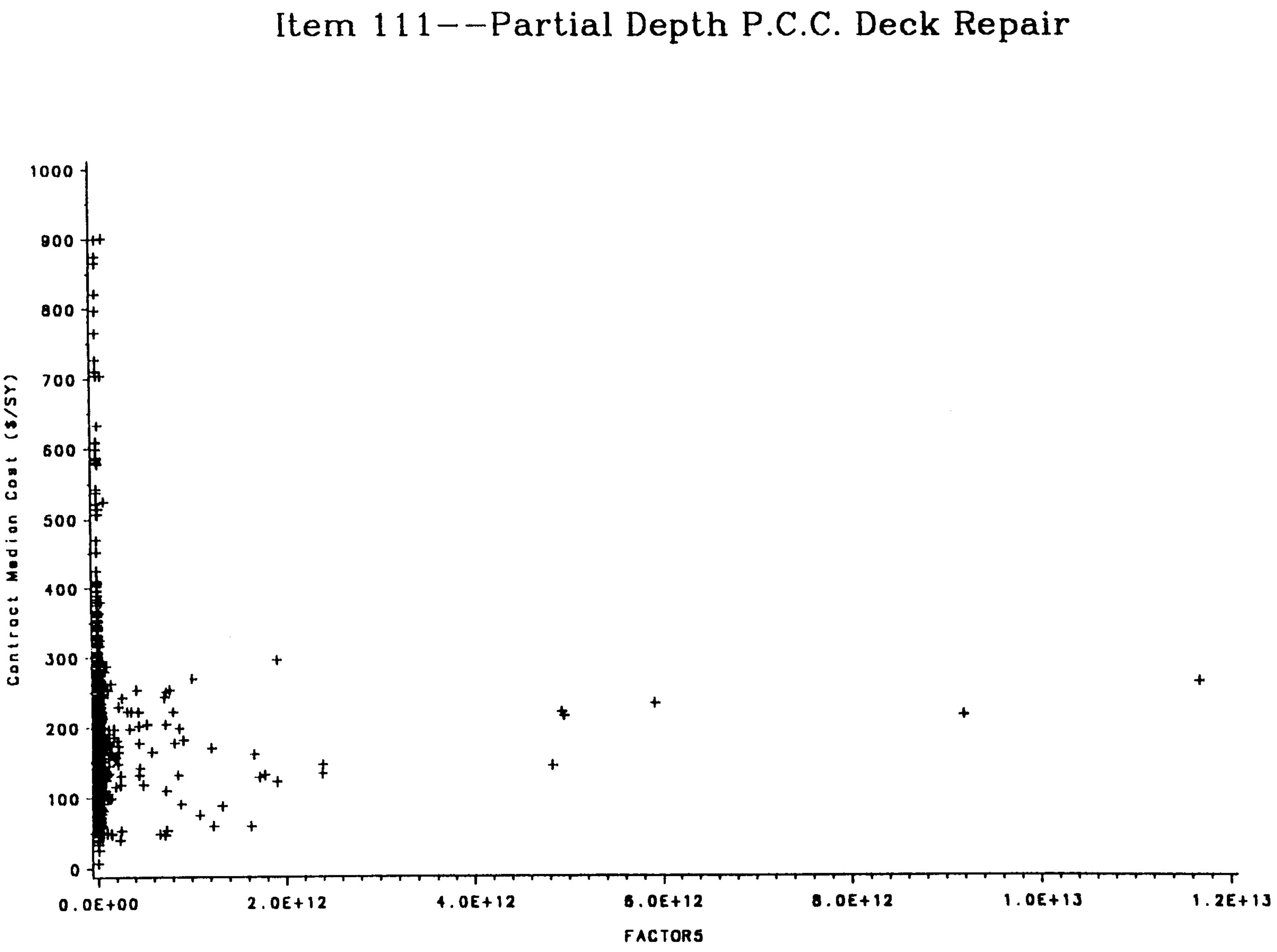


Figure 3-10. Adjusted national cost versus factor 5 for Item 111--partial depth p.c.c. deck patch.

Item 111--Partial Depth P.C.C. Deck Repair

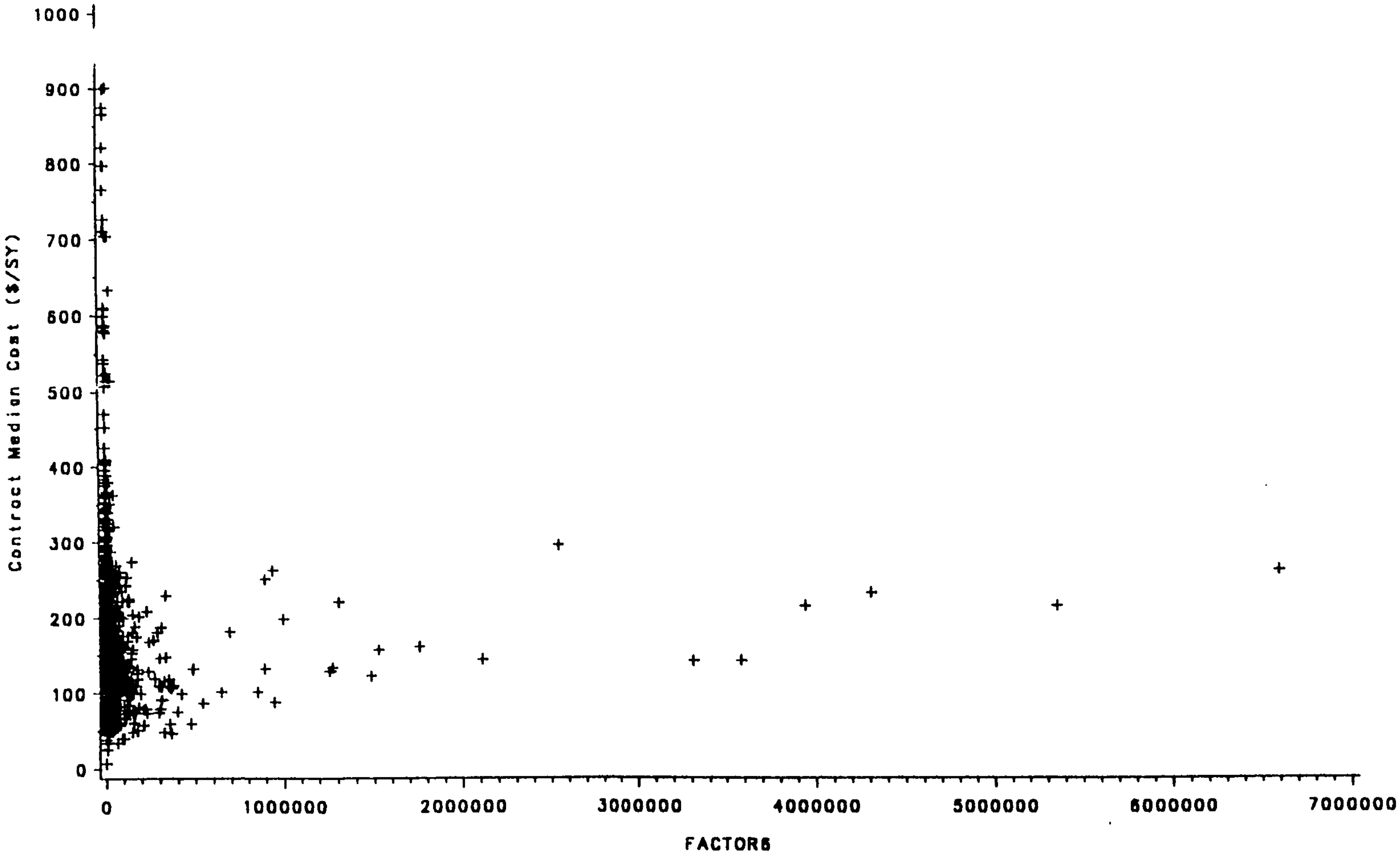


Figure 3-11. Adjusted national cost versus factor 6 for Item 111--partial depth p.c.c. deck patch.

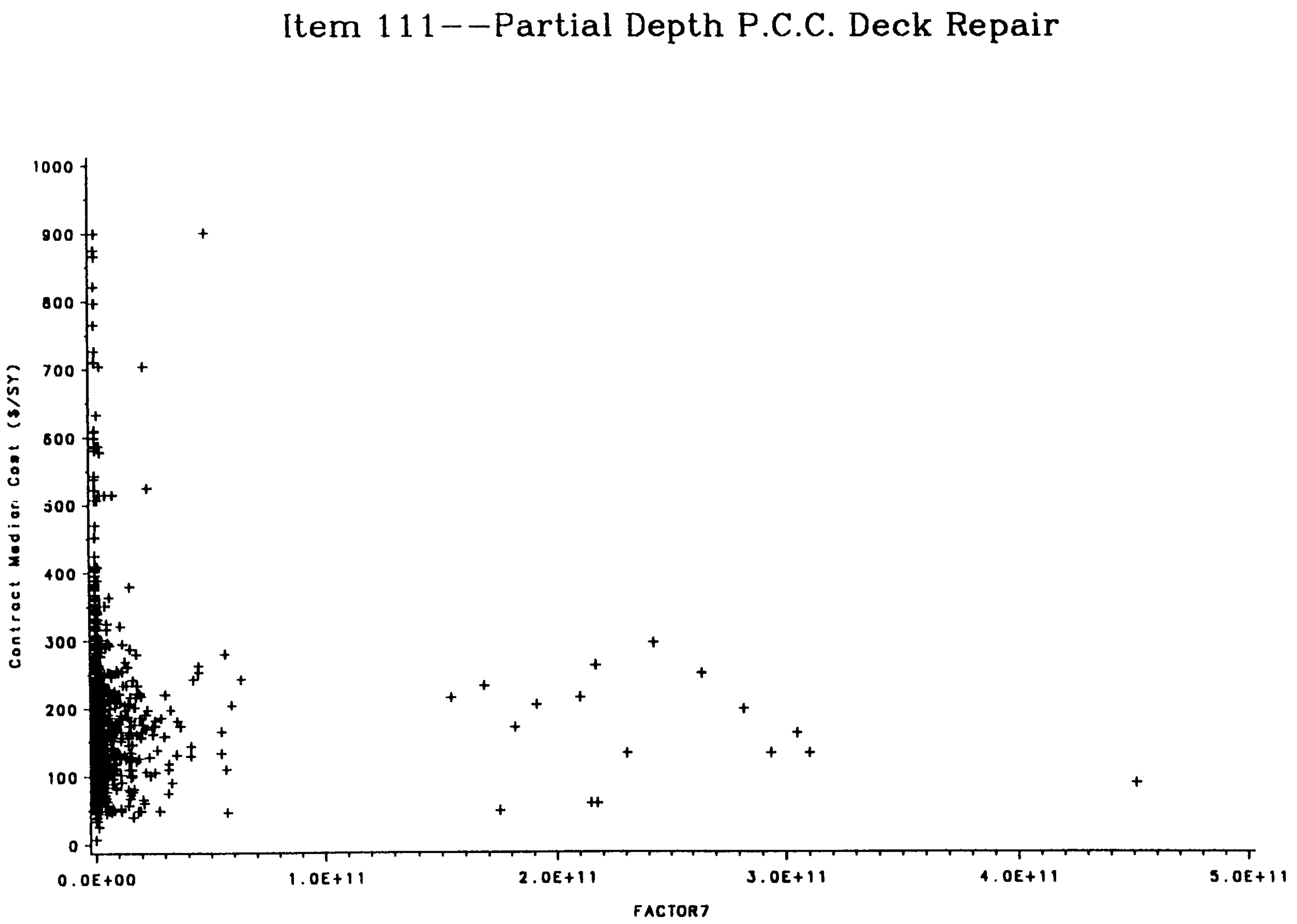


Figure 3-12. Adjusted national cost versus factor 7 for Item 111--partial depth p.c.c. deck patch.

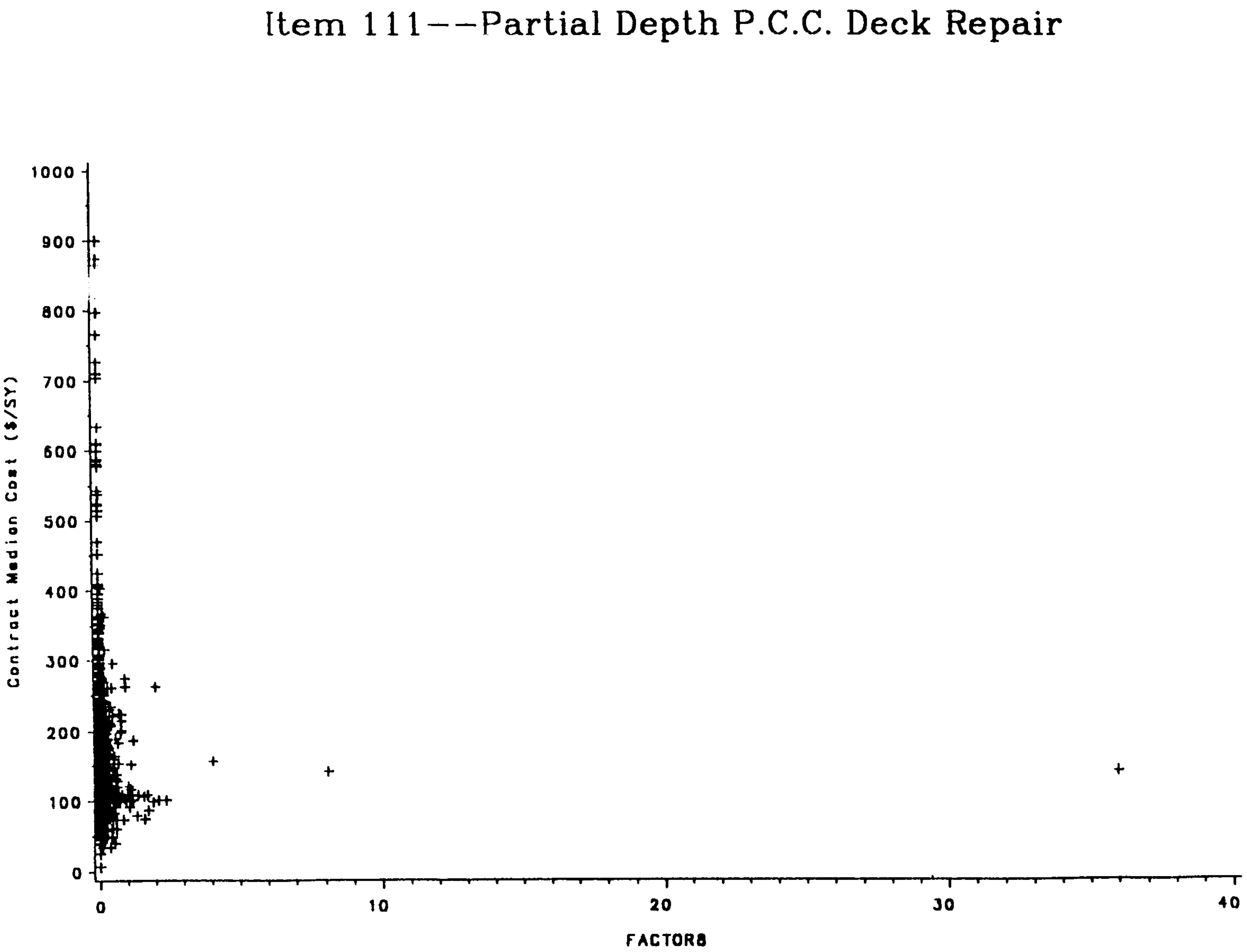


Figure 3-13. Adjusted national cost versus factor 8 for Item 111--partial depth p.c.c. deck patch.

The b_3 parameter and negative exponential term provide the shape of the decay curve. As the b_3 parameter increases the shape of the curve becomes much flatter for a given range of x. The b_1x term allows the tail of the decay model to have an asymptote which may or may not be horizontal. A positive or negative value of b_1 will provide a positive or negative slope for the asymptote. The value of the b_1 parameter may also be zero, providing a horizontal asymptote. Because of the great variation in the ranges of all of the factors, difficulty was experienced in obtaining values of b_3 which would provide the necessary steepness at small values of the independent variable. With further modification this model might prove to be appropriate, but it was rejected since other, simpler models, provide better fit.

Inverse Power Model

This model consists of three terms. As the b_4 parameter increases, there is a sharp increase in the steepness of the slope of the curve at lower values of the independent variable. At large values of x the third term approaches zero. The second term, b_2x, provides for varying slopes of the asymptote. The b_2 parameter can provide for a positive or negative slope of the asymptote, as well as for a horizontal asymptote. The first term of the model, the b_1 parameter, provides for a shift of the model along the vertical axis. Preliminary results from this model were quite promising by virtue of it's ability to fit various shapes of curves. Because of these results, this model was considered for indepth analysis of the data.

Hyperbolic Model

This is an extremely powerful model, and consists of two terms. The first term, b_1x, has a similar function in this model as in previous models -- it allows for variation in the asymptote. The second term provides the fit for the nonlinear model. This model can fit any portion of an hyperbolic function in any of the four quadrants of the Cartesian coordinate system by varying the signs of the three parameters, b_2, b_3 and b_4. The b_3 and b_4 terms provide the horizontal and vertical asymptotes for the model. This model also allows for shifts along the horizontal and vertical axes. This model worked well in preliminary applications and was considered for further use. However, during subsequent analysis of the data, it was found that problems can occur due to the inherent properties of this conic section. When the vertical asymptote occurs to the right of the origin, limitations must be placed on the independent variable so that realistic cost values are predicted. As the asymptote is approached from the right, the predicted cost will increase dramatically. If the value of the independent variable is the same as the asymptote, the cost will be undefined. If the value of the independent variable is less than the asymptotic value, the cost could be a very large negative value. To ensure realistic results, the value of the independent variable must be restricted to being greater than the vertical asymptotic value.

The location of the vertical asymptote and the restrictions necessitated by its location, could cause problems when the model is used to estimate costs. The results generated from the model would have to be verified before use. These complications greatly diminish the utility of the hyperbolic model for the case at hand. Therefore, it will not be used here.

Logarithmic Model

The last model consists of three terms. The first term, b_1, permits a shift along the vertical axis. The second term, b_2x, provides for possible variations in the slope of the asymptote. The third term, with the negative b_3 parameter provides the shape of the curve. This model suffers from the same problems as the exponential decay model, and that is the difficulty in forcing the log functions to fit the steepness of the data at small values of the independent variable. This model, with sufficient changes, might provide an acceptable model. However, since the inverse power model provides a good fit with relative simplicity, the logarithmic model was dropped from consideration.

Goodness of Fit

Regression Coefficient

The most commonly used measure of a regression model's fit is the coefficient of multiple regression, R^2. It measures the proportionate reduction of total variation in the dependent variable associated with the set of independent variables. The value of R_2 is between 0 and 1, inclusive and is defined as:

$$R^2 = 1 - \frac{SSE}{SSTO} \qquad (3\text{-}20)$$

where:

SSE = error sum of the squares

$$= \sum (Y_i - \hat{Y})^2$$

Y_i = the observed value of the dependent variable

$\hat{Y}$ = the predicted value of dependent variable based on the regressed model

SSTO = total sum of the squares (adjusted)

$$= \sum (Y_i - \bar{Y})^2$$

$\bar{Y}$ = mean of the observed values

The closer the R^2 value is to one, the better the model takes into account the variability in the data. Generally, a model is considered a good fit for the data if the R^2 value is greater than 0.80. This type of agreement is usually the result of carefully controlled laboratory experiments where all causal relationships are known.

It is not expected that data available for analysis in this task will provide R^2 values in the range of what is normally considered acceptable in controlled laboratory testing. As stated earlier in this chapter, the use of observational data generally produces poor models since all of the causal variables may not be known. In observing Figures 3-5 through 3-13 it is readily obvious that the R^2 values will be low due to the tremendous scatter. This scatter is particularly obvious at the lower ranges of the independent variables. It almost appears as if the contractors use no rational approach to determine the bid price in the lower quantity ranges. This may be the case for a smaller job since it is possible that estimating and bid preparation costs may exceed anticipated profits if an indepth estimate is prepared. Contractors may rely on their historical costs to reduce the effort in bid preparation causing unexplainable variations in bid prices between contractors in the low quantity levels. In order to increase the R^2 value it is necessary to have less scatter and a smoother fit. While this is desirable, caution must be used so that the true variability is not lost in attempts to improve the data.

Median Cost Values

In the analysis of the bid tabulations it is obvious that there can be, and very often are, large discrepancies between the bids offered by different contractors for the same item on the same contract. This wild variation can be attributed to several causes, including:

- A new contractor may not have the benefit of experience and will not be able to competitively perform certain types of work

- Some contractors may place a higher profit margin on certain items of work

- Some items may be subcontracted resulting in higher prices.

There are numerous causes for the tremendous variation in bid prices. SHAs can expect that the price paid for a particular quantity of work will typically be somewhere around the midpoint between the highest and lowest bid for that item. Most states recognize this and during the interviews with estimators it was revealed that most states keep a running average for use in developing the engineers estimates. Very few states acknowledge the role that quantity has on the cost function, however. Most often the SHAs keep track of only the low bidder cost, but some also track the low bid for the item as well.

Given that the bid price for a particular item may vary widely and the SHA can expect to pay between the high and low bids for that item, it is suggested that the median value be used to predict the SHAs cost. The median is the middle value when all observations are sorted in ascending order. The benefit in using the median to describe the data set is that the median is insensitive to a number of extremely small or large data values. The mean, on the other hand, is very sensitive to even one of these outliers. Since it is possible that there will be a large variation in the adjusted national cost for any value of the independent variables, the median of the cost will be used.

Lumped Mass Approach

To enhance the model further, a lumped mass approach will be used. This will be accomplished by taking all observations within a specified area of the plot and applying those observations at the center of this area. The procedure will be to round the independent variables and then find the median cost of all of the resulting observations.

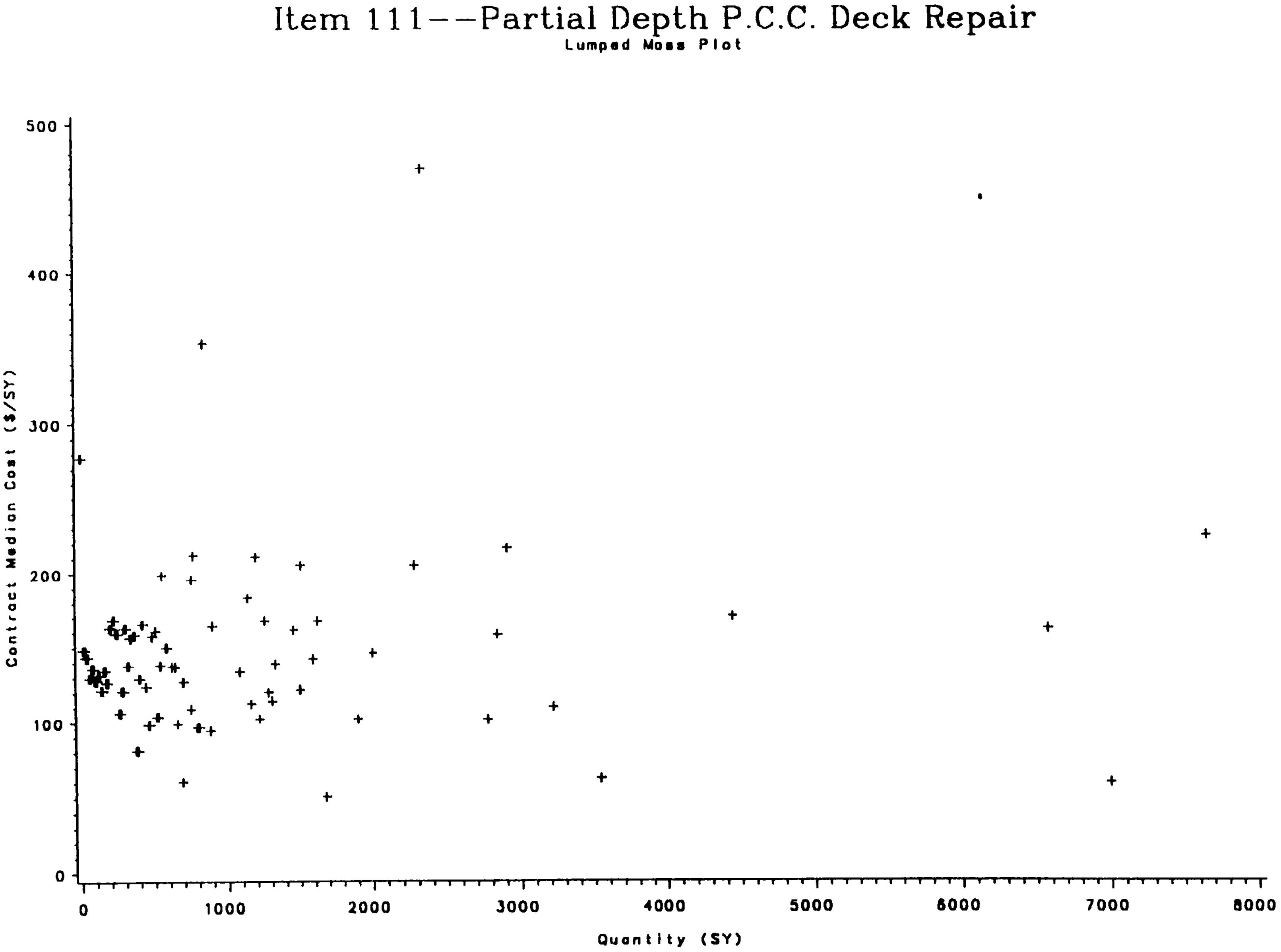


Figure 3-14. Median adjusted national average cost versus rounded factor 1 for Item 111--partial depth p.c.c. deck patch.

The point which represents the median cost at the rounded value of the independent value will then be weighted by the number of observations. The effect of this approach will be to remove some scatter from the plots, yet weight the statistical analysis in the same manner as the original data. The results of this procedure can be seen in Figure 3-14. When Figures 3-6 and 3-14 are compared, the effects of the modifications become evident. There is a significant change for small values of Factor 1. The clutter has been lessened, and the large variation in cost has been reduced. As the value of Factor 1 increases, the effect on the shape of the curve is lessened since there are not as many data points at those large values. By reducing the clutter at the low values of Factor 1 and retaining the shape at higher values, it will be possible to develop a better cost equation.

When using this lumped mass approach to reduce the clutter of data, it is important to carefully select the value to which the independent variable is rounded. If too high a rounded value is used, the trends may be altered. If too small a value is used, the clutter is not sufficiently removed and the trends may remain hidden. In order to obtain the optimum rounding value, a sensitivity analysis was performed. This sensitivity analysis was accomplished by starting with no rounding and gradually increasing the amount of rounding. For each rounding level a cost equation was generated, and the R^2 value recorded. The optimum rounding level was determined to be the level which produced the greatest R^2 value. This process is illustrated in the Table 3-9 for Item 111--partial depth p.c.c. deck patching. As can be seen in this table, as the rounding level increases, there is an increase in the R^2 value. This is attributed to the lumping and weighting of the data. By using this procedure the outliers are removed from the regression thus increasing the R^2 value. However, the influence of agglomeration of points is maintained by the weighting. The more data observations that make up a lumped point, the more influence this point has on the regressed model. As previously mentioned, if too large a rounded value is used, the trend of data is destroyed. This can be seen in Table 3-9 for rounding values of 25 and 30. When these values are used, the trends are destroyed, and a seemingly random pattern of data points is produced. This is verified by an R^2 value of zero, which indicates no rela the independent and dependent variables. For Item 111, this occured rather quickly between 20 and 25. For most items, however, there was a gradual reduction in the R^2 value before the R^2 value reached zero.

Table 3-9. Sensitivity analysis for rounding of Factor 1 for Item 111--partial depth p.c.c. deck patching.

Rounding Level	R^2
none	0.118
5	0.242
10	0.353
15	0.394
20	0.447
25	0
30	0

SAS Software

Description

The primary software used for data analysis was the SAS system (*10, 11, 12*). The SAS software provides tools for information storage and retrieval, data modification and programming, report writing, statistical analysis, and file handling. The SAS system provides capabilities to perform regression analysis as well as other types of statistical analyses. The graphics package available in the SAS system is capable of producing data plots on terminals, plotters or printers.

There are several procedures in the SAS system which are used for regression analysis. All of the procedures available in the SAS system are based on standard statistical practices. They fit an equation to a set of values, and the parameters of the equation are determined to optimize the fit. Most commonly, linear regression models are used. However, due to the trends shown by the data in this study, it was necessary to use the nonlinear regression procedure (PROC NLIN) available in the SAS System.

PROC NLIN

PROC NLIN is used to fit nonlinear regression models by least squares. Since nonlinear models are more difficult to fit than linear models, the regression equation must be specified, starting values must be assigned to all parameters of the models, and partial derivatives of the model with respect to each parameter must be provided. Because of the complexity of fitting a nonlinear model, several attempts are usually required before the correct model is obtained.

A partial listing of a SAS program is shown in Figure 3-15. This listing finds parameters for four different regression models; model 1, model 2, model 3 and model 4. The statements required for the nonlinear regression begin with the "proc nlin" statement. This statement starts the procedure, specifies the Gauss-Newton solution method, limits output to the best model and specifies that the data set to be used for regression is called "nlin." The "parms" statement assigns starting values to the parameters b_1, b_2, b_3 and b_4. The next statement defines the model to be used in the regression. In this listing, the four models used are those which were initially investigated: the exponential decay model (Model 1); the inverse power model (Model 2); the hyperbolic model (Model 3); and the logarithmic model (Model 4). Each of these models uses Factor 1 as the independent variable and "Mcost" as the dependent variable. The final statements are the partial derivatives of the model with respect to parameters b_1, b_2, b_3 and b_4. Each of these four nonlinear regression models produces output, as shown in Figure 3-16.

The PROC NLIN output is divided into three parts: an analysis of variance table, the parameter estimates and the correlation matrix of the parameters. The analysis of variance table is used to determine the goodness of fit of the model and consists of the sum of squares values for the regression model, the residual, the uncorrected total and the corrected total. Also, the mean square values are listed for the regression model and the residual. As described previously, the coefficient of the multiple regression, R^2, is used to judge goodness of fit. The R^2 value is easily calculated by subtracting the ratio of the residual sum of squares to the corrected total sum of squares from unity. For the output shown in Figure 3-15, the R^2 value is approximately 0.983.

The second section in the output provides information about the parameters of the model. For each parameter an estimate is made based on least squares analysis. A standard error for that estimate is listed, as well as the 95 percent confidence interval for the estimate based on the error term. Caution should be used when judging the size of the standard error term The size of the error alone may be deceiving, so the 95 percent confidence interval should be used to judge the error involved for that parameter. For example, the error for b_2 is much smaller than for b_3, but examination of the 95 percent confidence intervals shows that b_3 is actually predicted more accurately than b_2.

The final section of the output presents the Asymptotic Correlation Matrix of the Parameters. This matrix contains the coefficients of simple correlation between all pairs of the parameters.

Engineering Cost Estimates

General

As noted earlier in this chapter, the bid price data available from the SHAs contacted were not sufficient to permit the development of statistical cost models for a number of treatment items. In general, the lack of historical data in the case of some important treatment items probably reflects the relative newness, or experimental nature, of these items during the 1980's. Also, at least in one instance (concrete encasement) the lack of field data is attributed to the manner in which bid items are formulated, and it's cost becomes distributed among other cost items. Five important treatment items for which insufficient cost data exist were identified under "Data Observations," as follows:

#421	Quick-Set Hydraulic Mortar/Concrete Patches (shallow repairs).
#422	Quick-Set Hydraulic Mortar/Concrete Patches (deep repairs).
#431	Polymer Mortar/Concrete Patches (shallow repairs).
#432	Polymer Mortar/Concrete Patches (deep repairs).
#510	Encase with Portland Cement Concrete.

In order to provide cost information for these items, classical engineering cost estimating procedures were used.

```
*;
*   nonlinear model 1 - using factor 1 as variable;
*;
proc nlin method=gauss best=1 data=nlin;
  parms b1=.02
        b2= 200
        b3= 7000;
  model mcost=b1*factor1+b2*exp(-factor1/b3);
  der.b1=factor1;
  der.b2=exp(-factor1/b2);
  der.b3=b1*factor1*exp(-factor1/b2)/b2**2;
*;
*   nonlinear model 2 - using factor 1 as variable;
*;
proc nlin method=gauss best=1 data=nlin;
  parms b1=150
        b2=-.04
        b3=300
        b4=.5 ;
  model mcost=b1+b2*factor1+b3/factor1**b4;
  der.b1=1;
  der.b2=factor1;
  der.b3=1/factor1**b4;
  der.b4=-b3*log(factor1)/factor1**b4;
*;
proc nlin method=gauss best=1 data=nlin;
  parms b1= .00503
        b2= 116.75
        b3= -14.849
        b4= -.111;
  model mcost=b1*factor1+(b2+b3*factor1)/(1+b4*factor1);
  der.b1=factor1;
  der.b2=1/(1+b4*factor1);
  der.b3=factor1/(1+b4*factor1);
  der.b4=-factor1*(b2+b3*factor1)/(1+b4*factor1)**2;
*;
proc nlin method=gauss best=1 data=nlin;
  parms b1=100
        b2=.1
        b3=-2;
  model mcost=b1+b2*factor1+b3*log10(factor1);
  der.b1=1;
  der.b2=factor1;
  der.b3=log10(factor1);
```

Figure 3-15. Typical SAS nonlinear regression procedure statements.

```
NON-LINEAR LEAST SQUARES SUMMARY STATISTICS   DEPENDENT VARIABLE MCOSTF1

    SOURCE                  DF  SUM OF SQUARES     MEAN SQUARE

    REGRESSION               4    490178.25305    122544.56326
    RESIDUAL                66      1312.05069        19.87956
    UNCORRECTED TOTAL       70    491490.30373

    (CORRECTED TOTAL)       69     78774.55053

    PARAMETER       ESTIMATE     ASYMPTOTIC            ASYMPTOTIC 95 %
                                 STD. ERROR          CONFIDENCE INTERVAL
                                                     LOWER          UPPER
    B1              22.08838       5.084231      11.937370      32.239387
    B2               0.00118       0.000283       0.000619       0.001750
    B3           42251.90894   14420.662621   13460.086346   71043.731533
    B4               0.91826       0.059263       0.799934       1.036580


                 ASYMPTOTIC CORRELATION MATRIX OF THE PARAMETERS

CORR                 B1                B2                B3                B4

B1               1.0000           -0.9465            0.9321            0.9501
B2              -0.9465            1.0000           -0.8331           -0.8556
B3               0.9321           -0.8331            1.0000            0.9983
B4               0.9501           -0.8556            0.9983            1.0000
```

Figure 3-16. Typical SAS nonlinear regression procedure output.

In addition to the above five items, engineering cost estimating procedures also had to be used to estimate the C-103 newly developed physical-chemical methods. The newly developed techniques included the following two techniques (#610 and #620) and two surface area superstructure-substructure techniques (#710 and #720).

#610 Deep Impregnation using Grooving Technique
  #611 With Methyl Methacrylate
  #612 With Corrosion Inhibitor, Postrite
  #613 With Corrosion Inhibitor, Cortec 2020

#620 Spray-On Corrosion Inhibitor, Overlay with Inhibitor Modified Concrete
  #621 Spray Postrite on Air Dried Surface
  #622 Spray Cortec 2020 on Air Dried Surface
  #623 Spray Alox 901 on Air Dried Surface
  #624 Dry Concrete Spray on Postrite
  #625 Dry Concrete Spray on Cortec 2020
  #626 Dry Concrete Spray on Alox 901

#710 Type I Concrete Removal, Patch with Corrosion Inhibitor Modified Concrete
  #711 Corrosion Inhibitor DCI
  #712 Corrosion Inhibitor Cortec 2000

#720 Type II Concrete Removal, Spray-On Corrosion Inhibitor, Patch with Corrosion Inhibitor Modified Concrete
  #721 Spray-On Inhibitor Postrite, Patch Concrete Inhibitor DCI
  #722 Spray-On Inhibitor Cortec 2020, Patch Concrete Inhibitor Cortec 2000
  #723 Spray-On Inhibitor Alox 901, Patch Concrete Normal PCC

Approach

In terms of estimating costs, the first four of the five items listed above constitute the greatest problem. All involve patch repair of bridge elements other than the deck. Two types of rapid patching materials at two levels of repair depth formulate the four cases of treatment items #421, #422, #431, and #432. However, in investigating scenarios for bridge structural patching (including substructure members), it appears that the most probable set of cases involving the two types of rapid set materials consists of three depth ranges, as follows: $<$ 1 in (2.5 cm), 1-3 in (2.5 - 7.6 cm), and $>$ 3 in (7.6 cm). Polymer mortar/concrete is used for the shallow and intermediate depths, and quick-set hydraulic mortar/concrete for the intermediate and deepest patches (*14, 15*). Thus, for estimating purposes the four treatment levels are redefined as shown in Table 3-10.

Table 3-10. Redefinition of Patch Structural Treatments Using Rapid Setting Materials.

Patch Depth	Material	Treatment Item #
< 1 in (2.5 cm)	Polymer Mortar/Concrete	431
1-3 in (2.5 - 7.6 cm)	Polymer Mortar/Concrete	432
1-3 in (2.5 - 7.6 cm)	Quick-Set Hydraulic Mortar/Concrete	421
> 3 in (7.6 cm)	Quick-Set Hydraulic Mortar/Concrete	422

The primary difficulty with estimating the costs for these items is that they generally involve small quantities. The enormous effect of very small quantity levels on price scatter has already been dramatically illustrated earlier in this chapter. Another factor that affects prices for these items is the bridge member being repaired. This relates primarily to accessibility. Therefore, it was deemed necessary to estimate prices for the four treatment items in Table 3-10 for three quantity levels (low, medium, and high) and for each of seven concrete bridge member types, as follows:

- beams
- diaphragms
- piers
- pier caps
- backwalls
- abutments
- wingwalls

This results in 84 scenarios (combinations) for which cost estimates had to be prepared for treatment items #421, #422, #431, and #432.

The approach used to establish the three quantity levels was to define a "typical" concrete bridge and to use repair quantities in accordance with current practice (*13-15*) and engineering judgement. Mid-1991 national average unit cost values ($/SY) were determined using engineering estimating procedures and cost component data as presented by R.S. Means Co., Inc. (*8*). Costs for the patching materials were obtained from suppliers by telephone quotations.

The fifth case identified earlier as requiring engineering estimates for cost determinations is treatment item #510, surface area structural treatments involving encasement with portland cement concrete. Two scenarios were identified here, as follows (*13-15*):

- encasement of heavily deteriorated concrete piers
- jacketing of heavily deteriorated concrete abutments.

Here again, three quantity levels were evaluated (based on height of encasement or jacketing), and standard engineering estimating procedures and cost component data (*8*) were used.

With the six cases associated with treatment item #510, a total of ninety cost estimates were done. The detailed procedures and calculations are presented in Appendix B.

For the four newly developed techniques, a total of 14 items were identified above. As previously noted for patch deck techniques, percent of the deteriorated area of the deck at rehabilitation time would have an influence on the unit estimated cost. In addition to the sound but actively corroding condition, three levels of deterioration, 5, 10, and 20 percent of the deck area, were selected as typical.

As noted above, the estimated cost to repair superstructure - substructure elements is influenced by the member type and quantity of the deck to the to be repaired area. Member types included in the approach are the same as above, beams, diaphragms, piers, pier caps, backwalls, abutments, and wingwalls. Three levels of repair quantities (low, medium, and high) were estimated for each of the two types of superstructure - substructure concrete removal, seven member types, and three levels of repair quantity. For the Type I concrete removal, the concrete is removed to below the rebars. For Type II concrete removal, the concrete is removed to the rebar depth.

Thus, cost estimates were made using engineering estimating methods for a total of 213 newly developed rehabilitation scenarios (108 deck and 105 superstructure-substructure scenarios). Mid-1991 national average unit cost values ($/SY) were determined from published cost component data, previous cost estimates, and material costs obtained from suppliers by telephone quotations. Detailed procedures and calculations are presented in Appendix C.

4

Results and Discussion

Introduction

The results of the studies carried out to develop costs for the bridge protection and rehabilitation treatments are covered in this chapter. First, cost equations developed by regression analyses of bid tab data from the SHAs will be presented. That will be followed by costs and cost equations developed using engineering estimating procedures for the five patching/protection systems for which sufficient SHA bid tab data were not available for regression analyses and for the newly developed techniques.

Cost Equations From Bid Data

General

In this section the results of the regression analysis for each system discussed in Chapter 3 are presented. A description in each system is provided. This generic description will permit adaption of the cost model to other specifications. Along with the description is a discussion of the pay quantity for each item. For most items this varies for different states. So, any assumptions made for conversion to similar units is described.

As reported in Chapter 3 only one of the four proposed models was used in analyzing the data, that being the inverse power model (model 2). Recall that the inverse power model takes the form:

$$y = b_1 + b_2 x + \frac{b_3}{x^{b_4}} \tag{4-1}$$

where:

y = dependent variable, predicted national adjusted cost,
x = independent variable, one of eight possible factors:
  Factor 1 = quantity
  Factor 2 = (quantity * contract amount)/MPT amount
  Factor 3 = quantity * contract amount
  Factor 4 = quantity * number of bidders
  Factor 5 = ((quantity * (contract amount)^2)/MPT amount
  Factor 6 = (quantity * number of bidders * contract amount)/MPT amount
  Factor 7 = quantity * contract amount * number of bidders
  Factor 8 = (quantity * number of bidders)/MPT amount

b_1, b_2, b_3, and b_4 are the regressed parameters for the models. Information tabulated for each treatment includes:

- The [illegible]nding level

- The values obtained for the four parameters (b_1 through b_4)

- The R^2 value

This information is supplied for each of the factors defined above. For each of the twenty items, cost equations were generated for all eight of the factors--a total of 160 equations. As stated previously, if there appears to be no relationship exhibited (R^2 values are very low), cost equations are not reported.

Patch Deck

P.C.C. Patch Repairs--Partial Depth (#111)

This item of work includes all labor, material and equipment costs associated with the removal of unsound concrete, preparation of concrete surfaces, repair and/or replacement of damaged reinforcing steel, and the furnishing, placing, finishing, and curing of the portland cement concrete patch. The removal shall be sufficient to provide ¾ in (19 mm) minimum clearance below the top layer of reinforcing bars. The maximum depth of the repair should not exceed one-half of the slab thickness.

The pay quantity for this item is per square yard. This was chosen since it was most commonly used by SHAs in the bid documents.

A simple calculation is required to convert to square feet, the second most used quantity. Other SHAs used a pay quantity of cubic feet for the partial depth repair. This was based on the volume of material removed, not the surface area of the repair. Conversion to square feet was accomplished by assuming an average repair depth of 3 in (7.6 cm).

For Item 111, there were five cost equations produced, involving Factors 1, 2, 4, 6 and 8. The summary statistics for these equations are shown in Table 4-1. For each factor, information is provided about the level to which the independent variable should be rounded or estimated, the model regression parameters (b_1 through b_4) and the R^2 value for each model.

As shown in Table 4-1, information is not provided for Factors 3, 5, and 7. For these factors there was too much scatter in the data. After numerous attempts to smooth the data, an acceptable value for R^2 was not obtained, and efforts were abandoned to produce cost equations for these factors.

Based on the information provided in Table 4-1, it is recommended that Factor 4 be used as the independent variable in the inverse power model (model 2) for Item 111. This provides an R^2 value of 0.607, which is considered to be quite good. Factor 4 is the product of the repair quantity and the number of bids. This factor attempts to consider the economic climate at the time the job is let. If information is not available on the expected number of bidders, an acceptable cost equation is available using Factor 1. ($R^2 = 0.447$).

P.C.C. Patch Repairs--Full Depth (#112)

Item 112 includes all labor, material and equipment costs associated with the full depth removal of unsound deck concrete. Also included is preparation of surfaces, restoration of any damaged reinforcing steel, and the furnishing and placing of portland cement concrete to the required depth.

The pay quantity for this item is per square yard. Conversion from cubic yards to square yards was accomplished by assuming an average slab depth of 9 in (23 cm).

The results of the regression equations are shown in Table 4-2. Cost equations for Factors 3, 5, and 7 are not reported due to low R^2 values. The equations for Factors 1 and 4 have the highest R^2 values and are approximately the same, 0.527 and 0.550, respectively. Although the R^2 value for Factor 1 is slightly less than that of Factor 4, it is recommended that this equation be used for Item 112. The small difference in the R^2 value is offset by the ease of using the quantity of repair (Factor 1) rather than needing also to know the number of bidders (Factor 4).

Quick Set Hydraulic Mortar/Concrete Patches--Partial Depth (#121)

This item of work is similar to Item 111--partial depth p.c.c. deck repairs, except that Type III cement or proprietary materials are used instead of Type I portland cement. The work description is the same as Item 111, as is the pay quantity (square yards).

Table 4-3 summarizes the results of the regression analysis for Item 121. For this item, only Factor 5 is not reported, due to poor R^2 values. By far, the best equation results when Factor 1 is used in the regression model as the independent variable. The R^2 value of 0.834 is very good, especially considering the great variation inherent in the bidding procedure. It is recommended that the cost equation resulting from Factor 1 be used for Item 121.

Quick Set Hydraulic Mortar/Concrete Patches--Full Depth (#122)

This item was dropped from consideration when analysis of the bid data collected from the SHAs revealed that no state reported its use.

Table 4-1. Regression parameters for Item 111--partial depth p.c.c. deck repair.

Factor	Rounding Level	Parameters				R^2
		b_1	b_2	b_3	b_4	
1	10	134.4	0.00460	316,200	3.345	0.447
2	100	139.14	0.00010	157,700	1.867	0.193
4	100	132.89	0	1,382,600	2.381	0.607
6	500	133.50	0	974,000	1.713	0.242
8	0.0001	132.52	0.584	0.0917	0.862	0.374

Table 4-2. Regression parameters for Item 112--full depth p.c.c. deck repair.

Factor	Rounding Level	Parameters				R^2
		b_1	b_2	b_3	b_4	
1	10	221.11	0.0610	3794.1	1.8688	0.527
2	10	242.19	0.00036	67960.8	2.1677	0.427
4	100	214.24	0.00990	361,990	2.1120	0.550
6	500	231.23	0.000101	13,579,700	2.11	0.430
8	0.0001	216.68	85.52	0.1986	0.7757	0.368

Table 4-3. Regression parameters for Item 121--partial depth quick-set hydraulic mortar/concrete deck repairs.

Factor	Rounding Level	Parameters				R^2
		b_1	b_2	b_3	b_4	
1	10	235.61	-0.037.12	1408.71	0.5014	0.834
2	50	324.58	0.000167	3965.15	0.5901	0.614
3	100,000	283.15	0	14,159.3	0.2723	0.189
4	1	-359.32	0.002426	1,570.21	0.1184	0.515
6	10	315.27	-0.000441	2,049.67	0.3601	0.329
7	1,000,000	379.46	0	739,630	0.5200	0.409
8	0.0001	273.08	259.75	51,385	0.2346	0.251

Polymer Mortar/Concrete Patches--Partial Depth (#131)

This item of work is similar in scope to Item 111, and is fully explained in that section. The work description and pay quantity are the same, except that epoxy is used as a binder rather than portland cement in the patching mixture.

The parameters of the regression equations for Item 131 are reported in Table 4-4. Equations for Factors 3, 5, 7 and 8 are not reported due to extremely low R^2 values. The use of Factor 2 in the regression model resulted in an R^2 value of 0.984. It is recommended that the cost equation for this factor be used.

Polymer Mortar/Concrete Patches--Full Depth (#132)

This item was dropped from consideration when analysis of the bid data collected from the SHAs revealed that no state reported its use.

Conventional Surface Area Deck

Latex Modified Concrete Overlay (#210)

This item of work consists of all labor, material and equipment required to furnish and place a latex modified concrete overlay. The specifications for this work are usually lengthy and are quite similar from state to state. However, there are differences in the depths of the overlays. For the purposes of the cost equation developed here, all LMC overlays were assumed to be 1¼ to 1½ in (31.8 to 38.1 mm) in depth. These are the most typical depths specified by SHAs. When contracts specified variable depth overlays, it was assumed that these were 1½ in (38.1 mm) deep. The pay quantity used for this item is per square yard.

The results of the regression analyses are shown in Table 4-5. Cost equations were not generated for Factors 3, 5 and 7, due to lack of fit. All equations reported in Table 4-5 will provide sufficient accuracy. However the cost equation for Factor 8 has an R^2 value of 0.899. This value is very high and it is recommended that the equation that it represents be used in estimating the cost of latex modified concrete overlays. It should be noted that Factor 8 requires information about the number of bidders and the estimated MPT cost. If this information is not known, one of the other equations may be substituted without appreciable effect on the predicted cost.

Table 4-4. Regression parameters for Item 131--partial depth polymer mortar deck repairs.

Factor	Rounding Level	Parameters				R^2
		b_1	b_2	b_3	b_4	
1	1	145.77	0.3825	1206.24	0.4721	0.458
2	100	266.79	0.02933	83,400.	1.2214	0.984
4	1	328.44	0.02359	4315.22	0.9210	0.500
6	50	-501.04	0.03496	2861.02	0.1688	0.326

Table 4-5. Regression parameters for Item 210--latex modified concrete overlay.

Factor	Rounding Level	Parameters				R^2
		b_1	b_2	b_3	b_4	
1	100	34.05	0.000147	1682.33	0.8389	0.640
2	10,000	36.21	0	913,880	1.3588	0.697
4	500	32.79	2.6×10^{-5}	2246.05	0.6961	0.807
6	50,000	34.60	2.98×10^{-6}	83,298.0	0.8952	0.727
8	0.01	37.87	-0.00123	0.02809	1.4360	0.899

Membrane and A.C. Concrete Overlay (#220)

This item of work includes all labor, equipment and materials necessary to furnish and place sheet membrane waterproofing. Due to the large fluctuations in the price of asphalt, the use of differing specifications for asphalt mixes and the required overlay thicknesses, this item does not include the cost of the asphalt overlay. Much more realistic estimates of these costs can be made based on current market prices, rather than historical trends. While the details of the work differs among states that use this system, all procedures are essentially the same, and were considered such for this item. The pay quantity is per square yard.

It is recommended that the cost equation using Factor 1 be employed to estimate costs for Item 220. Table 4-6 shows that this results in an R^2 value of 0.783. This is surprisingly high considering the volatility of the bituminous industry. Equations for Factors 3, 4, 5, 7 and 8 were not reported due to the high degrees of scatter encountered.

Low Slump Dense Concrete Overlay (#230)

Item 230 includes all labor, materials and equipment costs associated with the furnishing and placement of an LSDC overlay. A survey of the states which provided bid information on this item indicated that the average depth of 2 in (5 cm) should be used. The actual depth specified may vary from this value both within a particular state and among the states. These variations result in a higher degree of scatter, and correspondingly lower R^2 value. The pay quantity for this item is per square yard.

Table 4-7 shows the results of the regression analysis for Item 230. The high degree of variation in the application of these overlays resulted in a generally poor fit for all Factors. The equation generated for Factors 3, 5, 6, 7 and 8 are not reported due to poor fit. The cost equation using Factor 4 has the highest R^2 value, 0.651. While this may not be as high as it is for some other items, the use of the equation for Factor 4 will provide an adequate prediction of cost.

Sealers: Boiled Linseed Oil (#241; #521)

This item includes all material, labor and equipment necessary to furnish and apply boiled linseed oil to concrete surfaces. The work also includes surface preparation using sand or water blasting. Most commonly, sealers are paid by the square yard, and this is the unit chosen for this item. Some states, however, use gallons as the pay unit. In the standard

Table 4-6. Regression parameters for Item 220--membrane and a.c. overlay.

Factor	Rounding Level	Parameters				R^2
		b_1	b_2	b_3	b_4	
1	100	9.781	-0.0001692	3,978,400	3,100	0.783
2	1000	9.0933	-3.257 x 10 [illegible]	163,770	1.4899	0.766
6	100	8.380	-1.111 x 10^{-8}	575.89	0.5445	0.382

Table 4-7. Regression parameters for Item 230--low-slump densified concrete overlay.

Factor	Rounding Level	Parameters				R^2
		b_1	b_2	b_3	b_4	
1	100	37.397	-9.677 x 10^{-5}	9,508,800	2.355	0.300
2	10,000	37.110	-5.792 x 10^{-6}	147,350	1.9861	0.518
4	1,000	31.879	8.82 x 10^{-5}	22,200	0.9791	0.651

specifications for each state, suggested coverage rates are given. These rates are used to convert from gallons to square yards.

Table 4-8 lists the values for the parameters of the regression equations. As can be seen in this table, only one cost equation is listed, the one using Factor 1. This equation has a very poor R^2 value, 0.174, and would not normally be reported. But since this is the best result produced from the available data, it is listed. The variation in bid prices, as evidenced by the very low R^2 value, is very large for this item. This may be attributed to the low cost of the item, approximately \$3-5/SY (\$3.50 - 6.00/m^2). At these low prices, even for very large quantities, the total cost does not have a great effect on the project cost, and therefore a little effort is probably expended by the bidders to determine an accurate bid price. Although the R^2 value is very low, it is recommended that the cost equation based on Factor 1 be used to estimate costs for boiled linseed oil.

Sealers: Silane and Siloxane (#242; #522)

The work included in this item is the furnishing and application of silane and siloxane sealers to concrete deck and structural elements. Work includes all labor, equipment and materials necessary to perform the required work. Also included in the work is surface preparation to remove any deleterious materials by water or sand blasting. The unit of pay is per square yard. Conversion from gallons of sealer to square yards is based on suggested coverage rates.

The regression cost equations for Items 242 and 522, as was the case with boiled linseed oil (Item 241, 521), displayed very poor goodness of fit to the data. The best results used Factor 1 and produced an R^2 value of only 0.080 (Table 4-9). A regression equation with such a poor R^2 value would generally not be proposed for use, but since it is the best one for this item, it is recommended. As was the case with Items 241 and 521, the low price of silanes and siloxanes, \$8-10/SY (\$9.50 - 12.00/m^2), is to blame for the wide variations in bid prices. Because it is not likely to have a large affect on the total contract price, a great deal of effort may not be expended by contractors in determining bid price.

Sealers: High Molecular Weight Methacrylate (#243)

This work includes furnishing and placing HMWM sealer on concrete bridge decks. The cost includes all labor, materials and equipment necessary to perform the work. The work includes surface preparation to remove any deleterious material, application of the sealer and

Table 4-8. Regression parameters for Items 241 ar boiled linseed oil sealer.

Factor	Rounding Level	Parameters				R^2
		b_1	b_2	b_3	b_4	
1	10	1.375	-3.0×10^{-5}	10.895	1.0123	0.174

Table 4-9. Regression parameters for Item 242 and 522--silane and siloxane sealers.

Factor	Rounding Level	Parameters				R^2
		b_1	b_2	b_3	b_4	
1	10	8.652	7.04×10^{-5}	56.077	1.2394	0.080

spreading of sand onto the surface. The pay quantity is per square yard. Conversion between gallons of sealers and square yards is based on the SHAs recommended coverage rate.

The equations generated for this item are better than those for linseed oil and silane and siloxanes. The best cost equation for Item 243 employs Factor 2, and an R^2 value of 0.506 was obtained. It should be noted that the inverse-power model reduced to a linear model for this item (Table 4-10). The b_3 parameter was determined to be zero, resulting in the loss of the inverse-power term. The b_4 term was not reported since the term dropped out. Equations using Factors 3, 5, 6 and 7 were not reported due to poor convergence.

Scarification: Milling and Unspecified Methods (#251)

This work consists of removing the surface portion of concrete decks, abrasive blasting of the concrete surface and cleaning of the surface. The depth of surface removal varies between contracts and states, but the most common depth is ¼ in (6 mm). This depth does vary, but it was assumed that only ¼ in (6 mm) was removed for all contracts observed. The method used to remove the surface is selected by the contractor. The most common method is milling, but the use of hydrodemolition (Item 252) is growing. Unfortunately, there was not enough data to separately analyze the hydrodemolition costs. These observations were merged into Item 251 since most SHAs do not specify which method a contractor may use. The pay unit is per square yard.

Table 4-11 lists the results of the regression analysis. Factors 2, 3, 5 and 7 were not successful in producing suitable equations for predicting cost. The equation using Factor 1, however, was very successful. The R^2 value of 0.921 is very high and indicates that the equation accurately fits the data. It is recommended that this equation be used to predict the cost of scarification.

Scarification: Hydrodemolition (#252)

There were not a sufficient number of observations of this item to permit statistical analysis. These observations were merged with those for Item 251 (scarification) and analyzed. A complete discussion of the results can be found in that section.

Table 4-10. Regression parameters for Item 243--high molecular weight methacrylate deck sealer.

Factor	Rounding Level	Parameters				R^2
		b_1	b_2	b_3	b_4	
1	10	10,192	-6.165×10^{-5}	0	-	0.148
2	10,000	8.9813	-2.687×10^{-6}	0	-	0.506
4	1000	10.079	6.730×10^{-6}	0	-	0.117
8	0.1	9.6576	-0.1897	0	-	0.213

Table 4-11. Regression parameters for Item 251--scarification of concrete deck surface--milling and unspecified methods.

Factor	Rounding Level	Parameters				R^2
		b_1	b_2	b_3	b_4	
1	50	6.952	2.38×10^{-5}	68770	1.8294	0.921
4	1,000	5.754	-2.25×10^{-7}	75540	1.3318	0.795
6	100,000	5.226	2.12×10^{-7}	145,570	0.9960	0.572
8	0.1	7.131	0.329	9.5×10^{-5}	2.3088	0.760

Removal of A.C. Concrete Overlay (Item #260)

It is quite common for local or state authorities to pave, with asphalt, over bridge structures. This paving may be part of a protection system (Item 220) or it may be to improve the rideability of a deteriorated surface. Regardless, it must be removed to enable rehabilitation of the deck. This item will include all labor, equipment and materials necessary to remove asphaltic concrete from the deck surface. This may be accomplished by milling or scraping, usually at the contractor's discretion. The pay unit is per square yard.

The work performed under this item is generally low-tech and inexpensive, $6-10/SY ($7-12/m^2). As such, less time may be spent by the contractors in establishing bid prices. Table 4-12 demonstrates this. Only four cost equations are reported (Factors 1, 2, 4 and 6) and the R^2 values for these are very low. The highest R^2 value is for Factor 4 and is 0.250, normally considered quite poor. Because this is the best fit for Item 260, it is recommended that the equation using Factor 4 be employed to predict costs of removing asphalt from bridge surfaces.

Experimental

Thin Polymer Overlays (#310)

This work consists of furnishing and placing a thin polymer overlay, and includes all equipment, material and labor necessary to complete the work. Thin polymer overlays usually consist of a polymeric material applied to a deck surface with sand, or other fine aggregate broadcast on top. The overlay can be placed in one, or several lifts, and general is between ¼ and ¾ in (6-19 mm) thick. The pay quantity is square yards.

Because the thickness of the overlay is variable and because these overlays are applied rather infrequently, it is expected that there will be large variation in the cost data. Table 4-13 presents information which supports this concern. The R^2 values were very low for Factors 2, 3, 5, 6, 7 and 8, and were not reported. The highest R^2 is 0.204 for Factor 4, and this equation is recommended for use in predicting costs. It should be noted that the regression resulted in a b_3 value of zero for the equations both from Factors 1 and 4, which caused the inverse power term to be dropped, producing in a simple linear model.

Table 4-12. Regression parameters for Item 260--removal of A.C. concrete overlay.

Factor	Rounding Level	Parameters				R^2
		b_1	b_2	b_3	b_4	
1	10	6.906	-7.3×10^{-5}	1831.76	1.6280	0.164
2	100	6.434	-1.01×10^{-6}	385.60	0.7197	0.146
4	100	6.350	-2.5×10^{-5}	5594.44	1.3265	0.250
6	1000	7.692	5.74×10^{-7}	-0.02547	-0.3639	0.124

Table 4-13. Regression parameters for Item 310--thin polymer overlay.

Factor	Rounding Level	Parameters				R^2
		b_1	b_2	b_3	b_4	
1	50	55.792	-0.00106	0	-	0.104
4	1000	56.109	-0.000359	0	-	0.204

Micro-Silica Concrete Overlays (#320)

This work item involves the furnishing and placing of a micro-silica concrete overlay. Included is all material, equipment and labor costs associated with the overlay. The most commonly specified depth of this type of overlay is 2 in (5 cm). The inclusion of data representing different depths contributes to the variation shown in the cost equations. The pay quantity is per square yard.

Unlike thin polymer overlays, micro-silica overlays are much more commonly used, and are more uniform in depth and character. This will provide for more stable cost equations, as evidenced in Table 4-14. There are five equations which may be used to predict cost. The best of these uses Factor 2, and has an R^2 of 0.614. The regression parameters for Factor 1 indicate that a linear model has resulted in that instance.

Polyester Overlay (#330)

Polyester overlays are most commonly used in California and Washington State. They consist of a polymeric material and fine aggregate pre-mixed and applied in similar fashion to regular p.c.c. overlays. They are very uniform in composition and depth. This item includes all labor, materials and equipment necessary to furnish and install a polyester overlay. The pay quantity is per square yard.

Table 4-15 indicates that the use of the cost equation based on Factor 1 will provide exceptional results. The value of R^2 of 0.983 is very high and, even though Item 330 is considered experimental, this is an indication of the uniformity of the specification. The R^2 values for the other two equations, Factor 2 ($R^2 = 0.489$) and Factor 6 ($R^2 = 0.301$) are low, and equations for Factors 3, 4, 5, 7 and 8 are not reported. It is recommended that the equation based on Factor 1 be used to predict costs.

Patch Structural

P.C.C. Patch Repairs--Shallow (#411)

This item includes all labor, materials and equipment to repair superstructure and substructure concrete elements. Included is the removal of unsound concrete, preparation of the concrete surfaces, repair or replacement of the steel reinforcing and furnishing and

Table 4-14. Regression parameters for Item 320--micro-silica concrete overly.

Factor	Rounding Level	Parameters				R^2
		b_1	b_2	b_3	b_4	
1	1000	45.967	-0.000693	0	-	0.304
2	1000	42.299	-8.192×10^{-5}	67,470.	1.0082	0.614
4	1000	34.018	-8.43×10^{-5}	6253.16	0.7567	0.579
6	1000	43.013	-2.60×10^{-5}	161,830	1.0079	0.365
8	0.001	-353.795	10.205	369.41	0.03363	0.379

Table 4-15. Regression parameters for Item 330--polyester overlay.

Factor	Rounding Level	Parameters				R^2
		b_1	b_2	b_3	b_4	
1	500	22.088	0.00118	42251.9	0.9183	0.983
2	500	48.555	-0.000158	10,463.6	0.6091	0.489
6	1500	83.883	-8.254×10^{-5}	656,789	1.0197	0.301

placing portland cement concrete. Shallow repairs are considered to be those to or above the level of reinforcing. The pay quantity is square yards. For shallow repairs reported as cubic yards or cubic feet, conversion to square yards was accomplished by assuming an average depth of repair of 2 in (5 cm).

Because superstructure and substructure repairs vary a great deal in complexity, location and accessibility it was expected that the R^2 values for this item would be low. However, the results listed in Table 4-16 are very poor. Only one cost equation, for Factor 1, is presented because the others resulted in much lower R^2 values. The R^2 of 0.133 for Factor 1 is low, but since it is the best for this item, it is recommended for use.

P.C.C. Patch Repairs--Deep (#412)

This work item is similar to Item 411 except that it is for deep repairs. Deep repairs are considered to be below the steel to full depth. While these types of repairs are performed on both superstructure and substructure elements, due to structural considerations, they are more commonly performed on substructures. The pay quantity is per square yard, and conversions from cubic yards to square yards is accomplished by assuming an average repair depth of 6 in (15 cm).

It was anticipated that the R^2 values for this item might be low due to the varied locations of the repairs covered. However, according to the results presented in Table 4-17, this is not the case. Of the five cost equations presented (Factors 1, 2, 4, 6 and 8) all R^2 values are above 0.5, with the maximum being 0.806 for Factor 1. Since the R^2 value for Factor 1 is the highest, it is recommended that that equation be used for cost estimation.

Surface Area Structural

Sealers: Boiled Linseed Oil (#521)

This item of work is included with Item 241. A complete description of the item and its cost equation is located in that section.

Table 4-16. Regression parameters for Item 411--shallow p.c.c. structural repairs.

Factor	Rounding Level	Parameters				R^2
		b_1	b_2	b_3	b_4	
1	0.1	487.169	-0.36689	291.233	0.8114	0.133

Table 4-17. Regression parameters for Item 412--deep p.c.c. structural repairs.

Factor	Rounding Level	Parameters				R^2
		b_1	b_2	b_3	b_4	
1	1	613.130	-0.02657	3327.83	2.9158	0.806
2	100	522.841	-0.000104	172,270	1.4760	0.538
4	10	618.505	-0.01244	34,199	2.0521	0.508
6	500	499.097	7.084×10^{-6}	356,770	1.2070	0.514
8	0.0001	540.429	-597.498	6.214×10^{-8}	2.9226	0.653

Sealers: Silane and Siloxane Sealers (#522)

This item of work is included with Item 242. A complete description of the item and its cost equation is located in that section.

Shotcrete (#530)

Shotcrete is a term used to describe pneumatically placed portland cement mortar. This work includes all materials, labor and equipment required to prepare the surface to receive the shotcrete, repair or replace any damaged steel reinforcing, attach wire fabric to the structural element, and apply the shotcrete. The pay quantity is cubic yards. Conversion from square yards is accomplished by assuming an average depth of 3 in (7.6 cm).

Table 4-18 lists the parameters for four cost equations for Item 530. The R^2 value for Factor 1 is 0.881 and this is surprisingly high considering the difficulties usually encountered in superstructure and substructure repairs. Factors 4 and 6 also have good R^2 values, 0.575 and 0.583, respectively. However it is recommended that the equation using Factor 1 be employed to estimate the costs of shotcrete repairs.

Coatings: Epoxy (#541)

This work item includes all materials, labor and equipment required to furnish and apply epoxy coating to superstructure and substructure elements. Also included in this work is surface preparation, as required, to provide a clean surface for application of the coating. The pay quantity for this item is square yards. Conversion from gallons of epoxy coating to square yards is accomplished by using the specified coverage rates supplied by the manufacturer or SHA.

The two cost equations that are shown in Table 4-19 are very good (Factor 1: $R^2 = 0.750$, and Factor 4: $R^2 = 0.794$) considering the difficulties involved with applying superstructure and substructure coatings. These difficulties may have manifested themselves in the wide variations encountered when Factors 2, 3, 5, 6, 7 and 8 are used in the regression analysis, but do not seem to apply to Factors 1 and 4. It is recommended that Factor 4, having the highest R^2 value, be used for estimating cost.

Table 4-18. Regression parameters for Item 530--shotcrete.

Factor	Roun evel	Parameters				R²
			b_2	b_3	b_4	
1	5	3,610.06	-6.118	18,820	1.851	0.881
4	10	2,847.75	0	10,175	0.6193	0.575
6	1000	3,246.12	0.00396	5,279,200	1.302	0.583
8	0.001	-1,755.35	0	3,461.92	0.08606	0.378

Table 4-19 Regression parameters for Item 541--epoxy coatings.

Factor	Rounding Level	Parameters				R²
		b_1	b_2	b_3	b_4	
1	10	-68.285	0.0008766	157.53	0.09199	0.750
4	100	-10.490	7.24×10^{-5}	149.640	0.2107	0.794

Coatings: Other (#542)

The coatings found in this group are composed of miscellaneous materials which have historically been applied to structures. These may include various compounds such as anti-graffetti coatings, color treatments, and others which do not fit into the work items for sealers or coatings. This work item includes all materials, labor and equipment costs associated with furnishing and applying these coatings and preparation of the concrete surface for them. The pay quantity is square yards, and conversion from gallons is accomplished by using the coverage rates supplied by the SHA or manufacturer.

Because of the vast differences in the types of materials covered in this item and their costs, it was expected that poor cost equations would result. As expected, only four equations had reportable R^2 values (Table 4-20). It should be noted that the inverse power model reverted to simple linear model for this item. Of the four equations reported, Factor 1 has the highest R^2 value (0.240). while this value indicates a poor fit, it is the best available. Therefore it is recommended that this be used to estimate cost for this item.

Costs for Engineering Estimates

General

As detailed in Chapter 3, costs for five of the treatment items had to be determined by classical estimating procedures because the SHAs were unable to provide sufficient bid price data to allow valid statistical modeling. Four of the items involved pertain to patch repairs to bridge members other than the deck using rapid setting materials. Specifically:

#421	Shallow repairs with quick-set hydraulic mortar/concrete (= < 3 in) (= < 7.6 cm)
#422	Deep repairs with quick-set hydraulic mortar/concrete (> 3 in) (> 7.6 cm)
#431	Shallow repairs with polymer mortar/concrete (< 1 in) (< 2.5 cm)
#432	Deep repairs with polymer mortar/concrete (1-3 in) (2.5 - 7.6 cm)

The fifth item, #510, involves the encasement of badly deteriorated concrete substructure members with portland cement concrete. It consists of encasing piers and jacketing abutments.

Table 4-20. Regression parameters for Item 542--structural coatings other than epoxy.

Factor	Rounding Level	Parameters				R^2
		b_1	b_2	b_3	b_4	
1	50	18.339	-0.003517	0	-	0.240
2	1000	17.202	-0.0001111	0	-	0.168
3	100,000,000	17.210	-6.283×10^{-10}	0	-	0.154
4	100	18.589	-0.001176	0	-	0.223

The methodology used to develop the cost estimates was detailed in Chapter 3. For the four patching treatments, it was deemed necessary to estimate costs for each of seven bridge components that might require patching -- beams, diaphragms, piers, pier caps, backwalls, abutments, and wingwalls. For each bridge component/treatment combination involving the five treatments, cost estimates were carried out at three quantity levels of repair required. These ranged from low to high, based on the literature and engineering judgment, for a "typical" highway bridge. The details of the estimating procedure and the computations for the ninety cost estimates carried out are presented in Appendix B.

Structural Procedure Descriptions

Brief descriptions of the work/materials involved in each of the five structural rehabilitation items, for which cost estimates are developed in this section, follow. Details can be found in Appendix B.

Quick Set Hydraulic Mortar/Concrete Patches--Shallow (#421)

Item 421 involves the repair of spalled and deteriorated concrete structure and substructure members having deterioration equal to or less than 3 in (7.6 cm) deep using quick set hydraulic mortar or concrete. It includes outlining in the repair area with a ¾ in (19 mm) deep saw cut, removal of deteriorated concrete, replacement of corroded or damaged reinforcement, blast cleaning of the exposed concrete and reinforcement, coating of the exposed surface with an epoxy bonding compound, and patching with quick set hydraulic mortar or concrete. The pay quantity is square yards, and the assumed average patch thickness for volumetric calculations is 2 in (5 cm).

Quick-Set Hydraulic Mortar/Concrete Patches--Deep (#422)

The procedure and pay quantity for Item 422 are the same as for Item 421. The only difference is that the average patch thickness for volumetric calculations is 4 in (10 cm), rather than 2 in (5 cm).

Polymer Mortar/Concrete Patches--Shallow (#431)

This item is for the same purpose, and involves essentially the same procedures and pay quantity as Item 421. The differences are:

- maximum patch depth is 1 in (2.5 cm)
- it is assumed that no reinforcement is involved due to the shallow depth
- epoxy bonding compound is not used
- the average patch depth, for purposes of volumetric calculations, is assumed to be ¾ in (19 mm).

Polymer Mortar/Concrete Patches--Deep (#432)

Item 432 is the same as Item 431 except the depth of patch is assumed to be between 1 and 3 in (2.5 - 7.6 cm). Due to the greater depth, it is assumed that reinforcement will be encountered and some replacement as well as cleaning of exposed rebar will be required. The average patch depth for volumetric calculations is assumed here to be 2 in (5 cm). Pay quantity is square yards.

Encase or Jacket with P.C.C. (#510)

Two distinctly different rehabilitation operations are covered by Item 510: encasement of badly deteriorated concrete piers, and jacketing of badly deteriorated abutments and wingwalls. These will be discussed separately.

The encasement of badly damaged concrete piers with portland cement concrete involves the following steps:

- removing unsound concrete
- cleaning of the pier surfaces of all foreign matter that would reduce proper bonding
- sand blasting exposed reinforcement

- installing an epoxy coated rebar cage around the pier
- setting forms
- applying epoxy bonding compound
- placing and curing concrete
- stripping forms

The thickness of the concrete encasement is 6 in (15 cm). The pay quantity is square yards, which is based on the product of the mean pier encasement perimeter and the encasement height.

Jacketing of badly deteriorated abutments and wing walls consists of:

- excavating slopewalls and backfill, as necessary, in order to expose deteriorated concrete
- removing deteriorated concrete by chipping and blast cleaning
- drilling and setting lagstuds for form and reinforcement support
- installing epoxy-coated welded wire fabric reinforcement
- setting forms
- applying epoxy bonding compound to the exposed concrete surfaces
- placing and curing concrete
- removing forms
- replacing slopewalls and/or backfill

The pay quantity is square yards and the average jacket thickness, for estimating repair volumes, is assumed to be 8 in (20 cm).

Results

The results of the ninety cost estimates carried out in Appendix B are summarized in Table 4-21. Notice that these are unit costs (\$/SY). Also notice that the costs reflect mid-1991, national average conditions. Two points clearly stand out in the information presented in Table 4-21. First, the unit cost values for the four patching treatments (#421,#422, #431, and #432) are very highly affected by low quantities. This mirrors the behavior observed with the bid data from the SHAs. The second point is that the unit costs for the two cases of treatment Item 510, "encasement with concrete," are both independent of quantity for the quantity ranges expected in practice. This is, almost certainly, a reflection of scale. The smallest quantities of encasement that would be carried out at a given site are close to the asymptote on the unit cost versus quantity curve, i.e. well beyond the low quantity values that result in very large unit prices. Therefore, the unit costs for encasing piers and jacketing abutments are estimated to be \$354/SY (\$423/m^2) and \$716/SY (\$856/m^2) (mid-1991 national average), respectively.

Cost Model for Patching Treatments (#421; #422; #431; #432)

In the interest of compactness of the cost data, it would be desirable to develop expressions for unit costs as a function of quantity for the four patching treatments (#421, #422, #431, and #432). Taking a rational approach to this matter, costs for the types of activities involved here are usually composed of two elements -- fixed cost and variable cost. Fixed cost usually consists of initial setup costs incurred before the first unit of production occurs. It is the cost of planning, and procuring and moving workers, equipment, and materials to the jobsite; erecting scaffolding, etc. All of these activities must be done before the first square yard of patching is accomplished, and once completed it remains relatively constant, independent of the total number of square yards of patching that is done. The variable cost component on the other hand, varies with the number of square yards of patching done. It consists of the costs of materials and labor and the overhead burden associated with them. The model that defines this situation is illustrated in Figure 4-1 is derived as follows:

$$\text{total cost, } T = F + V \tag{4-2}$$

$$\text{but} \quad V = aQ \tag{4-3}$$

$$\text{therefore} \quad T = F + aQ \tag{4-4}$$

Table 4-21. Estimated unit costs for treatments #421, #422, #431, #432 and #510.

Concrete Bridge Member	Repair Area, SY	Unit Cost, $/SY				
		#421	#422	#431	#432	#510
Beams	6.6	251	309	283	467	
	13.1	159	217	191	355	
	26.2	112	170	144	308	
Diaphragms	0.9	1,425	1,482	1,457	1,620	
	1.9	709	767	741	905	
	3.8	502	565	534	698	
Piers	2.6	708	766	690	904	
	6.6	319	377	331	514	
	13.2	192	310	214	388	
Piers (encasement)	7.8					354
	46.7					354
	140.0					354
Pier Caps	5.0	400	458	405	595	
	10.0	233	309	251	428	
	40.0	158	309	136	354	
Backwalls	1.5	1,383	1,441	1,414	1,579	
	3.0	724	782	756	920	
	12.0	230	343	262	426	
Abutments	1.2	1,746	1,805	1,778	1,942	
	3.0	738	796	769	934	
	6.0	402	574	433	597	
Abutments (Jacketing)	15.0					716
	25.0					717
	50.0					716
Wingwalls	0.7	2,152	2,210	2,169	2,348	
	1.8	877	935	908	1,073	
	3.6	471	529	503	667	

Note: ($/m^2) = ($/SY) * 1.196
m^2 = (SY) * 0.836

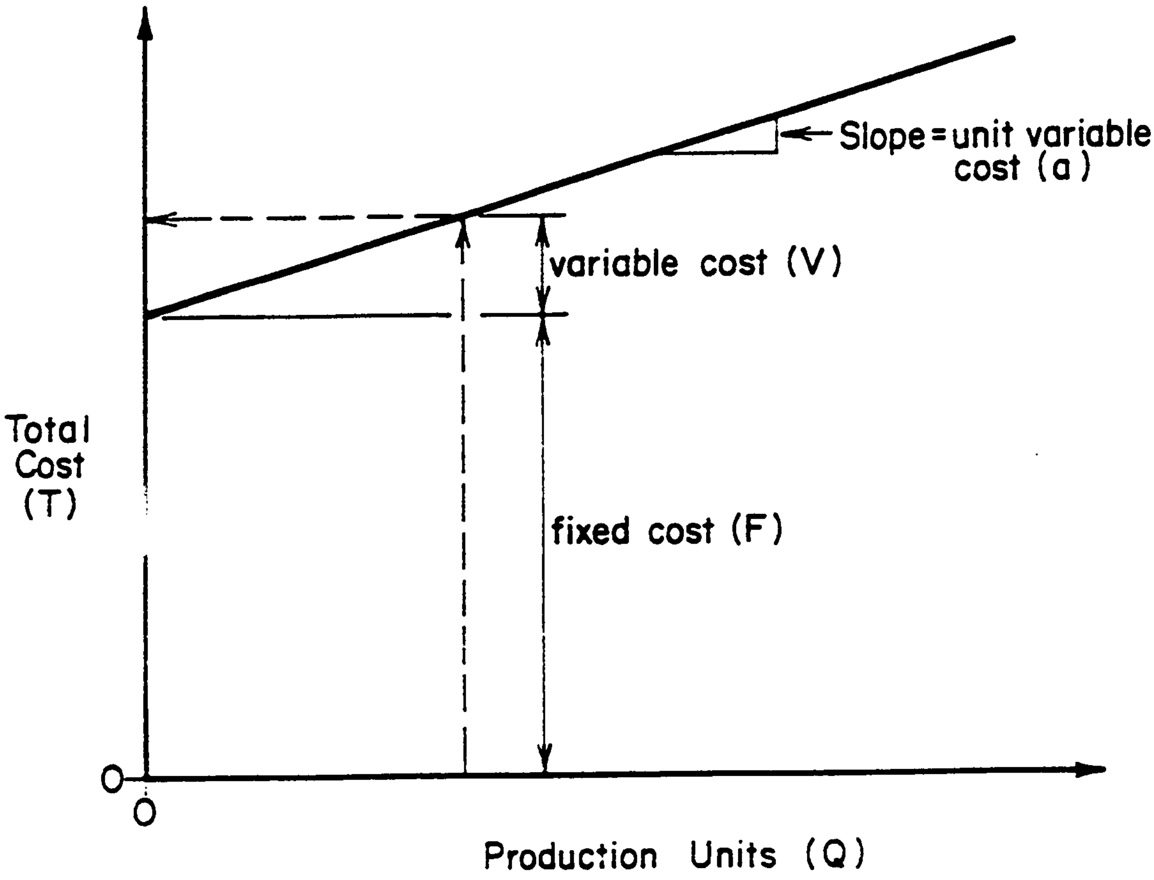


Figure 4-1. Conceptual rational cost model.

$$\text{Unit Cost, } C = \frac{T}{Q}, \text{ by definition} \tag{4-5}$$

$$\text{therefore } C = \frac{F + aQ}{Q}$$

$$\text{or, } C = \frac{F}{Q} + a \tag{4-6}$$

Notice that equation 4-6 is a linear expression in terms of cost (C) versus the reciprocal of quantity (1/Q), and that regressing unit cost versus quantity in this fashion will result in a linear equation in which the slope term is the fixed cost (F) and the intercept term is the unit variable cost (a).

Regressions using this model on the information in Table 4-21 are shown in Figures 4-2 through 4-5 for the four treatment items. Notice from the regression equations presented in Figures 4-2 through 4-5 that the fixed costs for all four treatment items are approximately the same ($1,435 to $1,485), but the unit variable costs range from $104/SY ($124/m^2) for the shallow hydraulic mortar/concrete patch (#421) to $314/SY ($376/m^2) for the deep polymer mortar/concrete patch (#432). Notice also that lumping all of the bridge elements together apparently does not produce a great amount of scatter. However, this is misleading due to the compressed ordinate (unit cost) scale. For example, for a 6.6 SY (5.5 m^2) repair quantity using treatment item #421, the overall regression equation (Figure 4-2) predicts a unit cost of:

$$\frac{1{,}485}{6.6} + 104 = \$329/\text{SY} \ (\$393/\text{m}^2)$$

However, Table 4-21 shows that for beam repairs of 6.6 SY (5.5 m^2) using treatment Item 421, the estimated cost is $251/SY ($300/m^2). Therefore, while the regression equations here are useful for verifying the nature of the components of unit cost, they do not take into account the effect of bridge member type, which has a significant influence.

In order to provide practical means for obtaining unit cost data that do reflect the effect of bridge member type, the data for each treatment item/bridge member combination were regressed to the model. The resulting regression terms (F and a) are presented in Table 4-22. For the example cited above,

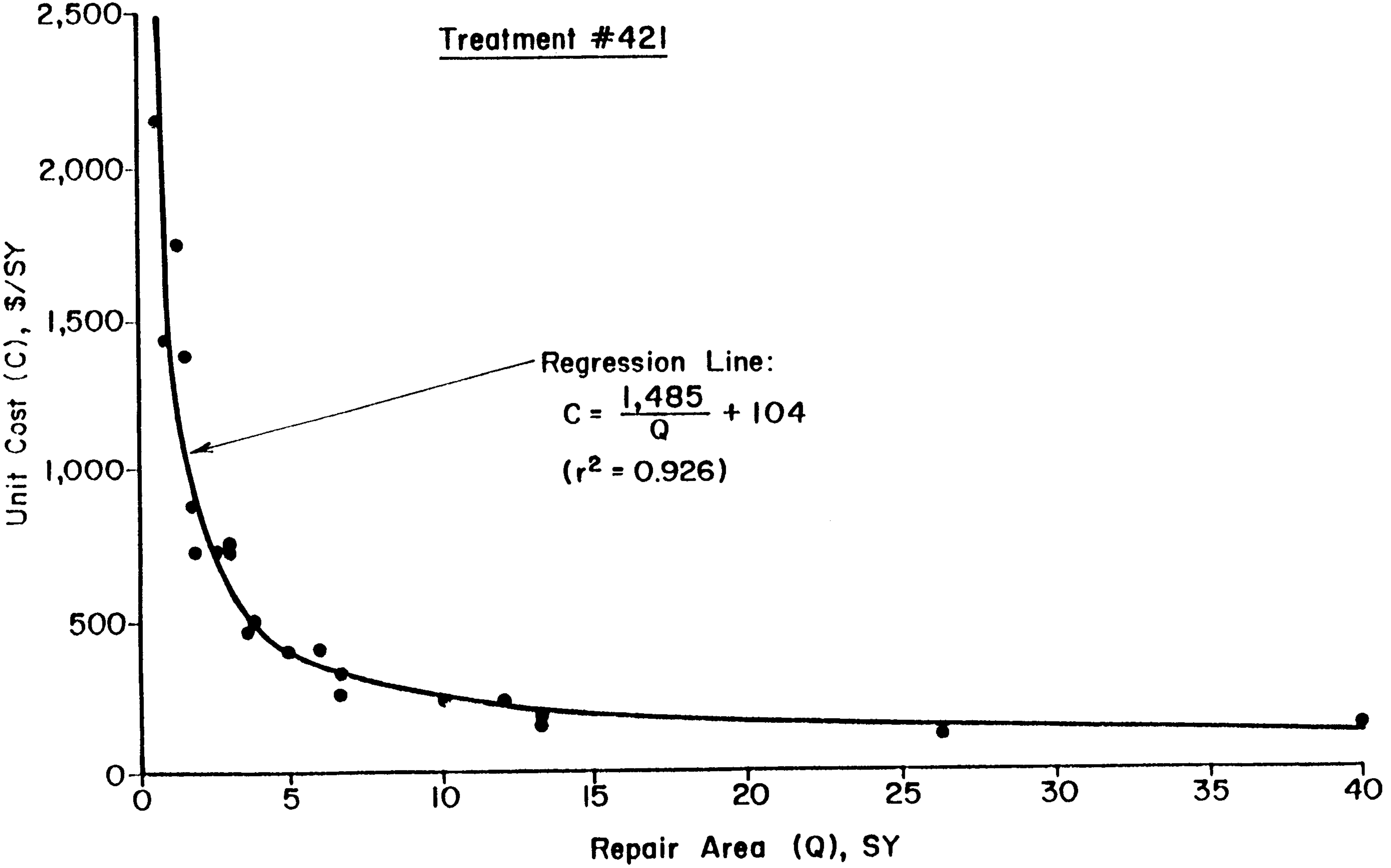


Figure 4-2. Unit cost versus repair area for treatment #421 (all bridge elements).

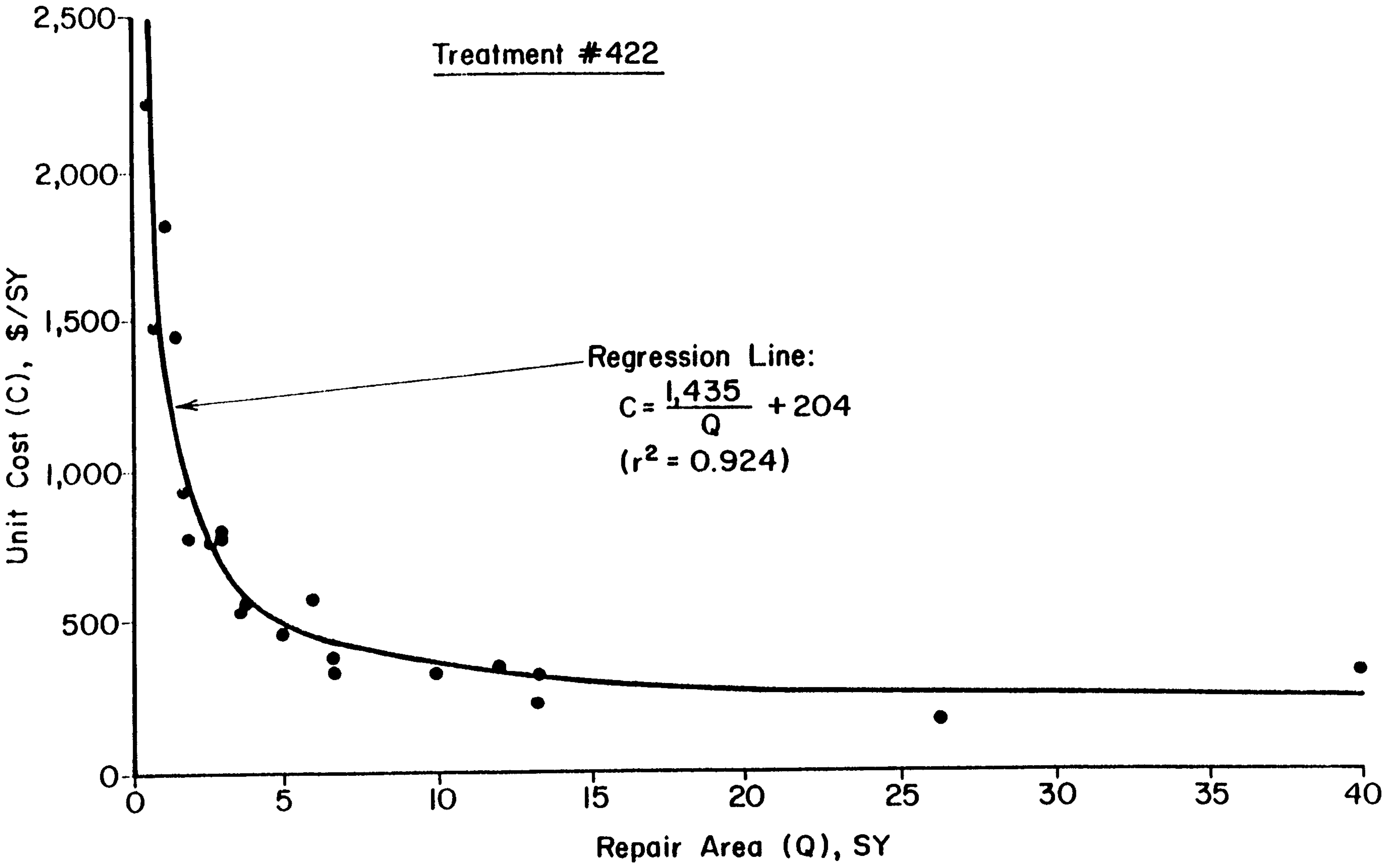


Figure 4-3. Unit cost versus repair area for treatment #422 (all bridge elements).

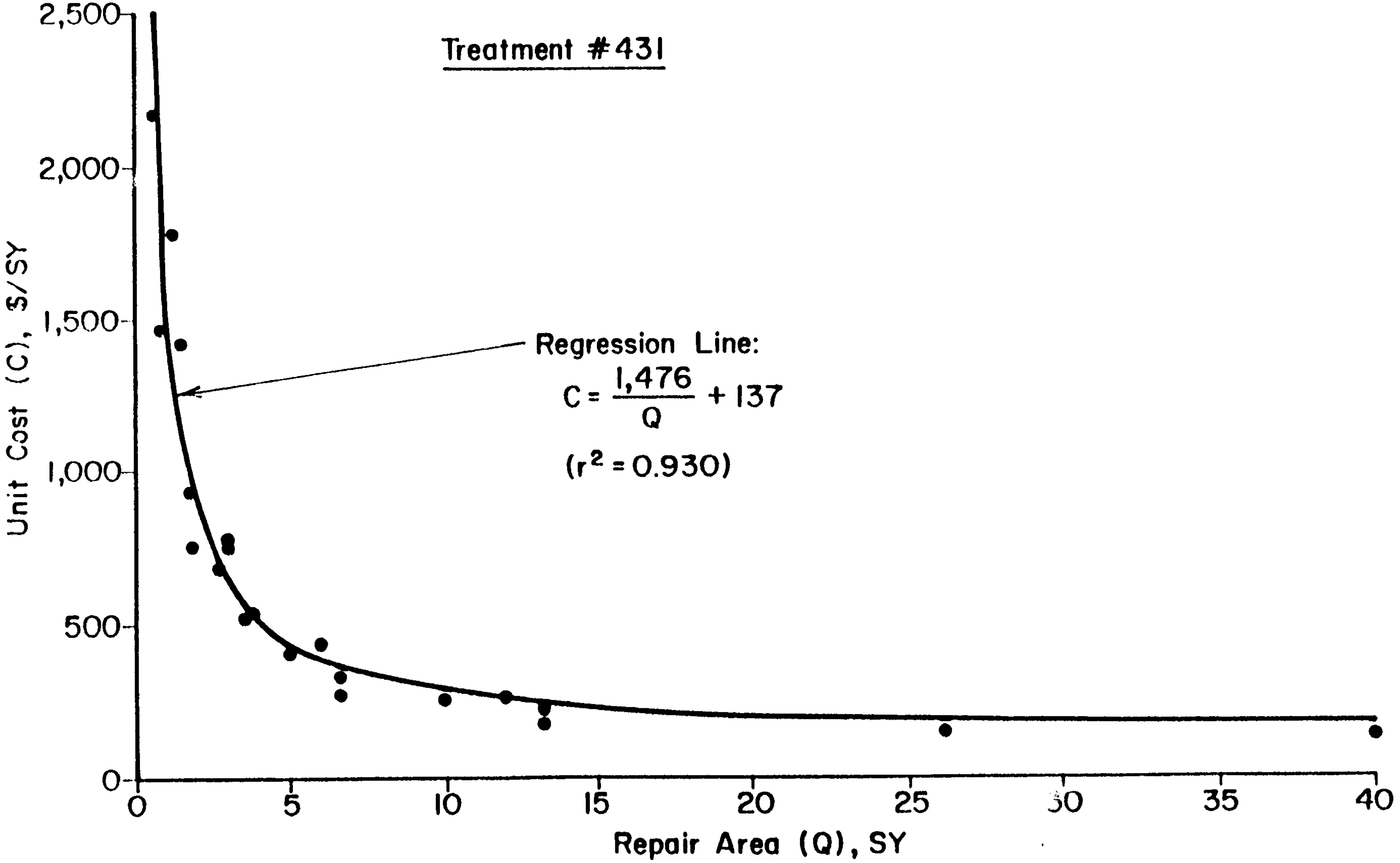


Figure 4-4. Unit cost versus repair area for treatment #431 (all bridge elements).

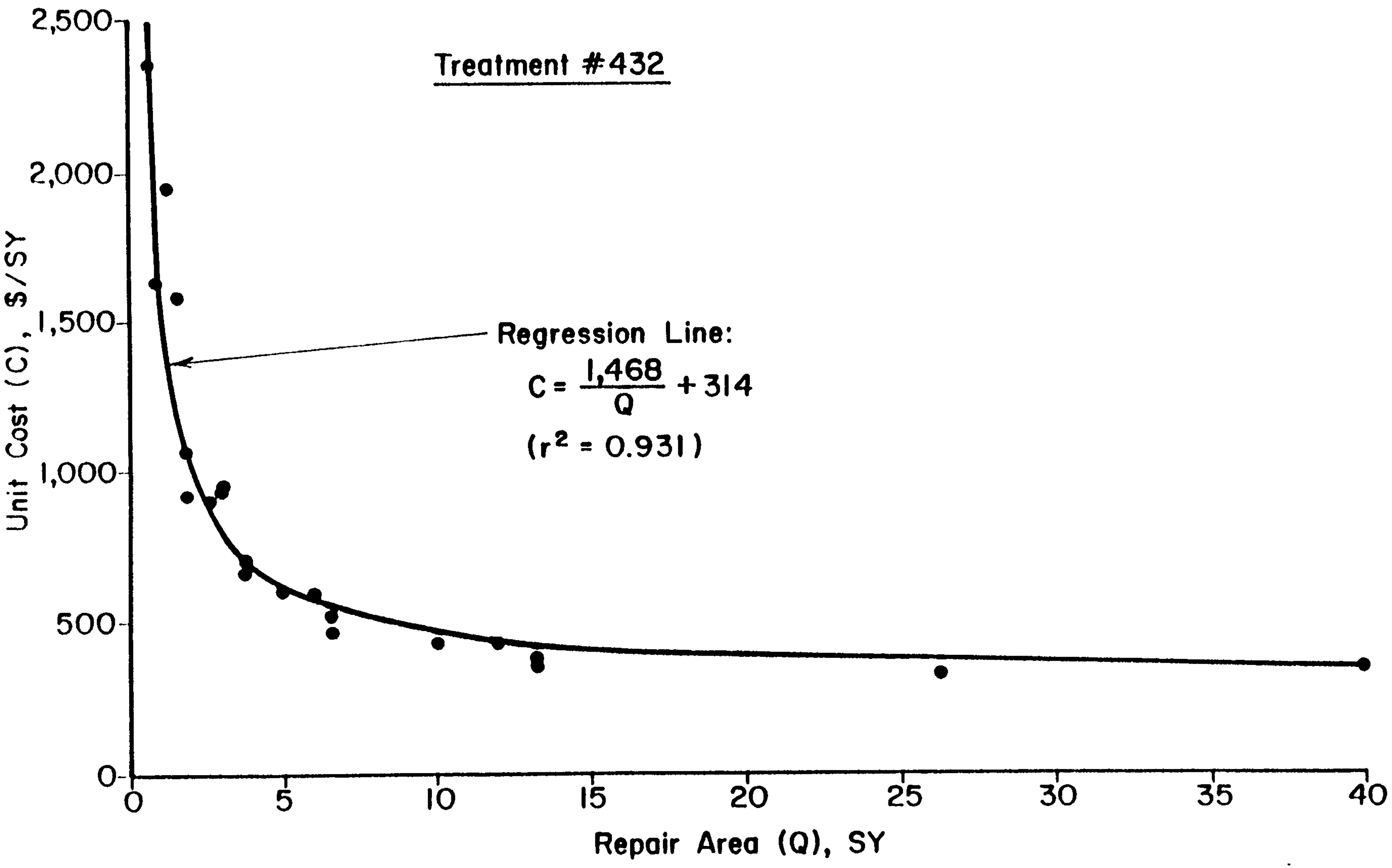


Figure 4-5. Unit cost versus repair area for treatment #432 (all bridge elements).

Table 4-22. Constants for cost model for treatments #421, #422, #431, and #432.*

Concrete Bridge Member	Treatment #421		Treatment #422		Treatment #431		Treatment #432	
	F	a	F	a	F	a	F	a
Beams	1,226	65	1,226	123	1,226	97	1,415	251
Diaphragms	1,111	175	1,105	238	1,111	207	1,110	371
Piers	1,670	66	1,522	174	1,541	97	1,671	261
Pier Caps	1,398	112	886	263	1,537	97	1,393	308
Backwalls	1,977	65	1,887	174	1,975	98	1,977	261
Abutments	2,016	66	1,886	220	2,018	97	2,017	261
Wingwalls	1,461	65	1,461	123	1,447	102	1,461	261
All	1,485	104	1,435	204	1,476	137	1,468	314

$$\text{*Unit Cost (\$/SY)} = \left[\frac{F}{\text{Repair Quantity (SY)}} + a\right]$$

Note: $(\$/m^2) = (\$/SY) * 1.196$
$m^2 = (SY) * 0.836$

$$F = 1{,}226$$
$$a = 65$$

$$\text{and } C = \frac{1226}{6.6} + 65 = \$251/SY\ (\$300/m^2)$$

agreeing with Table 4-21. The difference between unit costs calculated using the regression equations and the estimated values is nil for over 50% of the 84 cases, but in one instance it is almost 14%. The mean difference is 1.8%. Notice that the regression terms in Table 4-22 may not give accurate results for quantity values outside the range presented in Table 4-21 for the respective bridge member.

Comparisons With Field Data

There are very little data from the SHAs to compare with the estimated unit costs. This of course is not surprising since it is the reason for carrying out the cost estimates. Four bids on two contracts showed unit costs for treatment Item 421 that were generally in the range of \$265/SY to \$442/SY (\$317 - \$529/m²) (3 bids on one project). However, the one bid on the second contract gave \$1,977/SY (\$2,364/m²) for the same item. The quantities were about 6 SY (5 m²) in both instances. The bridge member involved is not known. Therefore, using the regression equation on Figure 4-2, the estimated unit cost is:

$$\frac{1{,}485}{6} + 104 = \$352/SY \ (\$421/m^2)$$

This is about midway of the range for the bids on the one project, but far below the single bid on the other project.

One bid on each of 8 projects regarding treatment Item 432 gave unit costs that ranged from \$1,536 to \$5,884/SY (\$1,837 - \$7,037/m²) for quantities from 0.11 to 2.22 SY (0.09 - 1.86 m²). Again, the bridge member(s) involved are not known. So, using the regression equation on Figure 4-5, estimated unit costs are:

$$\text{For } 0.11 \text{ SY } (0.09 \text{ m}^2)\text{:} \quad C = \frac{1468}{0.11} + 314 = \$13{,}659/SY \ (\$16{,}336/m^2)$$

$$\text{For } 2.22 \text{ SY } (1.86 \text{ m}^2)\text{:} \quad C = \frac{1468}{2.22} + 314 = \$975/SY \ (\$1{,}166/m^2)$$

Obviously, the extreme sensitivity of the cost to very low quantity levels makes comparisons in this instance very tenuous. With this in mind, the comparison between the calculated and actual values are not unreasonable.

The most data from the SHAs for the five treatment items involved in the estimating activities was for Item 431. Twenty bids on five contracts were tabulated. Table 4-23 compares the mean unit costs from the bid tabulations for each contract along with the quantity involved, and presents the estimated unit cost values calculated from the regression equation on Figure 4-4. Again, considering the extreme randomness of the field data and the few observations involved, the results are probably reasonable.

Table 4-23. **Comparison of estimated unit cost values with SHA bid tab data for treatment Item #431.**

Job No.	No. of Bids	Quantity, SY	Unit Cost, $/SY	
			Bid Mean	Estimated
1	3	0.222	4,739	6,786
2	2	0.889	1,240	1,797
3	3	1.111	3,680	1,466
4	9	3.000	1,359	629
5	3	61.000	627	161

Note: ($/m^2) = ($/SY) * 1.196
m^2 = (SY) * 0.836

Some 1980 bid tabulations provided by the Pennsylvania Department of Transportation for an earlier study give unit cost data on "epoxy mortar repair" from six bids on bridge rehab contracts. Assuming that the repairs approximate the definition for treatment Item 432, those unit prices are compared with estimated unit costs in the Table 4-24, using the regression equation in Figure 4-5. Here again, overall comparisons are reasonable, all factors considered.

Table 4-24. Comparison of estimated unit cost values with PennDOT bid tab data for treatment Item 432.

Quantity, SY	Unit Cost, $/SY	
	Bid Tab	Estimated
1.3	464	1,443
1.3	1,160	1,443
3.3	946	759
13.3	454	424
14.0	905	419
82.8	171	332

Note: $(\$/m^2) = (\$/SY) * 1.196$
$m^2 = (SY) * 0.836$

There were no bid tab data at all for treatments #422 and #510. Notice that the cost values reported throughout this section are adjusted to mid 1991 national average values.

Newly Developed Procedure Descriptions

A brief description of the work/materials involved in each of the three newly developed deck treatments and the two superstructure-substructure rehabilitation treatments, for which cost estimates are developed in this section, follow. Details can be found in Appendix C.

Deep Impregnation of Bridge Decks Using Grooving Technique (#610)

Grooves are cut into the deck on lines of equal contour. The grooves are 3/4 inch (1.91 cm) wide, 1 1/2 in (3.81 cm) deep, and 3.0 in (7.62 cm) on center. The concrete is dried to a depth of 1/2 in (1.25 cm) below the top reinforcing steel mat using propane fired infrared heaters. The concrete is allowed to cool slowly under an insulating mat to ambient temperature. The treatment fluid is poured into the grooves and allowed to soak into the concrete. The grooves are then backfilled with a mortar. The deep impregnation process uses one of three different impregnation fluid backfill mortar mixture combinations.

For the deep monomer impregnation process (#611), methyl methacrylate is used as the monomer and this requires an additional step of polymerizing the monomer in situ before the grooves are backfilled. The groove backfill material is a latex modified mortar which is poured onto the deck and squeezed into the grooves.

For the deep corrosion inhibitor impregnation processes (#612 and #613), the impregnation fluid is Postrite and the mortar is a DCI modified LMC for item #612 and the impregnation fluid is Cortec 2020 and the mortar is a Cortec 2000 LMC modified mortar.

Spray-on Corrosion Inhibitor and Overlay with a Corrosion Inhibitor Modified Concrete (#620)

Using a dry milling process, removed 1 1/2 in (3.81 cm) of concrete. Patch deteriorated areas with corrosion inhibitor modified concrete. Shot blast the entire deck surface, apply four spray applications of corrosion inhibitor, and overlay with corrosion inhibitor modified LMC or LSDC.

For treatment processes #621, #622, and #623, the concrete is to remain in an air dried state for the time period between the completion of the milling operation to the completion of the spray-on corrosion inhibitor applications. For treatment process #621, the spray-on corrosion inhibitor is Postrite and the overlay is a DCI modified LMC or LSDC. Treatment #622 uses Cortec 2020 as the spray-on corrosion inhibitor and Cortec 2000 modified LMC or LSDC. Treatment #623 uses Alox 901 as the spray-on corrosion inhibitor and the overlay concrete is either LMC or LSDC. For both treatment processes #622 and #623, the deck has to be shot blasted clean before the overlay is placed.

For treatment processes #624, #625, and #626, the deck concrete is dried with an infrared heater before the spray-on applications of Postrite, Cortec 2020, and Alox 901, respectively. Otherwise, they are the same as treatments #621, #622, and #623, respectively.

Resin-Modified Bituminous Concrete System For Decks With Membranes

For decks with a bituminous-concrete membrane protection system that is no longer providing an acceptable level of protection from chloride ingress or has an unacceptable riding surface. Mill off the bituminous concrete to within about 1/2 in (1.27 cm) of the membrane. Place two-inch open graded bituminous concrete overlay and fill the bituminous concrete voids with a latex modified portland cement mortar mixture. Mortar mixture is sufficiently fluid for gravity filling of the voids. Cure the mortar mixture for three days.

Superstructure and Substructure Patching with Corrosion Inhibitor Modified Concrete, Type I and Concrete Removal (#710)

Standard patching techniques are used. Areas are marked out, scored 3/4 in (1.91 cm) along the patch perimeter with a concrete saw, concrete is removed to a depth of at least 3/4 in (1.91 cm) below the rebar and backfilled with corrosion inhibitor modified concrete. A penetrating sealer is applied to the entire structural element. For treatment #711, DCI is the concrete corrosion inhibitor admixture, for treatment #712, Cortec 2000 is the corrosion inhibitor admixture.

Superstructure and Substructure Patching with Corrosion Inhibitor Modified Concrete, Type II Concrete Removal (#720)

Standard patching techniques are employed. Concrete is removed to the depth of the rebar. Four spray-on applications of a corrosion inhibitor are applied. The cavity is backfilled with a corrosion inhibitor modified concrete and a penetrating sealer is applied to the entire surface of the concrete structural element. For method #721, Postrite is used as the spray-on corrosion inhibitor and DCI as the corrosion inhibitor admixture. For method #722, the spray-on inhibitor is Cortec 2020 and the admixture is Cortec 2000. For method #723, the spray-on inhibitor is Alox 901 and no corrosion inhibitoring admixture is used in the patch concrete. Both #722 and #723 methods required that the cavity be sandblasted clean before the cavity concrete is placed.

Cost Estimates of Newly Developed Systems

Table 4.25 presents the results for 36 deep impregnation cases, a monomer and two corrosion inhibitor impregnations, four deterioration levels at rehabilitation, and three levels of multiple deck contracts. In general as the level of deterioration increased from 0 to 20 percent, the cost increase ranged from 10 to 15 percent. As the multiple deck contracts increased from 1 to 10, the range of cost decrease was 10 to 20 percent. Thus illustrating the benefits of a multiple deck contract. It is interesting to note that the cost of deep impregnation with methyl methacrylate is less than either of the corrosion inhibitors. Also that the potential cost savings is not trivial, ranging from \$34 to \$86/SY (\$41 to 103/m_2).

Table 4.25 Bridge Deck Protection Deep Impregnation Using the Grooving Technique, \$/SY*

Impregnant	% Deterioration	Decks/YR/Contrctor		
		1	4	10
Methyl Methacrylate Monomer	0	196	157	150
	5	204	165	157
	10	211	173	165
	20	226	188	180
Postrite (15% Calcium Nitrite Solution	0	229	201	195
	5	237	209	203
	10	245	217	211
	20	260	232	226
Cortec 2020	0	269	241	235
	5	277	249	243
	10	284	256	250
	20	299	271	266

***NOTE:** Mid 1991 Costs

(\$/m^2) = (\$/SY) * 1.196
m^2 = (SY) * 0.836

Table 4.26 presents the results for 36 spray-on overlay non-dried cases and Table 4.27 presents the results for 36 spray-on overlay dried cases. As illustrated, there is little cost difference between the inhibitor types. Also, cost increase as the percent deterioration of rehabilitation increases and there is cost savings to be realized from a multiple bridge deck contract.

Table 4.28 presents the cost for the resin-modified bituminous concrete rehabilitation technique for decks with membrane-bituminous-concrete protection systems.

Table 4.29 presents the cost estimates for 105 cases of newly developed superstructure-substructure rehabilitation cases. Of interest is the fact that the cost estimates indicate that there is little to be gained by not removing the concrete to below the reinforcing steel.

Table 4.26 Bridge Deck Protection Corrosion Inhibitor Spray-On Overlay System (Non-Dried), $/SY*

Inhibitor	% Deterioration	Decks/YR/Contractor		
		1	4	10
Postrite (15% calcium nitrite solution)	0	62	47	44
	5	71	55	52
	10	79	63	60
	20	96	80	77
Cortec 2020	0	60	44	41
	5	68	52	49
	10	76	60	57
	20	92	77	74
Alox	0	66	50	47
	5	74	58	55
	10	82	66	63
	20	98	83	80

NOTE: *Mid-1991 Costs
($/$m^2$) = ($/SY) * 1.196
m^2 = (SY) * 0.836

Table 4.27 Bridge Deck Protection Corrosion Inhibitor Spray-On Overlay System (Dried), $/SY*

Inhibitor	% Deterioration	Decks/YR/Contractor		
		1	4	10
Postrite (15% Calcium Nitrite Solution)	0	105	81	76
	5	110	86	81
	10	114	90	85
	20	119	95	90
Cortec 2020	0	102	78	74
	5	107	83	79
	10	111	87	82
	20	116	92	88
Alox	0	111	87	82
	5	116	92	87
	10	120	96	91
	20	125	101	96

NOTE: *Mid-1991 Costs
($/$m^2$) = (#/SY) * 1.196 m^2 = (SY) * 0.836

Table 4.28 Bridge Deck Protection Resin-Modified Bituminous Concrete System For Decks with Membranes

$22.47/SY

*NOTE: Mid-1991 Costs
$($m^2$) = ($/SY) * 1.1196
m^2 = (SY) * 0.836

Table 4.29 Substructure/Superstructure Rehabilitation Using Corrosion Inhibitor Modified Concrete and Corrosion Inhibitor Spray-On Patch Systems, $/SY*

Bridge Member	% Deterioration	Type I**		Type II***		
		Cal-Nitr.	Cortec	Cal.-Nitr.	Cortec	Alox
Beams	0.5	218	214	227	224	220
	1.0	124	119	132	129	125
	2.0	75	71	84	81	77
Diaphragms	1.0	1,429	1,425	1,437	1,434	1,430
	2.0	691	687	699	697	693
	3.0	478	473	486	483	479
Piers	2.0	690	686	698	695	692
	5.0	288	284	297	294	290
	10.0	219	215	166	163	159
Pier Caps	5.0	372	368	380	377	373
	10.0	219	214	208	205	201
	40.0	219	214	131	128	124
Backwalls	5.0	1,386	1,381	1.394	1,391	1,387
	10.0	707	702	715	712	708
	40.0	253	249	205	202	199
Abutments	2.0	1,761	1,757	1,769	1,766	1,762
	5.0	721	716	729	726	722
	10.0	492	488	382	379	375
Wing-Walls	2.0	2,118	2,173	2,186	2,183	2,179
	5.0	864	859	872	869	865
	10.0	445	411	454	451	447

NOTE: *Mid-1991 Costs

** Type I = Remove concrete to below rebars and patch with corrosion inhibitors modified concrete.

***Type II = Remove concrete to rebar depth and apply Corrosion-Inhibitor-Spray-On Patch System.

5

Summary and Recommendations

Summary of Recommended Prices and Price Equations

Based on statistical analyses and engineering estimation techniques, it is recommended that the following equations be used to predict the price of rehabilitation treatments (See Table 3.6 for definitions of the Item No.):

Table 5.1 Summary of Recommended Price Equations

Item No.	Price Equation
111	$C = 133 + \frac{1,382,600}{(\text{Factor } 4)^{2.38}}$, \$/SY
112	$C = 214 + 0.01 * (\text{Factor } 4) + \frac{361,990}{(\text{Factor } 4)^{2.11}}$, \$/SY
121	$C = 236 - 0.037 * (\text{Factor } 1) + \frac{1408}{(\text{Factor } 1)^{0.50}}$, \$/SY

Item No.	Price Equation
131	$C = 267 + 0.029 * (\text{Factor } 2) + \frac{83{,}400}{(\text{Factor } 2)^{1.22}}, \text{ \$/SY}$
210	$C = 38 - 0.0012 * (\text{Factor } 8) + \frac{0.028}{(\text{Factor } 8)^{1.44}}, \text{ \$/SY}$
220	$C = 9.8 - 0.000$[illegible] $* (\text{Factor } 1) + \frac{3{,}978{,}400}{(\text{Factor } 1)^{3.10}}, \text{ \$/SY}$
230	$C = 32 + 8.82 \text{ x } 10^{-5} * (\text{Factor } 4) + \frac{22{,}200}{(\text{Factor } 4)^{0.98}}, \text{ \$/SY}$
241	$C = 1.4 - 3.0 \text{ x } 10^{-5} * (\text{Factor } 1) + \frac{10.9}{(\text{Factor } 1)^{1.01}}, \text{ \$/SY}$
242	$C = 8.7 + 7.04 \text{ x } 10^{-5} * (\text{Factor } 1) + \frac{56.1}{(\text{Factor } 1)^{1.24}}, \text{ \$/SY}$
243	$C = 9 - 2.69 \text{ x } 10^{-6} * (\text{Factor } 2), \text{ \$/SY}$
251	$7 + 2.38 \text{ x } 10^{-5} * (\text{Factor } 1) + \frac{68{,}770}{(\text{Factor } 1)^{1.83}}, \text{ \$/SY}$
252	use price equation for Item 251
260	$C = 6.4 - 2.5 \text{ x } 10^{-5} * (\text{Factor } 4) + \frac{5{,}594}{(\text{Factor } 4)^{1.33}}, \text{ \$/SY}$
310	$C = 56 - 0.00036 * (\text{Factor } 4), \text{ \$/SY}$
320	$C = 42 - 8.2 \text{ x } 10^{-5} * (\text{Factor } 2) + \frac{67{,}470}{(\text{Factor } 2)^{1.01}}, \text{ \$/SY}$

Item No.	Price Equation
330	$C = 22 + 0.0012 * (\text{Factor } 1) + \frac{42{,}250}{(\text{Factor } 1)^{0.92}}$, \$/SY
411	$C = 487 - 0.367 * (\text{Factor } 1) + \frac{291}{(\text{Factor } 1)^{0.81}}$, \$/SY
412	$C = 613 - 0.027 * (\text{Factor } 1) + \frac{3{,}328}{(\text{Factor } 1)^{2.92}}$, \$/SY
421	$C = 104 + \frac{1{,}485}{(\text{Factor } 1)}$ (see note 1), \$/SY
422	$C = 204 + \frac{1{,}435}{(\text{Factor } 1)}$ (see note 1), \$/SY
431	$C = 137 + \frac{1{,}476}{(\text{Factor } 1)}$ (see note 1), \$/SY
432	$C = 314 + \frac{1{,}468}{(\text{Factor } 1)}$ (see note 3), \$/SY
510	C = \$354/SY (encasing bridge piers) C = \$716/SY (jacketing bridge abutments)
521	use price equation for Item 241
522	use price equation for Item 242
530	$C = 3{,}610 - 6.11 * (\text{Factor } 1) + \frac{18{,}820}{\text{Factor } 1\ )^{1.85}}$, \$/CY
541	$C = -10 + 7.24 \times 10^{-5} * (\text{Factor } 4) + \frac{150}{(\text{Factor } 4)^{0.21}}$, \$/SY

Item No.	Price Equation
542	C = 18 - 0.0035 * (Factor 1), $/SY

where:

C = price per unit measurement
Factor 1 = quantity
Factor 2 = (quantity * contract amount)/MPT amount
Factor 4 = quantity * number of bidders
Factor 8 = (quantity * number of bidders)/MPT amount

Note 1: For Items 421, 422, 431, and 432 unit prices vary significantly with the locations of the repair. Therefore, for specific bridge members, use the regression coefficients tabulated below for the equation $C = F * Q^{-1} + a$

Concrete Bridge Member	Treatment #421		Treatment #422		Treatment #431		Treatment #[illegible]	
	F	a	F	a	F	a	F	a
Beams	1,226	65	1,226	123	1,226	97	1,415	251
Diaphragms	1,111	175	1,105	238	1,111	207	1,110	371
Piers	1,670	66	1,522	174	1,541	97	1,671	261
Pier Caps	1,398	112	886	263	1,537	97	1,393	308
Backwalls	1,977	65	1,887	174	1,975	98	1,977	261
Abutments	2,016	66	1,886	220	2,018	97	2,017	261
Wingwalls	1,461	65	1,461	123	1,447	102	1,461	261

Note 2: $\$/m^2 = (\$/SY) * 1.196$
$\$/m^3 = (\$/CY) * 1.308$

Use of Price Equations

Caution should be exercised when using these equations to predict prices. Most of the equations, with the exception of Items 310, 510, and 542, have an inverse term. As the quantity of the item approaches zero, the model will produce a price which gets very large, and at zero quantity is undefined. While the equations are useful in providing price estimates, judgement should be exercised while using them.

The most commonly used independent variable in the price equations was Factor 1 which represents the quantity of the item specified. As discussed previously in Chapter 2, most SHAs base their price models solely on quantity. These price equations presented will provide more accurate models, while maintaining relative simplicity. Other factors which were used in the equations were Factors 2, 4, and 8. These three factors are not as simple as Factor 1 and require some *a priori* knowledge about the entire construction project. Factor 2 is defined as (quantity * contract amount)/MPT amounts, Factor 4 is defined as (quantity * number of bidders), and Factor 8 is defined as (quantity * number of bidders)/MPT amount. The additional information required for these factors should be readily available, and can be determined by comparisons with projects of similar scope within the state. The accuracy to which this additional information is estimated may have a significant impact on the predicted price. In order to prevent possible over- or underestimation of the unit price, a sensitivity analysis should be performed. This can be accomplished by using a range of values and observing the resulting variation in predicted price.

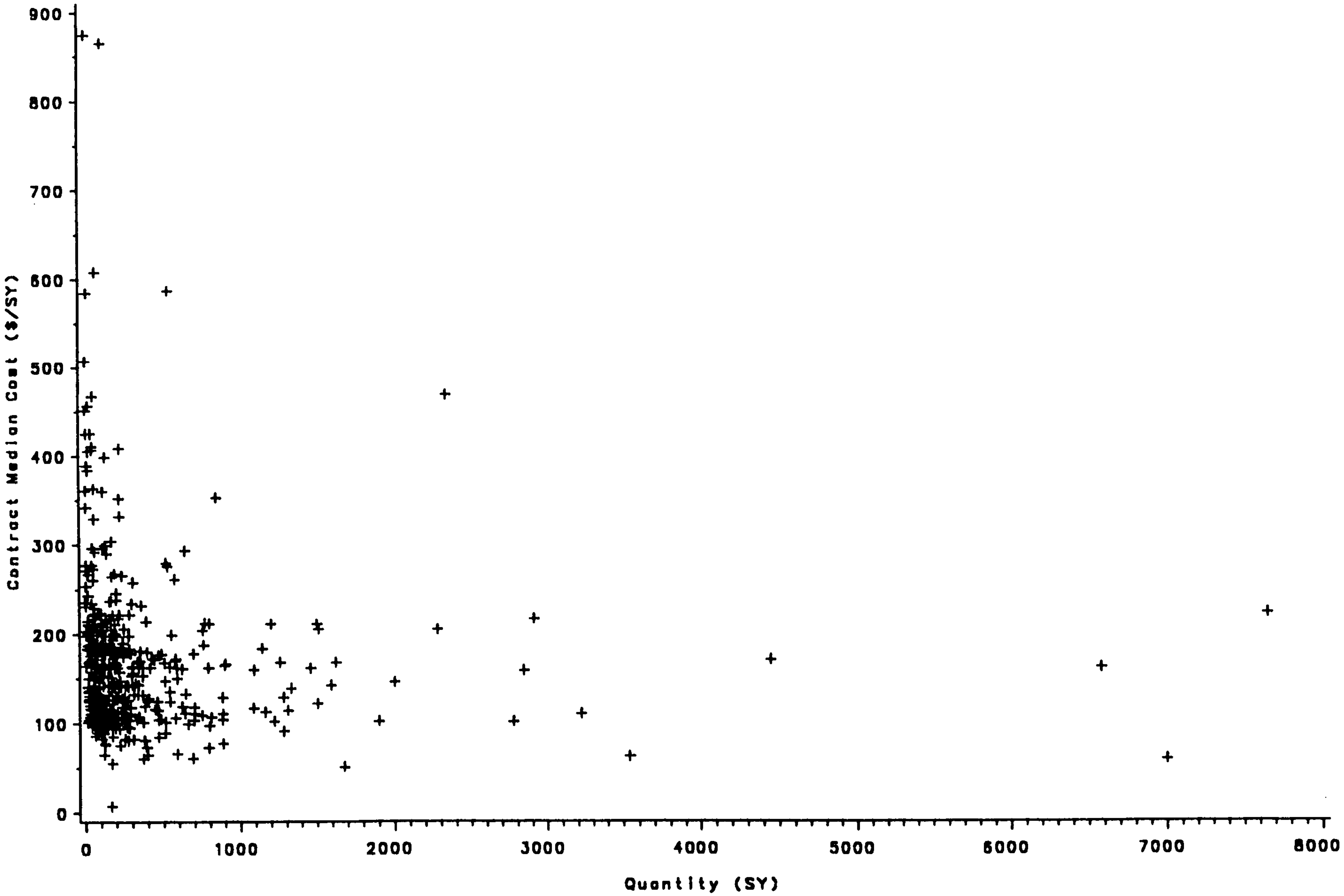
Recommendations for Further Development

It should be realized that the price equations developed were based on historical bid tabulations provided by the SHAs visited. They included all contract data that was acquired for all bidders. By including all bidders on all projects the variation is increased since all bidders may not follow a rational approach to estimating bid prices. This, added to contractors shifting overhead and profit percentages between items, leads to what would be statistically poor models in some instances. It would be impossible to remove these factors and irrational bids within the time and funding constraints of this task. Another way to counteract the effect of these outliers is addition of more data. If more data are included in future efforts, the effect of the irrational bids will be increasingly diminished.

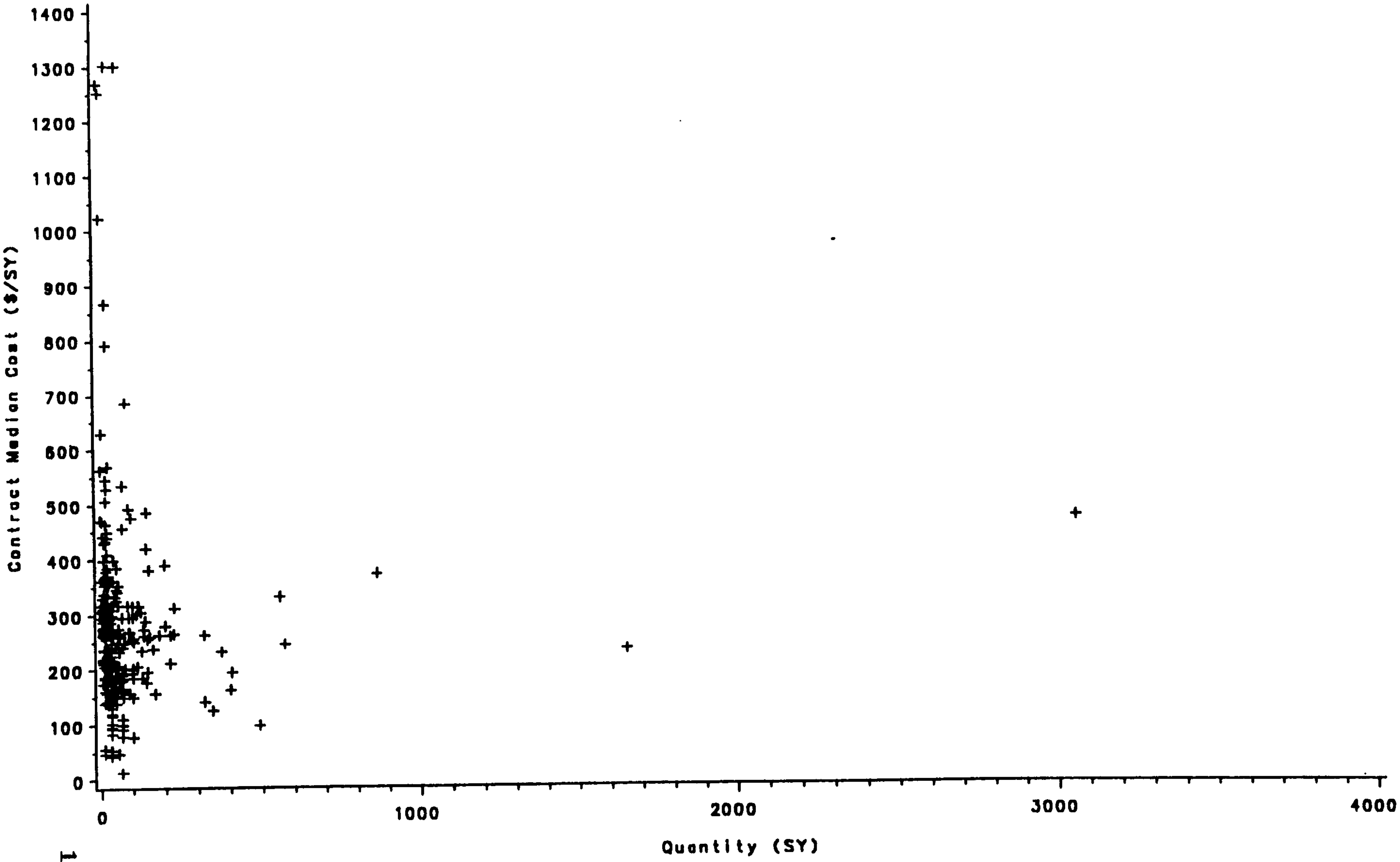
Appendix A

Plots of National Average Cost Versus Repair Quantity (Factor 1) for Each Repair Item.

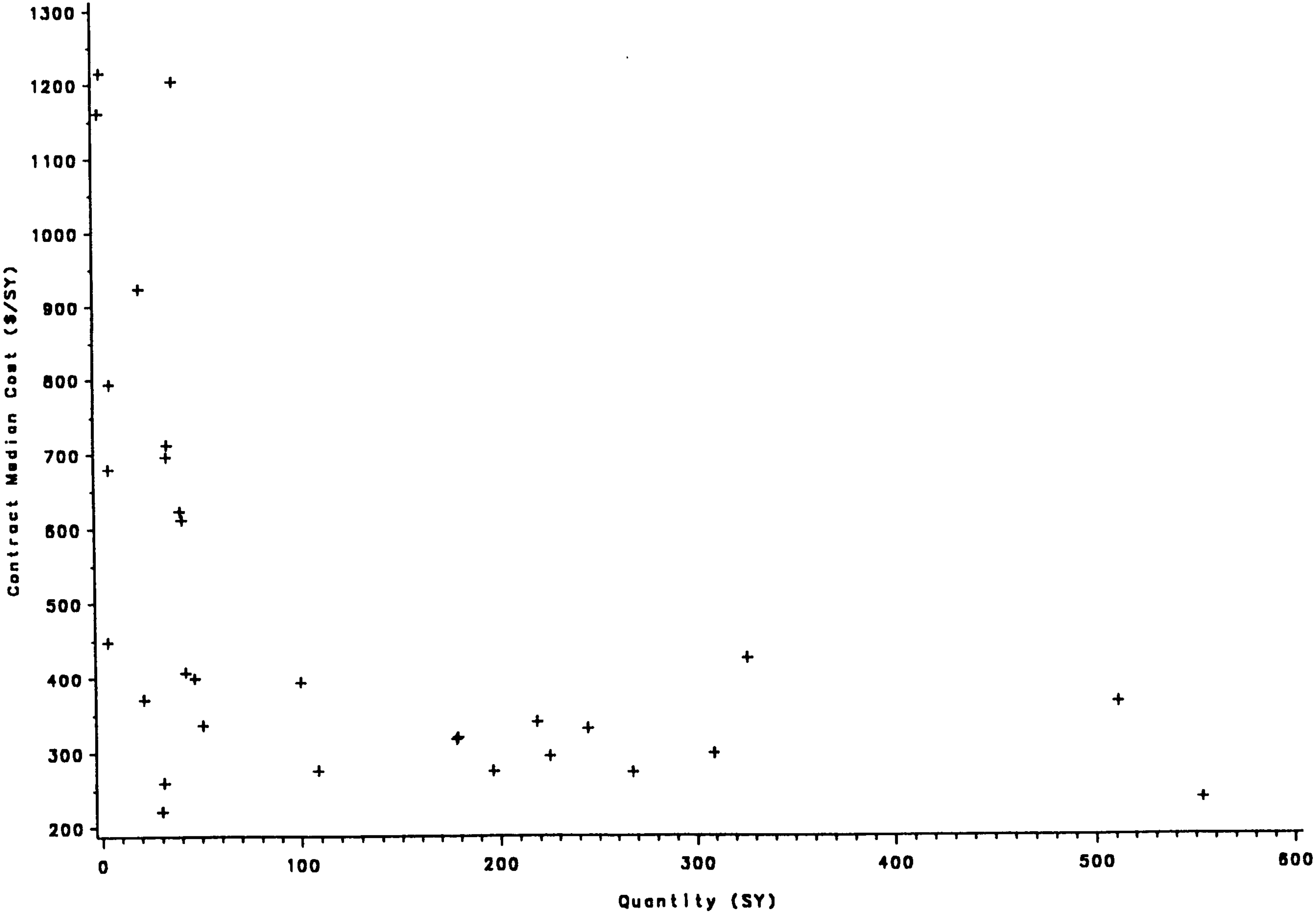
Item 111--Partial Depth P.C.C. Deck Repair



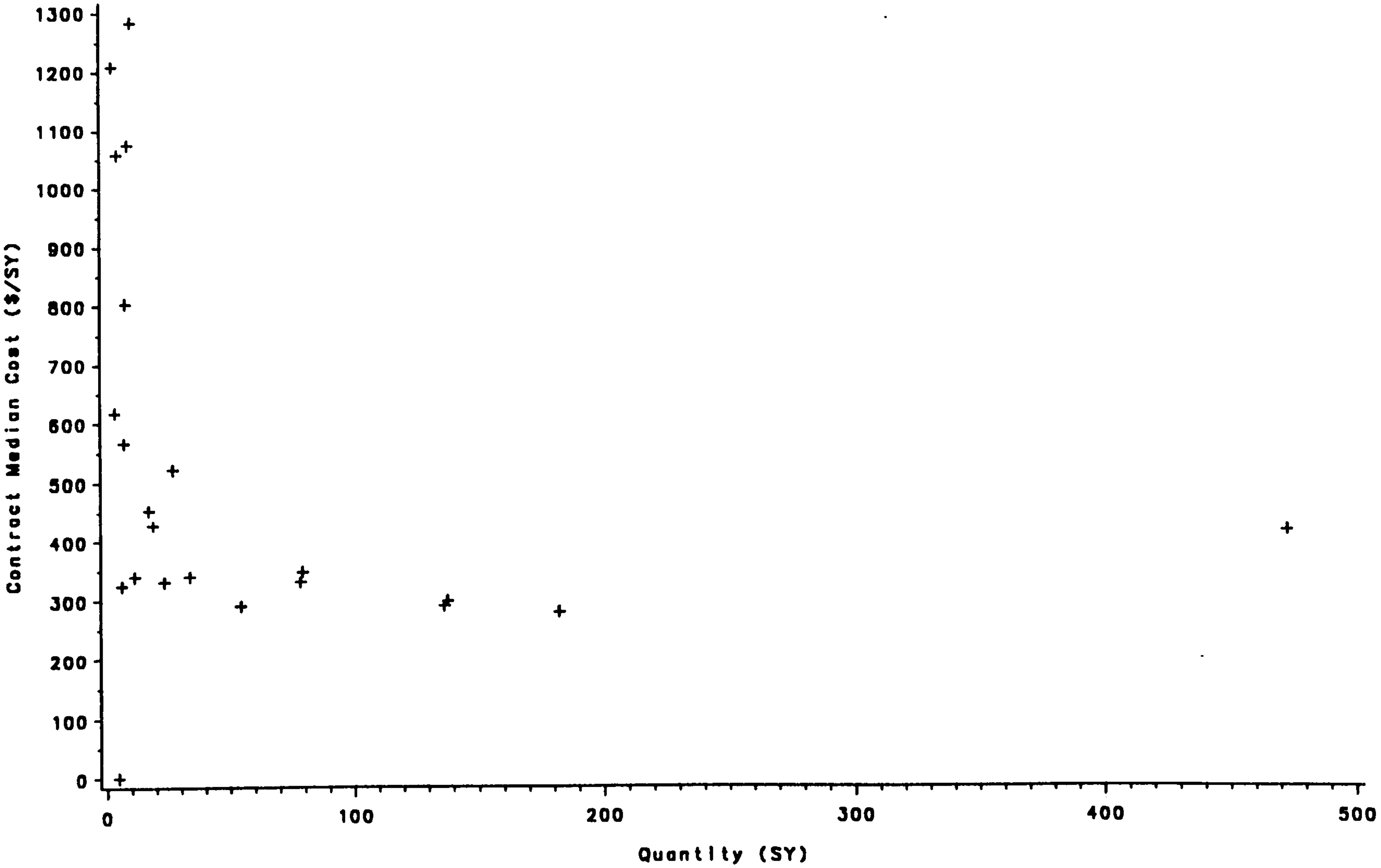
Item 112--Full Depth P.C.C Deck Repair



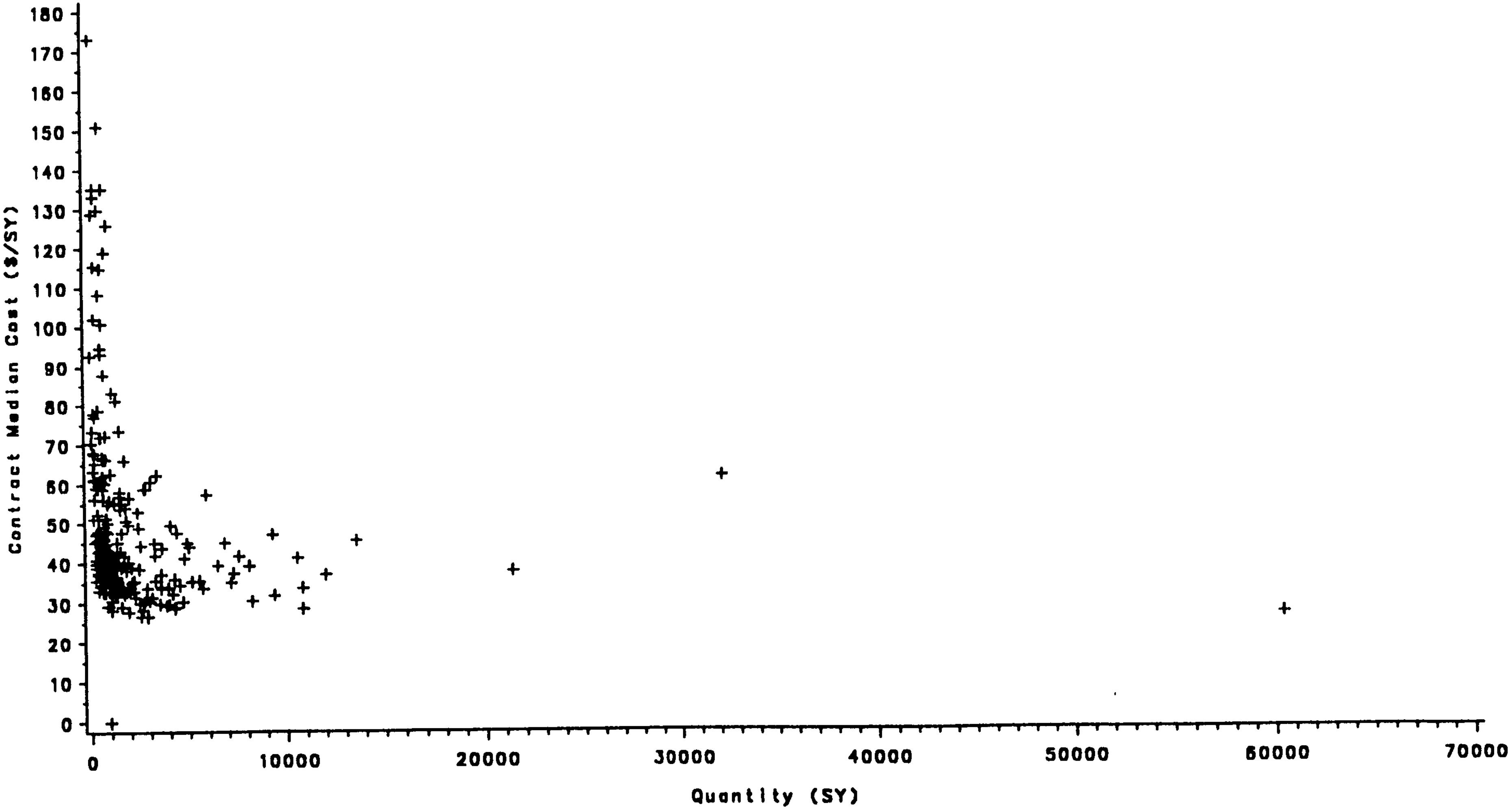
Item 121 -Partial Depth Quick Set Hydraulic Mortar/Concrete Deck Repair



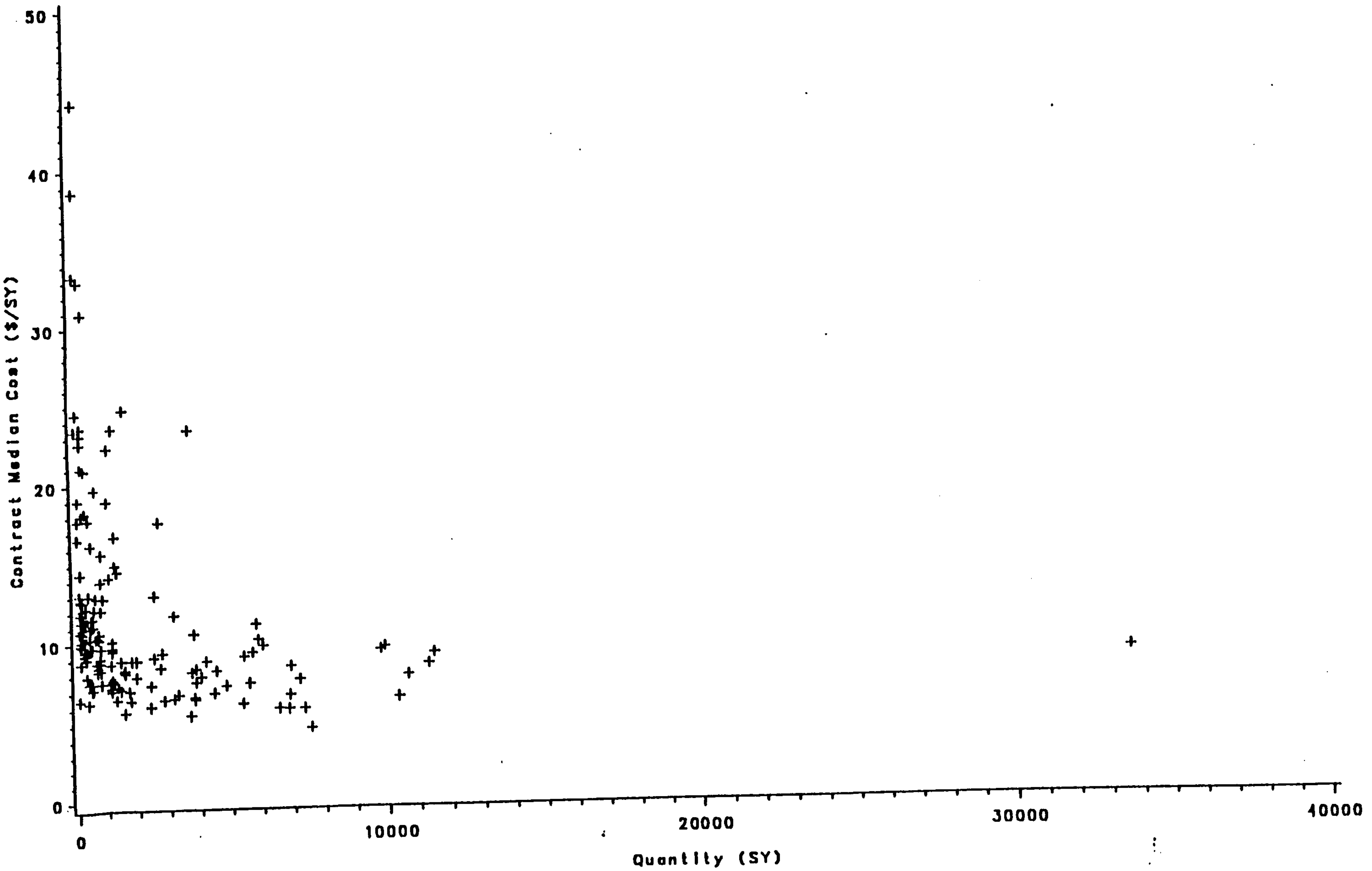
Item 131--Partial Depth Polymer Mortar/Concrete Deck Repair



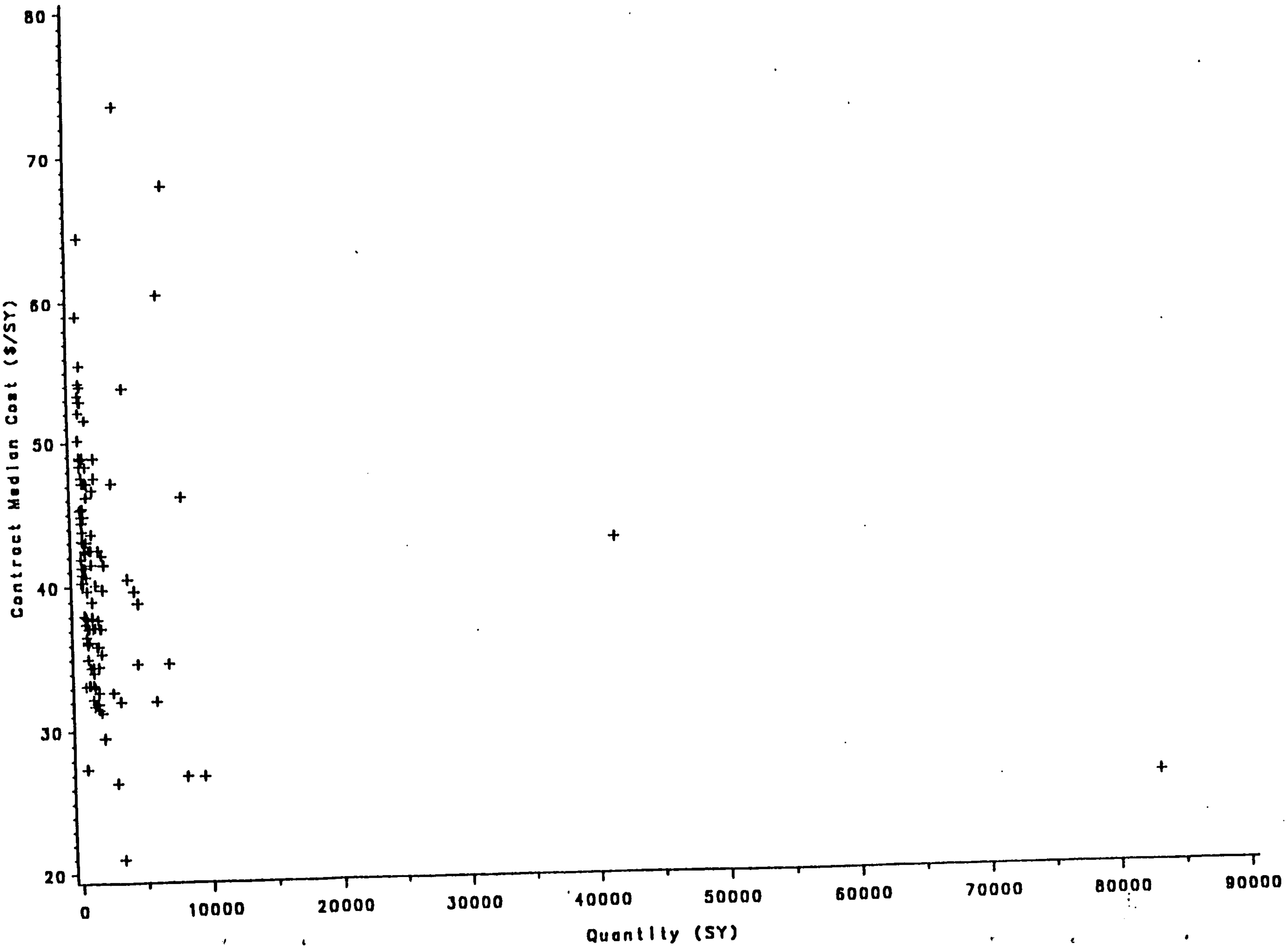
Item 210--Latex Modified Concrete Overlay



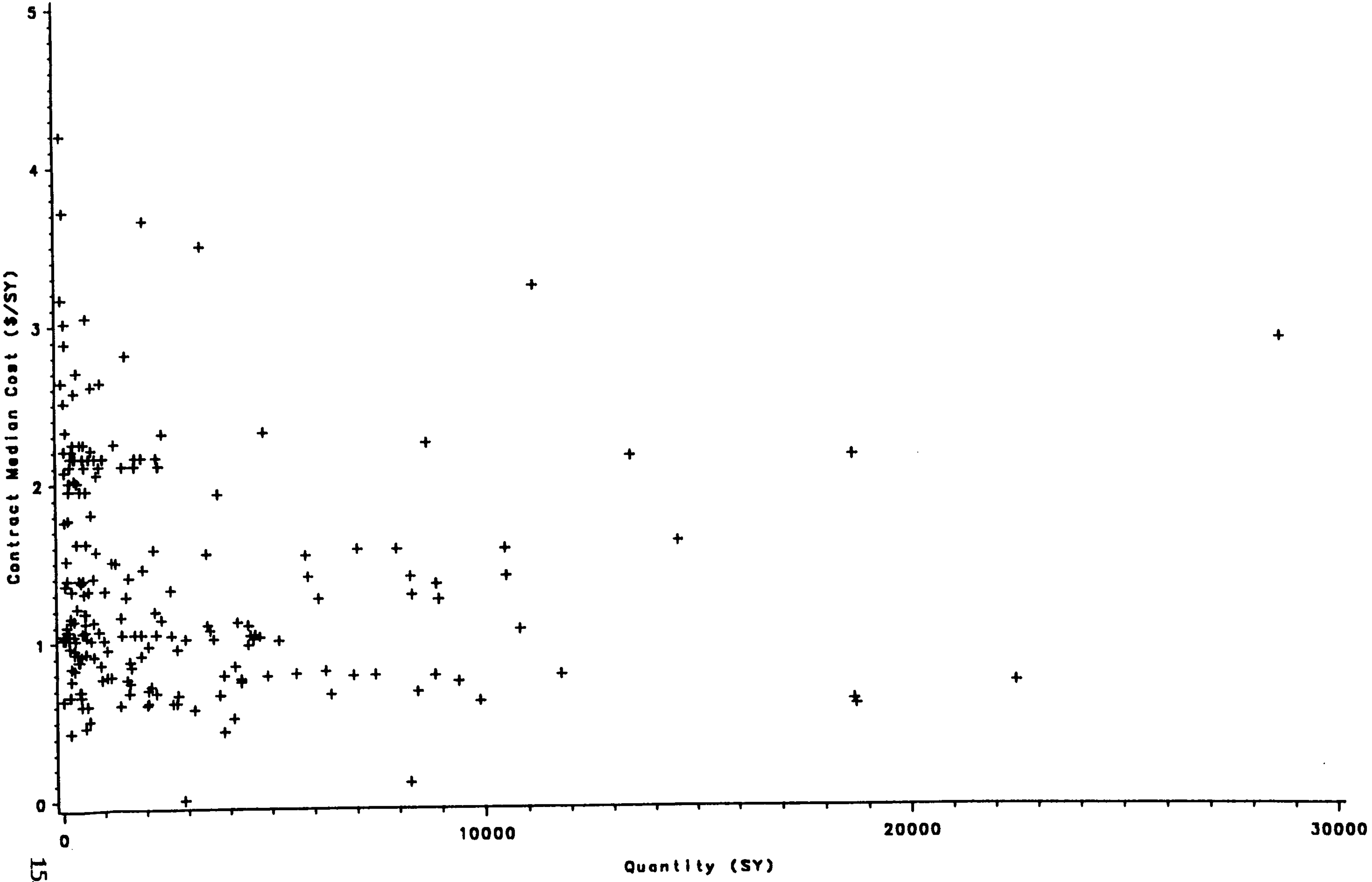
Item 220--Membrane and Asphalt Cement Concrete Overlay



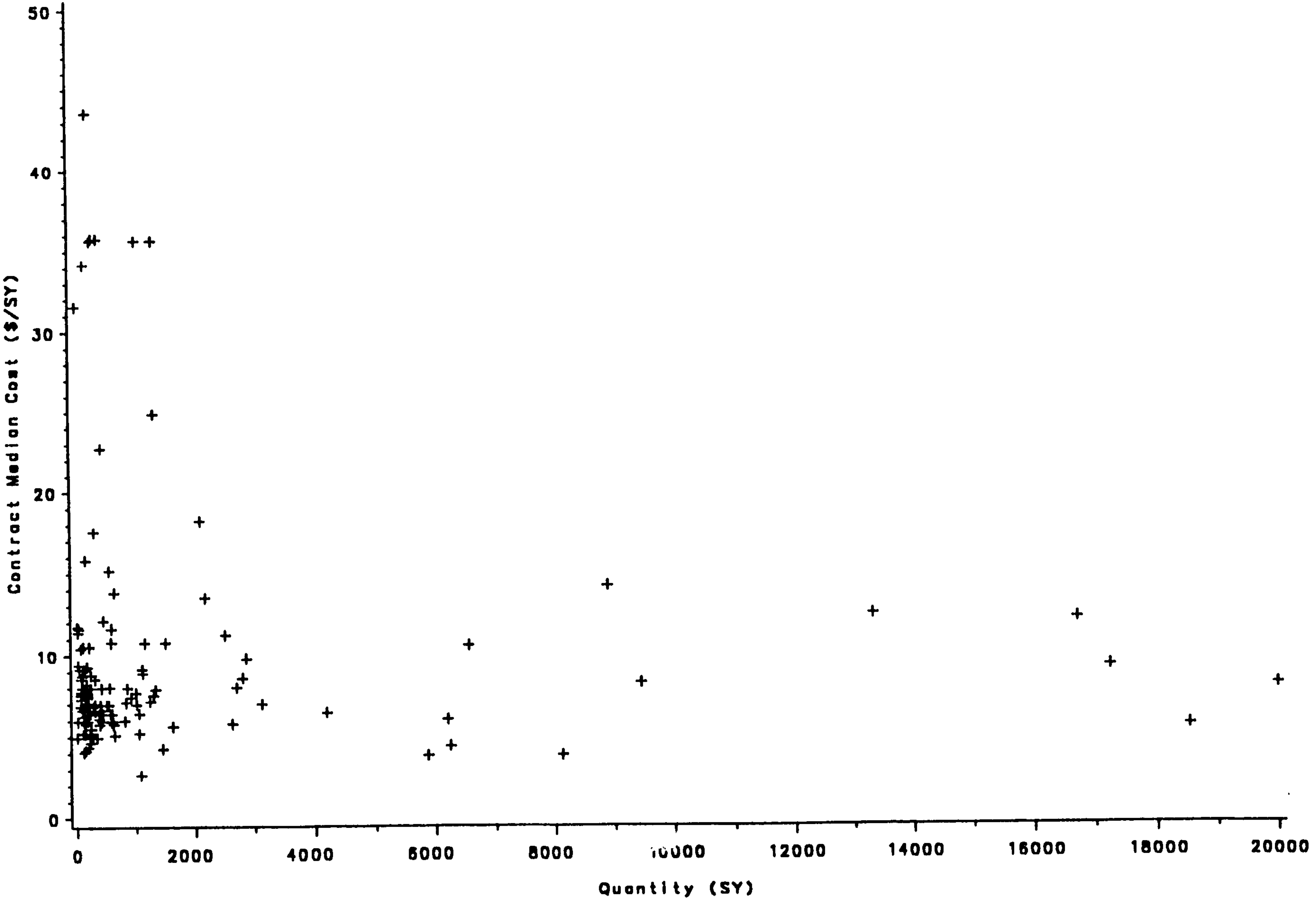
Item 230--Low Slump Densified Concrete Overlay



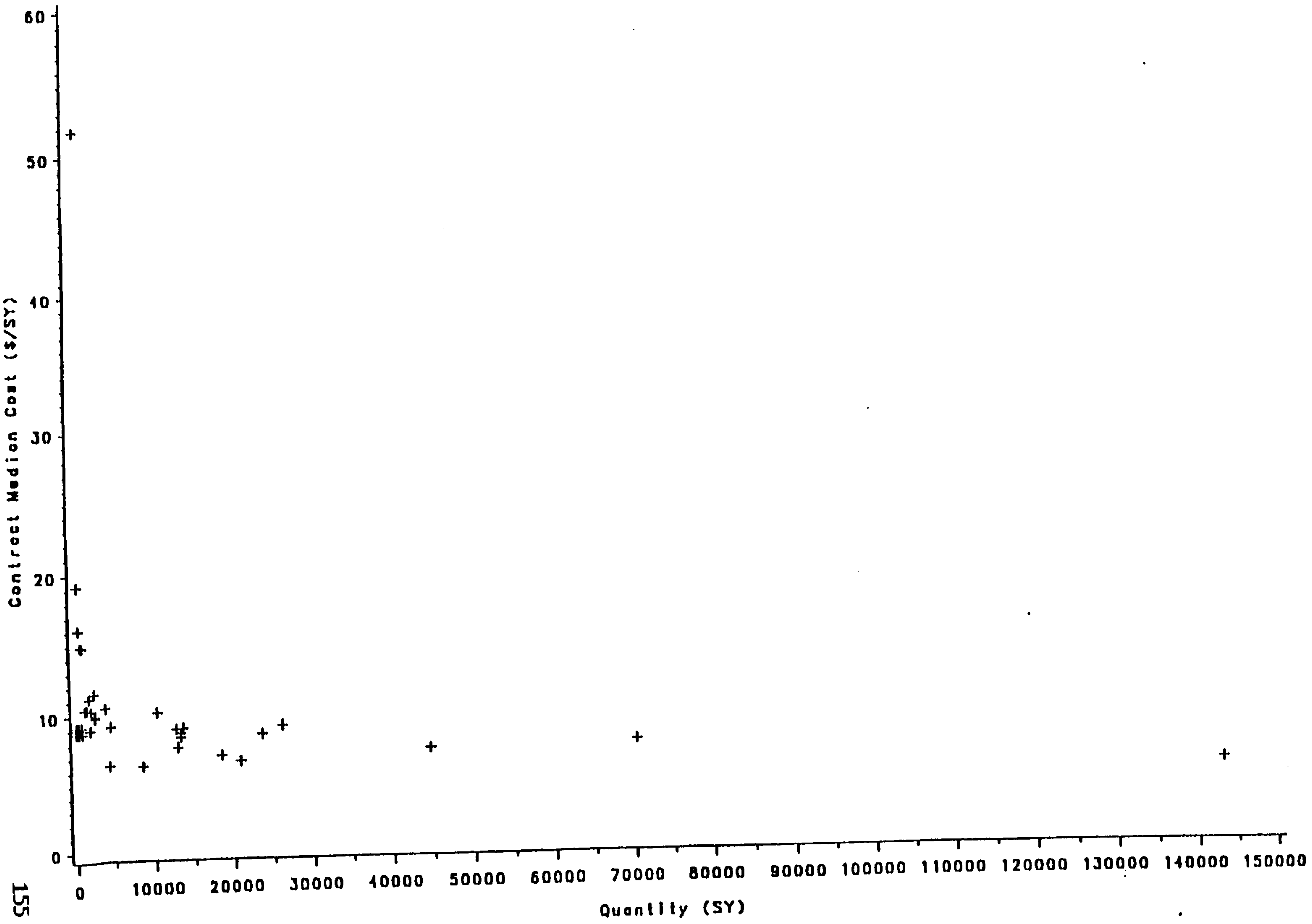
Items 241 & 521--Boiled Linseed Oil Sealer



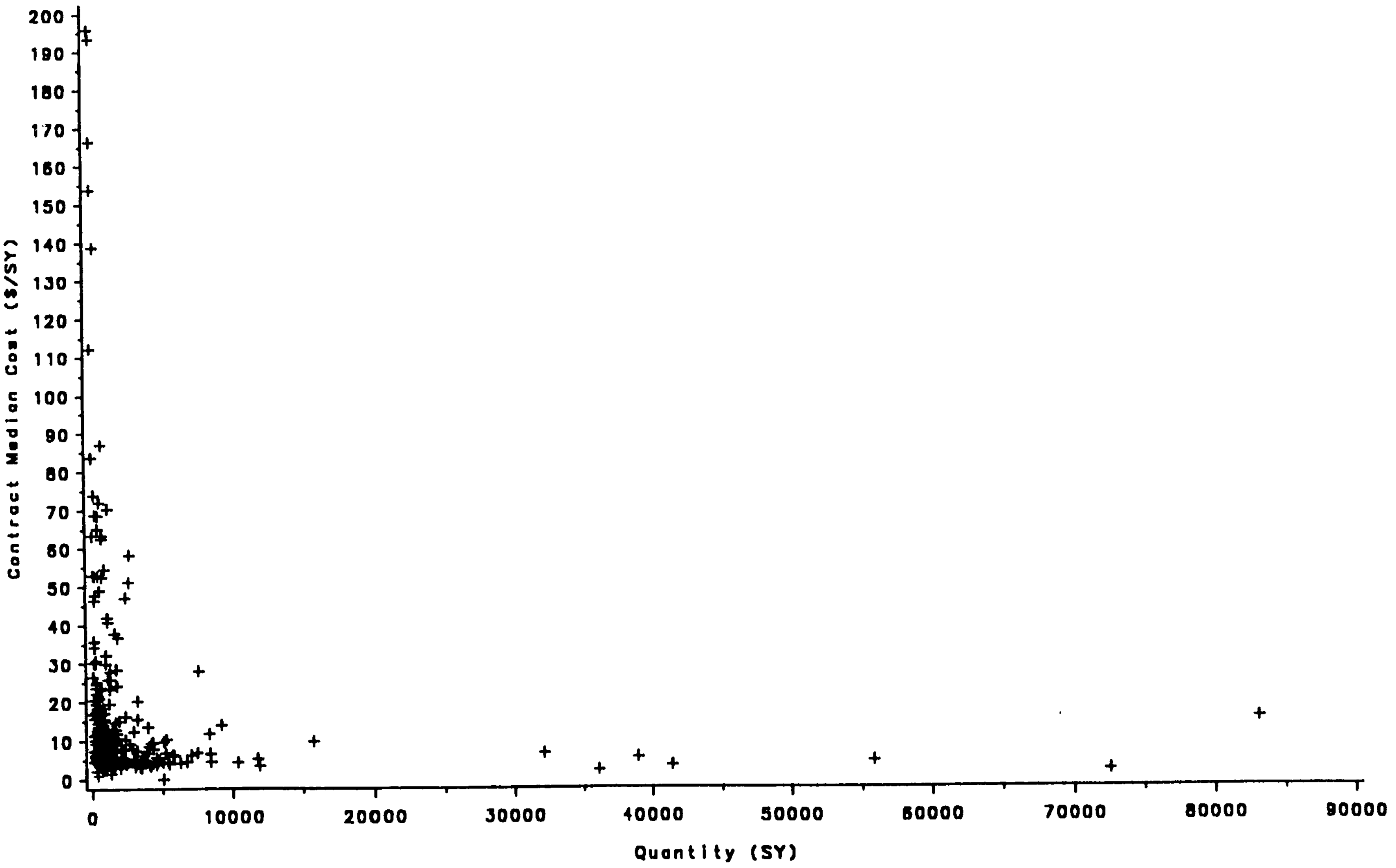
Items 242 & 522--Silane and Siloxane Sealers



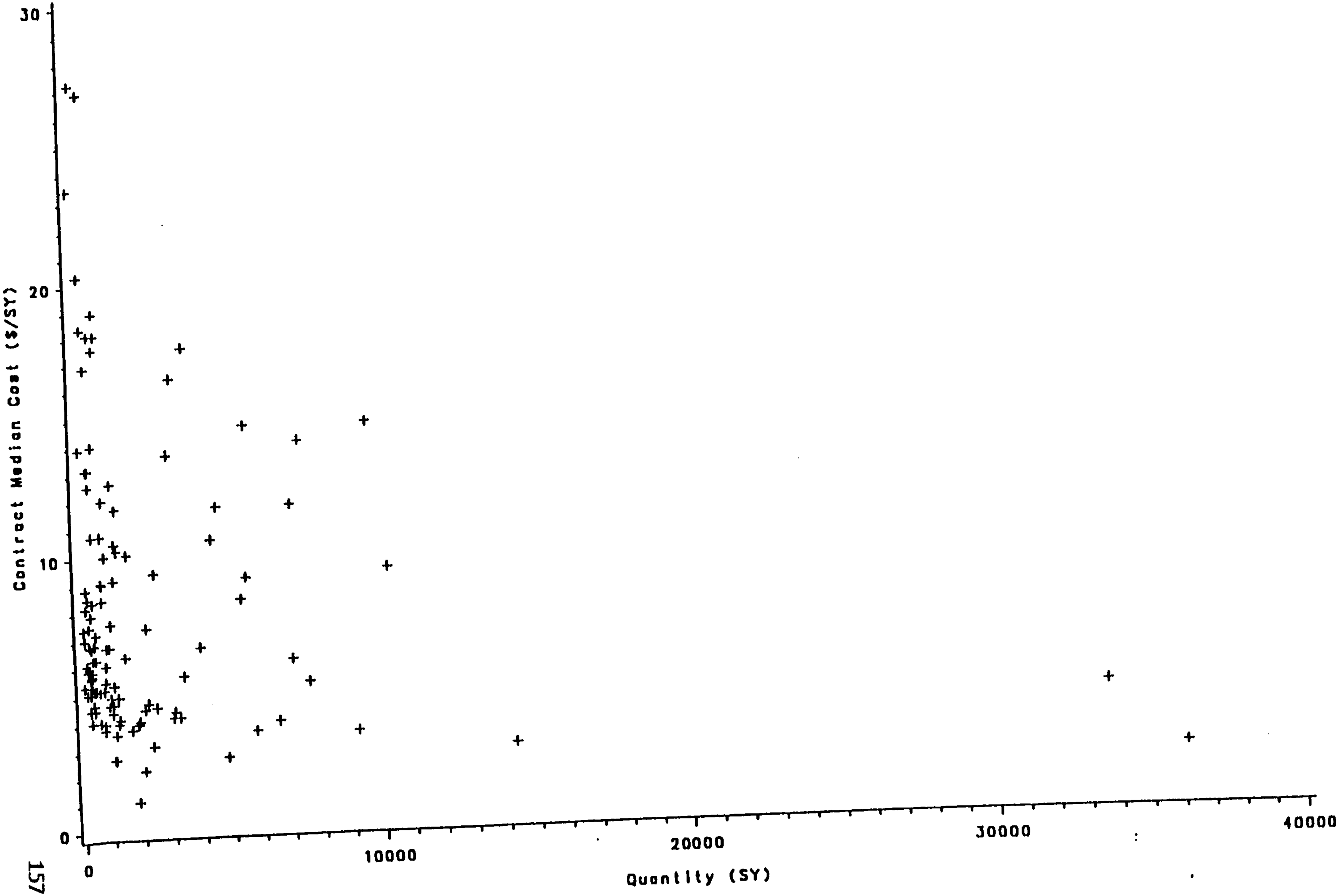
Item 243--High Molecular Weight Methacrylate Deck Sealer



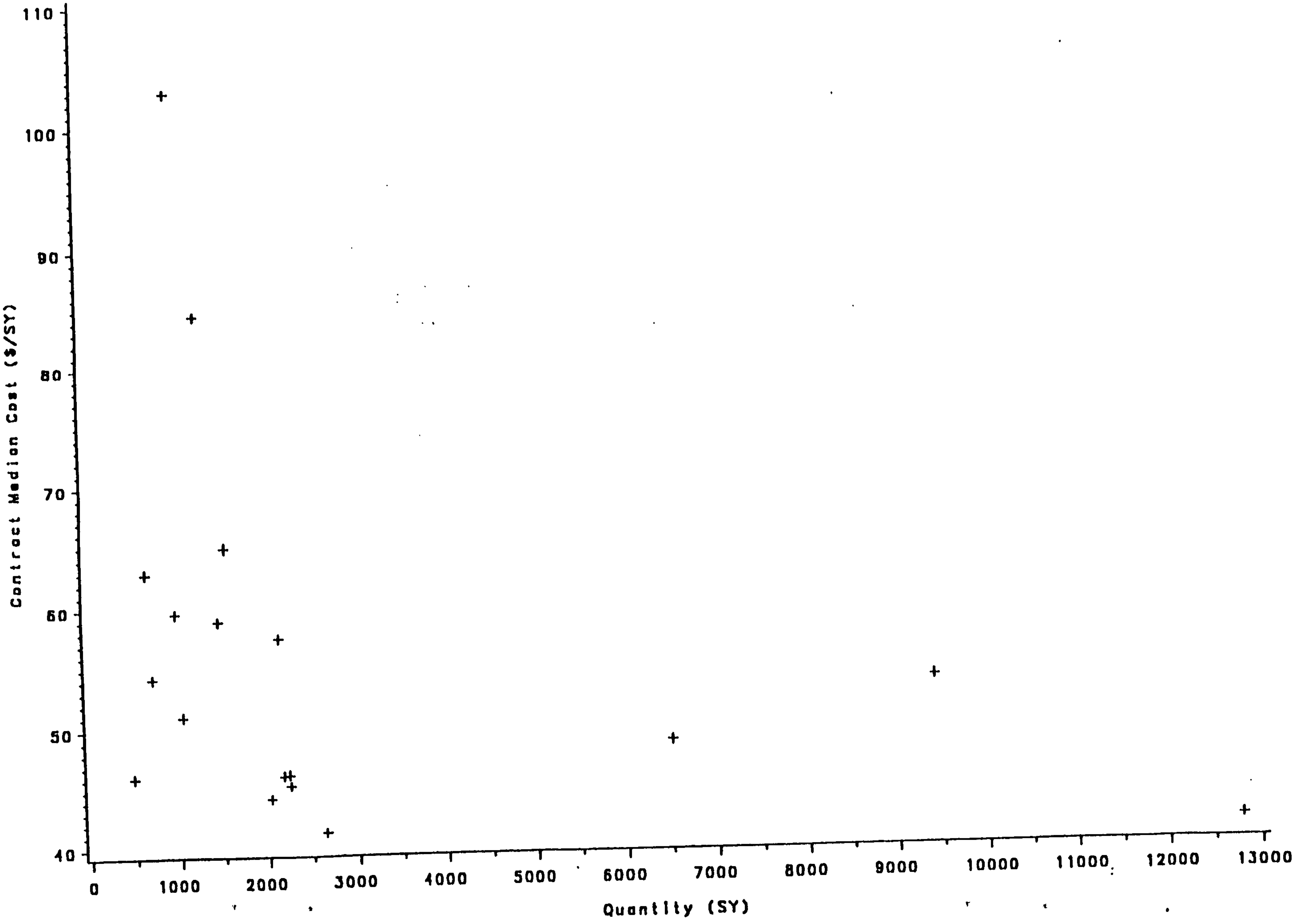
Item 251—Milling, Hydrodemolition and Scarification of Decks



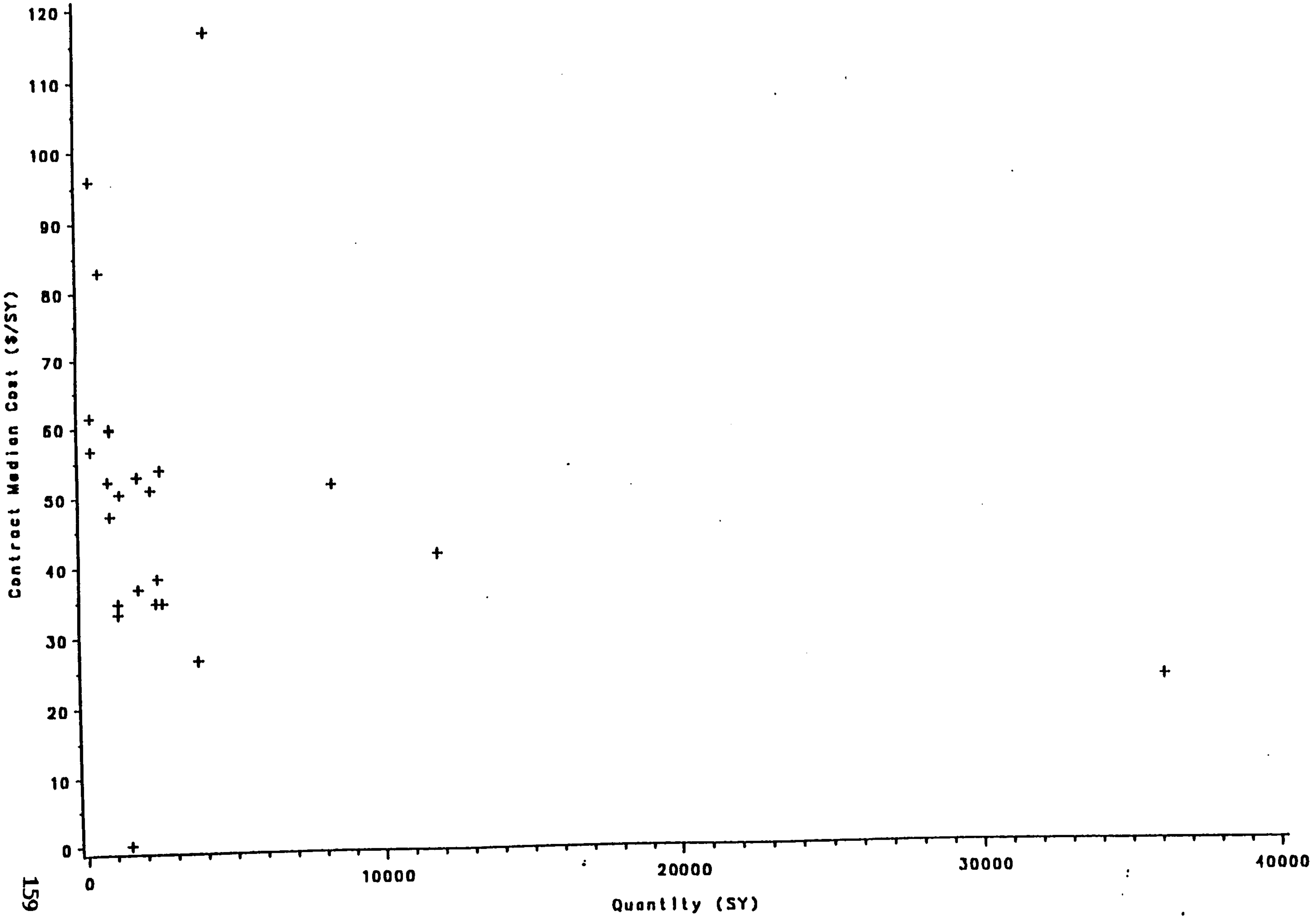
Item 260--Removal of Asphalt from Deck Surface



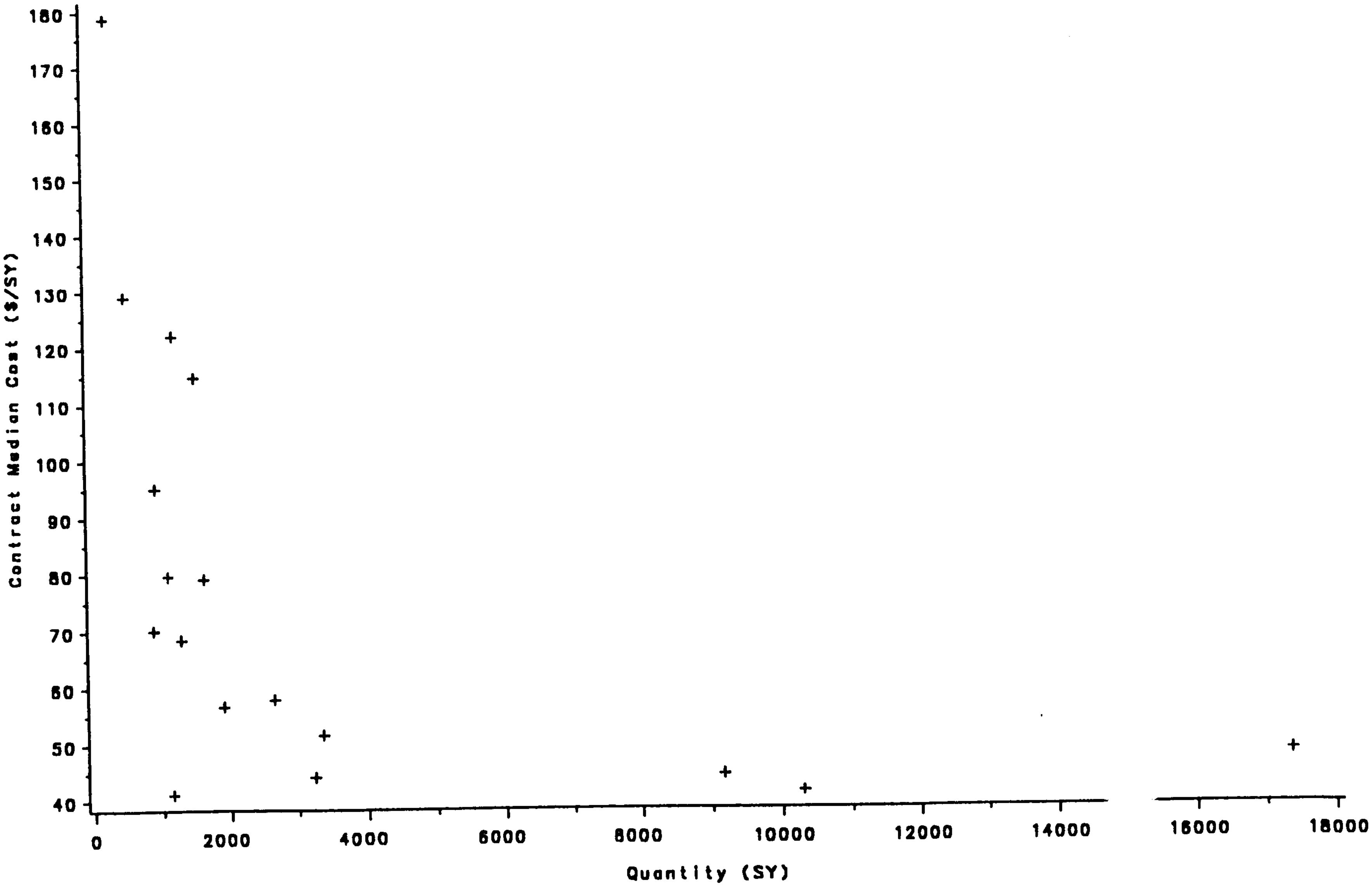
Item 310--Thin Polymer Deck Overlays



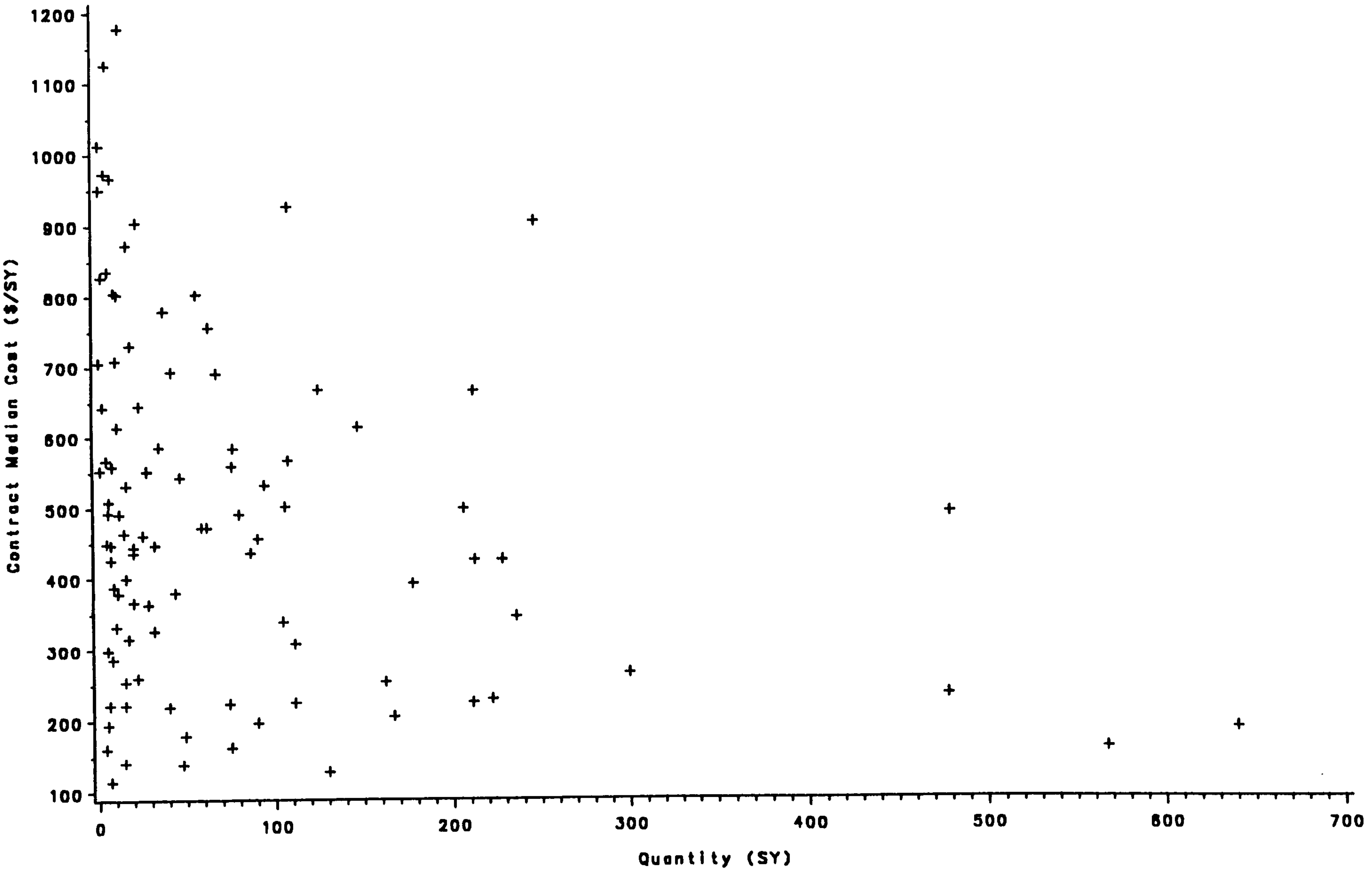
Item 320--Micro-silica Concrete Overlay



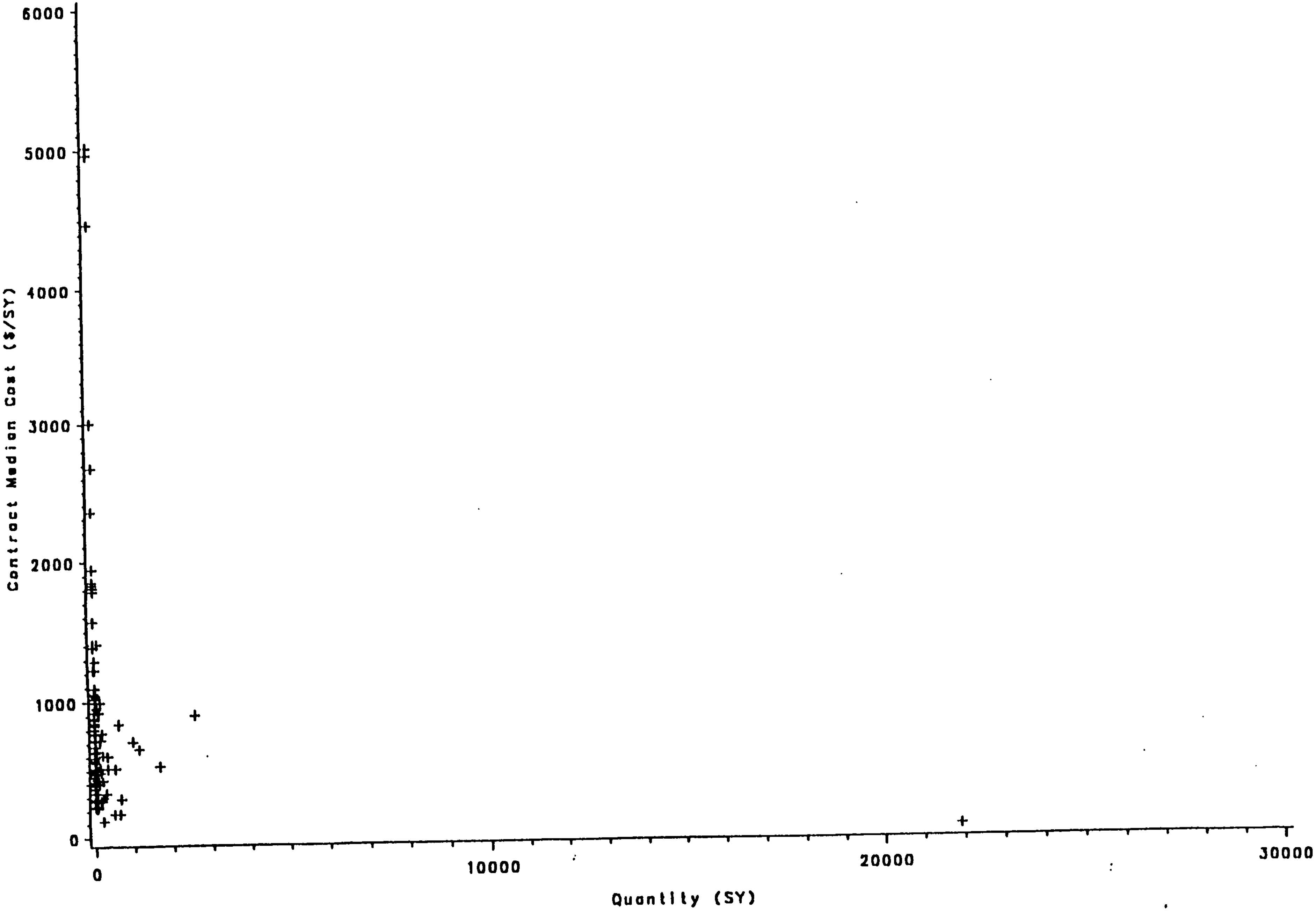
Item 330--Polyster Deck Overlays



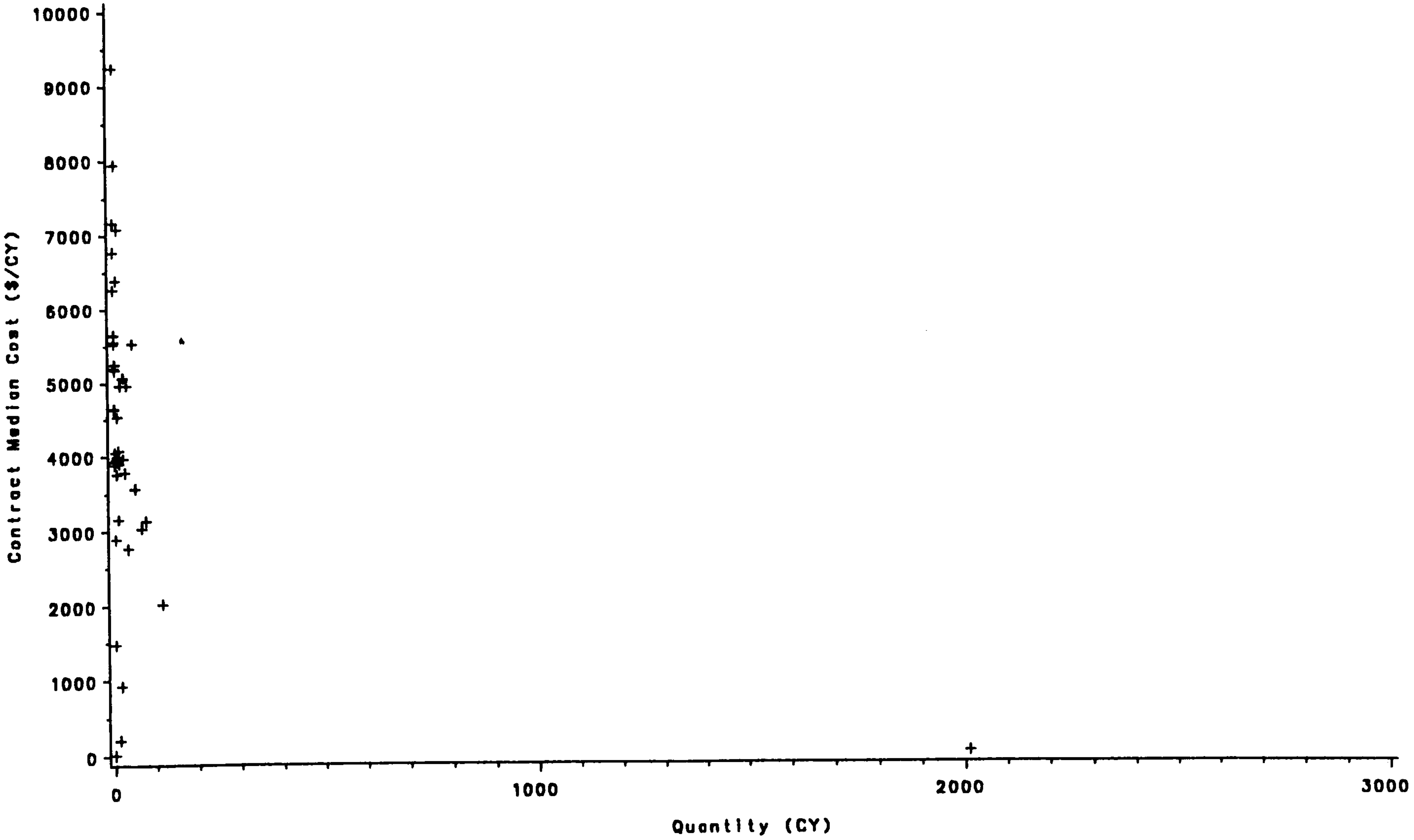
Item 411—–Shallow P.C.C. Structural Repairs



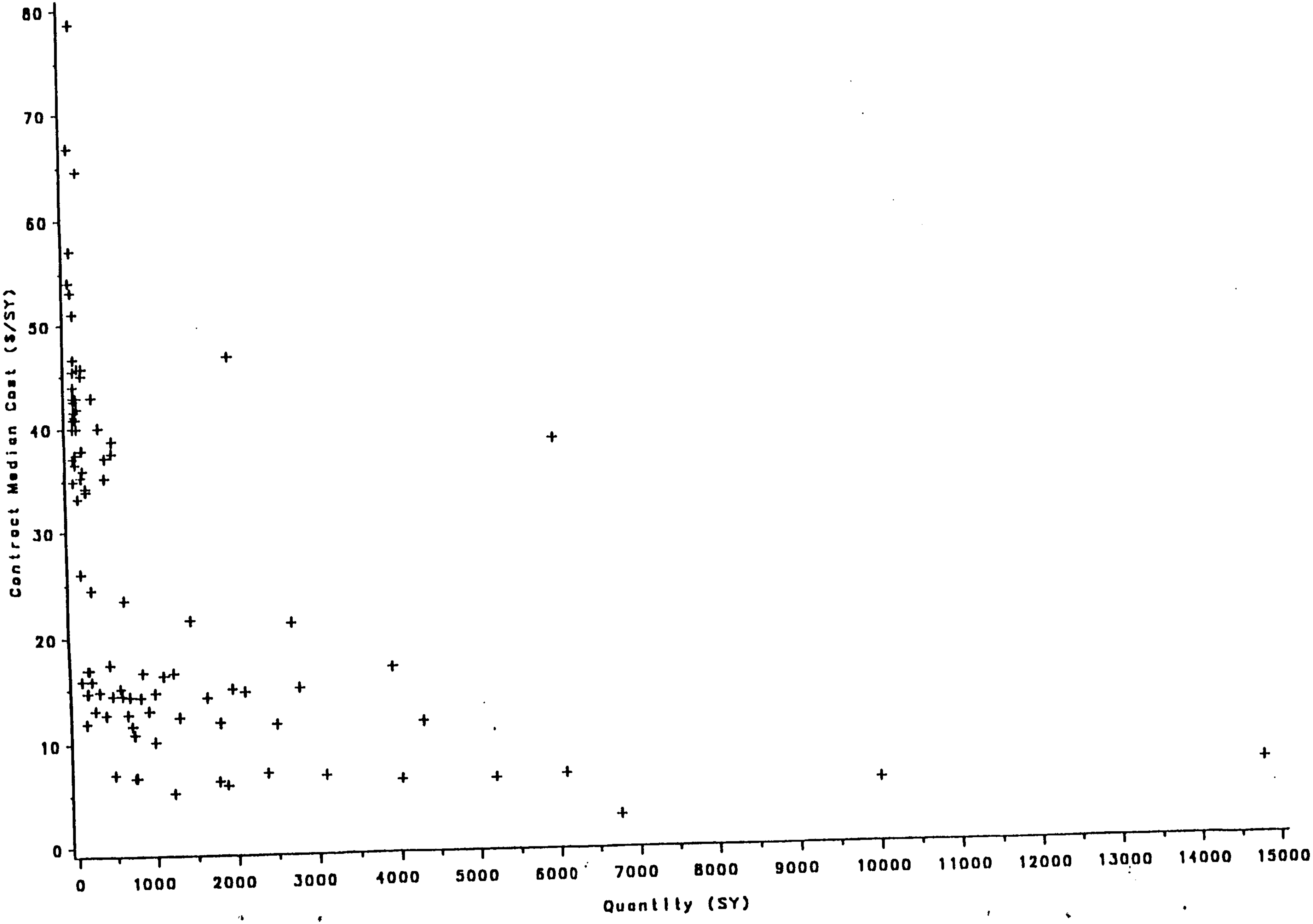
Item 412--Deep P.C.C. Structural Repairs



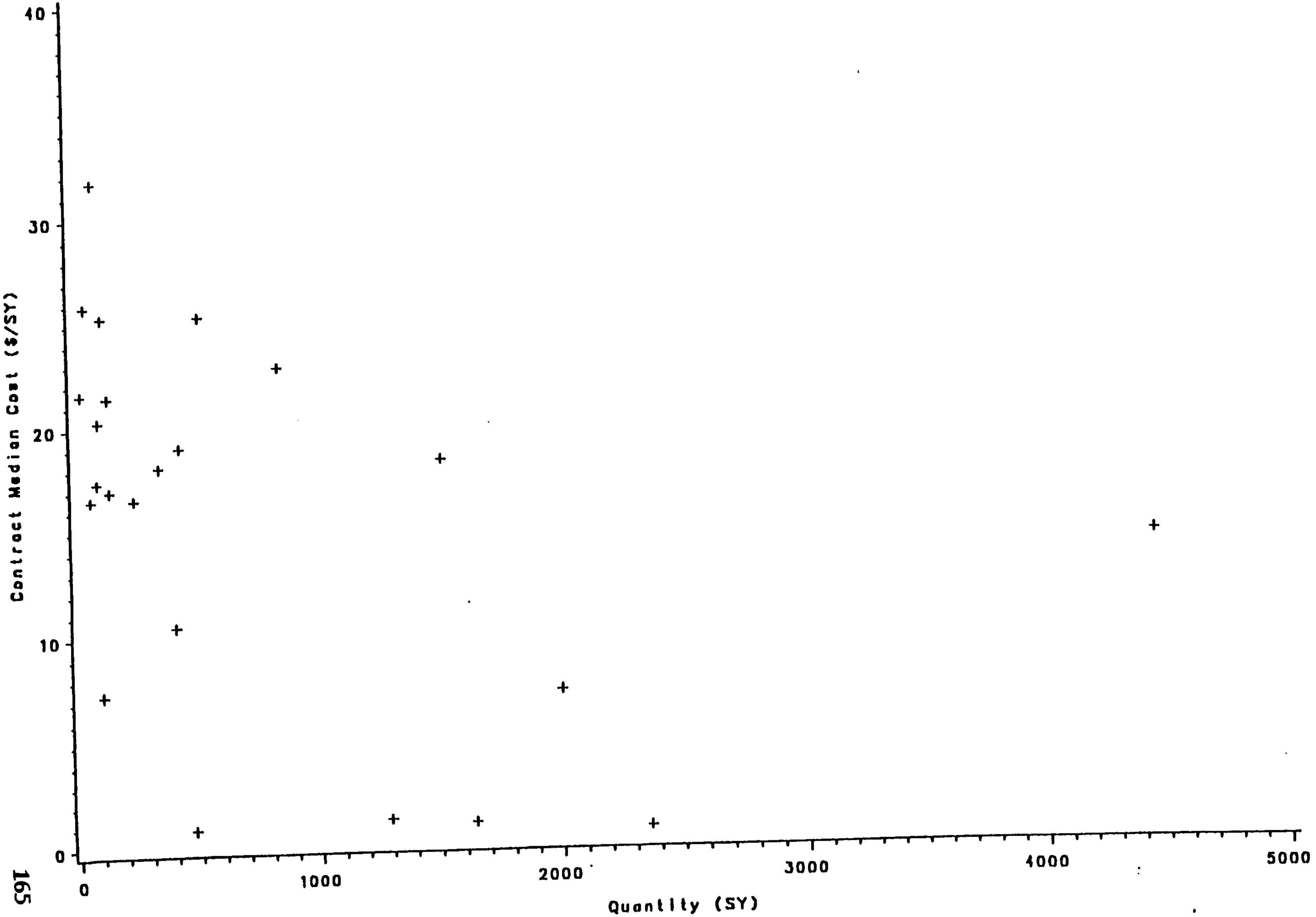
Item 530--Shotcrete Structural Repairs



Item 541--Epoxy Structural Coatings



Item 542--Structural Coatings Other Than Epoxies



Appendix B

Detailed Calculations for Cost Determinations Using Engineering Estimating Procedures

Detailed Calculations for Cost Determinations Using Engineering Estimating Proceedures

General

Insufficient data were available from the field study to allow empirical determination of costs for five treatment items. Those items are:

#421 Topical Structural Treatments: Quick-Set Hydraulic Mortar/Concrete Patches (shallow repairs).

#433 Topical Structural Treatments: Quick-Set Hydraulic Mortar/Concrete Patches (deep repairs).

#431 Topical Structural Treatments: Polymer Mortar/Concrete Patches (shallow repairs).

#432 Topical Structural Treatments: Polymer Mortar/Concrete Patches (deep repairs).

#510 Areal Structural Treatments: Encase With Portland Cement concrete.

Therefore, costs for these were developed using engineering estimating procedures. This appendix details the rationale and computations involved in determining estimated cost values for the five treatments.

For a given bridge, the unit cost for any one of the treatment procedures will vary depending on which bridge member is involved in the repair and on the extent of damage requiring repair. Therefore, it is necessary to provide cost estimates covering an appropriate range of damage for each bridge component. A "typical" concrete bridge was assumed, as follows:

- Three Span: 100 ft (30.5 m) center span; two 50 ft (15.2 m) end spans
- Roadway Width: 44 ft (13.4 m)
- Super Structure: P/S concrete I-beam
  - Center Span: five AASHTO type V I-beams
  - End Spans: five AASHTO type II I-beams
- Piers: 3 ft x 3 ft (0.9 x 0.9 m) square, 16.5 ft (5.0 m) high; two bents, three piers per bent

Repair depths for the four topical structural treatments were assumed to be as follows, based on practices set forth in prior studies (References 1-3):

< 1 in (2.5 cm) #431, 1-3 in (2.5 - 7.6 cm) #421 and #432, and > 3 in (7.6 cm) #422.

Areal structural treatment #510 (encase with portland cement concrete) was assumed to include the following two activities:

- encasement of deteriorated concrete piers and
- jacketing of deteriorated abutments.

The concrete bridge members, or elements, were categorized as follows:

- beams
- diaphragms
- piers
- pier caps
- backwalls

- abutments
- wingwalls

Notice that treatment items under consideration here (#421, #422, #431, #432, and #510) do not include bridge decks and deck appurtenances.

In all, 30 scenarios are evaluated at three deterioration levels, for a total of 90 cases. The computations are summarized in Table B-1.

Table B-2 provides a key for following the computational development, from column to column, in Table B-1. Tables B-3 through B-11 provide input information to Table B-1 as defined in Table B-2.

Table B-1. Computation of estimated unit costs.

(1) Concrete Member Type	(2) Treatment	(3) Repair Range	(4) Repair Area, SY	(5) Repair Volume, CY	(6) Performance Units	(7) Performance Standard, MH/Unit	(8) Production Planning, Units/day	(9) Crew No.	(10) Crew Rate, $/MH	(11) Crew Cost, $	(12) Equipment Group No.	(13) Equipment Cost, $/day	(14) Equipment Cost, $	(15) Material Group No.	(16) Material Cost, $/SY	(17) Material Cost, $	(18) Total Cost, $	(19) Including Mobilization & Engr., $	(20) Grand Total Unit Cost, $/SY
Beams	Topical Structural Treatments: #431. Polymer Mortar/Concrete Repairs (shallow).	low	6.6	0.14	Each	24	1	1	30.90	742	1	399.39	399	1	90.73	599	1,740	1,865	283
		medium	13.1	0.27	Each	24	1	1	30.90	742	1	399.39	399	1	90.73	1,189	2,330	2,498	191
		high	26.2	0.55	Each	24	1	1	30.90	742	1	399.39	399	1	90.73	2,377	3,518	3,771	144
Beams	Topical Structural Treatments: #421. Quick-Set Hydraulic Mortar/Concrete Repairs (shallow).	low	6.6	0.37	Each	24	1	1	30.90	742	1	399.39	399	2	61.12	403	1,544	1,655	251
		medium	13.1	0.73	Each	24	1	1	30.90	742	1	399.39	399	2	61.12	801	1,942	2,082	159
		high	26.2	1.46	Each	24	1	1	30.90	742	1	399.39	399	2	61.12	1,601	2,742	2,939	112
Beams	Topical Structural Treatments: #432. Polymer Mortar/Concrete Repairs (deep).	low	6.6	0.37	Each	24	1	1	30.90	742	1	399.39	399	3	243.84	1,609	2,750	2,948	467
		medium	13.1	0.73	Each	24	1	1	30.90	742	1	399.39	399	3	243.84	3,194	4,335	4,647	355
		high	26.2	1.46	Each	24	1	1	30.90	742	1	399.39	399	3	243.84	6,389	7,530	8,072	308
Beams	Topical Structural Treatments: #422. Quick-Set Hydraulic Mortar/Concrete Repairs (deep).	low	6.6	0.73	Each	24	1	1	30.90	742	1	399.39	399	4	115.44	762	1,903	2,040	309
		medium	13.1	1.46	Each	24	1	1	30.90	742	1	399.39	399	4	115.44	1,512	2,653	2,844	217
		high	26.2	2.91	Each	24	1	1	30.90	742	1	399.39	399	4	115.44	3,025	4,166	4,466	170
Diaphragms	Topical Structural Treatments: #431. Polymer Mortar/Concrete Repairs (shallow).	low	0.9	0.02	Each	24	1	1	30.90	742	1	399.39	399	1	90.73	82	1,223	1,311	1,457
		medium	1.9	0.04	Each	24	1	1	30.90	742	1	399.39	399	1	90.73	172	1,313	1,408	741
		high	2.8	0.06	Each	24	1	1	30.90	742	1	399.39	399	1	90.73	254	1,395	1,495	534
Diaphragms	Topical Structural Treatments: #421. Quick-Set Hydraulic Mortar/Concrete Repairs (shallow).	low	0.9	0.05	Each	24	1	1	30.90	742	1	399.39	399	2	61.12	55	1,196	1,282	1,425
		medium	1.9	0.11	Each	24	1	1	30.90	742	1	399.39	399	2	61.12	116	1,257	1,348	709
		high	2.8	0.16	Each	24	1	1	30.90	742	1	399.39	399	2	61.12	171	1,312	1,406	502
Diaphragms	Topical Structural Treatments: #432. Polymer Mortar/Concrete Repairs (deep).	low	0.9	0.05	Each	24	1	1	30.90	742	1	399.39	399	3	243.84	219	1,360	1,458	1,620
		medium	1.9	0.11	Each	24	1	1	30.90	742	1	399.39	399	3	243.84	463	1,604	1,719	905
		high	2.8	0.16	Each	24	1	1	30.90	742	1	399.39	399	3	243.84	683	1,824	1,955	698

(continued)

Table B-1. Computation of estimated unit costs.

(1) Concrete Member Type	(2) Treatment	(3) Repair Range	(4) Repair Area, SY	(5) Repair Volume, CY	(6) Performance Units	(7) Performance Standard, MH/Unit	(8) Production Planning, Units/day	(9) Crew No.	(10) Crew Rate, $/MH	(11) Crew Cost, $	(12) Equipment Group No.	(13) Equipment Cost, $/day	(14) Equipment Cost, $	(15) Material Group No.	(16) Material Cost, $/SY	(17) Material Cost, $	(18) Total Cost, $	(19) Including Mobilization & Engr., $	(20) Grand Total Unit Cost, $/SY
Diaphragms	Topical Structural Treatments: #422. Quick-Set Hydraulic Mortar/Concrete Repairs (deep).	low	0.9	0.10	Each	24	1	1	30.90	742	1	399.39	399	4	115.44	104	1,245	1,335	1,482
		medium	1.9	0.21	Each	24	1	1	30.90	742	1	399.39	399	4	115.44	219	1,360	1,458	767
		high	2.8	0.31	Each	24	1	1	30.90	742	1	399.39	399	4	115.44	335	1,476	1,582	565
Piers	Topical Structural Treatments: #431. Polymer Mortar/Concrete Repairs (shallow).	low	2.6	0.05	CY	36	1	5	30.87	1,111	6	326.47	326	1	90.73	236	1,673	1,793	690
		medium	6.6	0.14	CY	36	1	5	30.87	1,111	6	326.47	326	1	90.73	599	2,036	2,183	331
		high	13.2	0.28	CY	36	1	5	30.87	1,111	6	326.47	326	1	90.73	1,198	2,635	2,825	214
Piers	Topical Structural Treatments: #421. Quick-Set Hydraulic Mortar/Concrete Repairs (shallow).	low	2.6	[illegible]	CY	30	1	2	33.68	1,010	5	548.23	548	2	61.12	159	1,717	1,841	708
		medium	6.6	0.37	CY	30	1	2	33.68	1,010	5	548.23	548	2	61.12	403	1,961	2,102	319
		high	13.2	0.73	CY	30	1	2	33.68	1,010	5	548.23	548	2	61.12	807	2,365	2,535	192
Piers	Topical Structural Treatments: #432. Polymer Mortar/Concrete Repairs (deep).	low	2.6	0.14	CY	30	1	2	33.68	1,010	5	548.23	548	3	243.84	634	2,192	2,350	904
		medium	6.6	0.37	CY	30	1	2	33.68	1,010	5	548.23	548	3	243.84	1,609	3,167	3,395	514
		high	13.2	0.73	CY	30	1	2	33.68	1,010	5	548.23	548	3	243.84	3,219	4,777	5,121	388
Piers	Topical Structural Treatments: #422. Quick-Set Hydraulic Mortar/Concrete Repairs (deep).	low	2.6	0.29	CY	30	1	2	33.68	1,010	5	548.23	548	4	115.44	300	1,858	1,992	766
		medium	6.6	0.73	CY	30	1	2	33.68	1,010	5	548.23	548	4	115.44	762	2,320	2,487	377
		high	13.2	1.47	CY	30	1	2	33.68	1,485	5	548.23	806	4	115.44	1,524	3,815	4,090	310
Piers	Areal Structural Treatments: #510. Encase with Portland Cement Concrete	low	7.8	1.30	CY	30	1	2	33.68	1,314	7	444.55	578	5	87.36	681	2,573	2,758	354
		medium	46.7	7.78	CY	30	1	2	33.68	7,861	7	444.55	3,459	5	87.36	4,080	15,400	16,509	354
		high	140.0	23.33	CY	30	1	2	33.68	23,573	7	444.55	10,371	5	87.36	12,230	46,174	49,499	354
Pier Caps	Topical Structural Treatments: #431. Polymer Mortar/Concrete Repairs (shallow).	low	5.0	0.10	CY	36	1	5	30.87	1,111	6	326.47	326	1	90.73	454	1,891	2,027	405
		medium	10.0	0.21	CY	36	1	5	30.87	1,111	6	326.47	326	1	90.73	907	2,344	2,513	251
		high	40.0	0.83	CY	36	1	5	30.87	1,111	6	326.47	326	1	90.73	3,629	5,066	5,431	136

(continued)

Table B-1. Computation of estimated unit costs.

(1) Concrete Member Type	(2) Treatment	(3) Repair Range	(4) Repair Area, SY	(5) Repair Volume, CY	(6) Performance Units	(7) Performance Standard, MH/Unit	(8) Production Planning, Units/day	(9) Crew No.	(10) Crew Rate, $/MH	(11) Crew Cost, $	(12) Equipment Group No.	(13) Equipment Cost, $/day	(14) Equipment Cost, $	(15) Material Group No.	(16) Material Cost, $/SY	(17) Material Cost, $	(18) Total Cost, $	(19) Including Mobilization & Engr., $	(20) Grand Total Unit Cost, $/SY
Pier Caps	Topical Structural Treatments: #421. Quick-Set Hydraulic Mortar/Concrete Repairs (shallow).	low	5.0	0.28	CY	30	1	2	33.68	1,010	5	548.23	548	2	61.12	306	1,864	1,998	400
		medium	10.0	0.56	CY	30	1	2	33.68	1,010	5	548.23	548	2	61.12	611	2,169	2,325	233
		high	40.0	2.22	CY	30	1	2	33.68	2,243	5	548.23	1,217	2	61.12	2,445	5,905	6,330	158
Pier Caps	Topical Structural Treatments: #432. Polymer Mortar/Concrete Repairs (deep).	low	5.0	0.28	CY	30	1	2	33.68	1,010	5	548.23	548	3	243.84	1,219	2,777	2,977	595
		medium	10.0	0.56	CY	30	1	2	33.68	1,010	5	548.23	548	3	243.84	2,438	3,996	4,284	428
		high	40.0	2.22	CY	30	1	2	33.68	2,243	5	548.23	1,217	3	243.84	9,754	13,214	14,165	354
Pier Caps	Topical Structural Treatments: #422. Quick-Set Hydraulic Mortar/Concrete Repairs (deep).	low	5.0	0.56	CY	30	1	2	33.68	1,010	5	548.23	548	4	115.44	577	2,135	2,289	458
		medium	10.0	1.11	CY	30	1	2	33.68	1,122	5	548.23	609	4	115.44	1,154	2,885	3,093	309
		high	40.0	4.44	CY	30	1	2	33.68	4,486	5	548.23	2,434	4	115.44	4,618	11,538	12,369	309
Backwalls	Topical Structural Treatments: #431. Polymer Mortar/Concrete Repairs (shallow).	low	1.5	0.03	CY	36	1	4	33.93	1,221	2	621.71	622	1	90.73	136	1,979	2,121	1,414
		medium	3.0	0.06	CY	36	1	4	33.93	1,221	2	621.71	622	1	90.73	272	2,115	2,267	756
		high	12.0	0.25	CY	36	1	4	33.93	1,221	2	621.71	622	1	90.73	1,089	2,932	3,143	262
Backwalls	Topical Structural Treatments: #421. Quick-Set Hydraulic Mortar/Concrete Repairs (shallow).	low	1.5	0.08	CY	36	1	4	33.93	1,221	2	621.71	622	2	61.12	92	1,935	2,074	1,383
		medium	3.0	0.17	CY	36	1	4	33.93	1,221	2	621.71	622	2	61.12	183	2,026	2,172	724
		high	12.0	0.67	CY	36	1	4	33.93	1,221	2	621.71	622	2	61.12	733	2,576	2,761	230
Backwalls	Topical Structural Treatments: #432. Polymer Mortar/Concrete Repairs (deep).	low	1.5	0.08	CY	36	1	4	33.93	1,221	2	621.71	622	3	243.84	366	2,209	2,368	1,579
		medium	3.0	0.17	CY	36	1	4	33.93	1,221	2	621.71	622	3	243.84	732	2,575	2,760	920
		high	12.0	0.67	CY	36	1	4	33.93	1,221	2	621.71	622	3	243.84	2,926	4,769	5,112	426
Backwalls	Topical Structural Treatments: #422. Quick-Set Hydraulic Mortar/Concrete Repairs (deep).	low	1.5	0.17	CY	36	1	4	33.93	1,221	2	621.71	622	4	115.44	173	2,016	2,161	1,441
		medium	3.0	0.33	CY	36	1	4	33.93	1,221	2	621.71	622	4	115.44	346	2,189	2,347	782
		high	12.0	1.33	CY	36	1	4	33.93	1,625	2	621.71	827	4	115.44	1,385	3,837	4,113	343

(continued)

Table B-1. Computation of estimated unit costs.

(1) Concrete Member Type	(2) Treatment	(3) Repair Range	(4) Repair Area, SY	(5) Repair Volume, CY	(6) Performance Units	(7) Performance Standard, MH/Unit	(8) Production Planning, Units/day	(9) Crew No.	(10) Crew Rate, $/MH	(11) Crew Cost, $	(12) Equipment Group No.	(13) Equipment Cost, $/day	(14) Equipment Cost, $	(15) Material Group No.	(16) Material Cost, $/SY	(17) Material Cost, $	(18) Total Cost, $	(19) Including Mobilization & Engr., $	(20) Grand Total Unit Cost, $/SY
Abutments	Topical Structural Treatments: #431. Polymer Mortar/Concrete Repairs (shallow).	low	1.2	0.03	CY	72	0.5	4	33.93	1,221	3	660.21	660	1	90.73	109	1,990	2,113	1,778
		medium	3.0	0.06	CY	72	0.5	4	33.93	1,221	3	660.21	660	1	90.73	272	2,153	2,308	769
		high	6.0	0.13	CY	72	0.5	4	33.93	1,221	3	660.21	660	1	90.73	544	2,425	2,600	433
Abutments	Topical Structural Treatments: #421. Quick-Set Hydraulic Mortar/Concrete Repairs (shallow).	low	1.2	0.06	CY	72	0.5	4	33.93	1,221	3	660.21	660	2	61.12	73	1,954	2,095	1,746
		medium	3.0	0.17	CY	72	0.5	4	33.93	1,221	3	660.21	660	2	61.12	183	2,064	2,213	738
		high	6.0	0.33	CY	72	0.5	4	33.93	1,221	3	660.21	660	2	61.12	367	2,248	2,410	402
Abutments	Topical Structural Treatments: #432. Polymer Mortar/Concrete Repairs (deep).	low	1.2	0.06	CY	72	0.5	4	33.93	1,221	3	660.21	660	3	243.84	293	2,174	2,331	1,942
		medium	3.0	0.17	CY	72	0.5	4	33.93	1,221	3	660.21	660	3	243.84	732	2,613	2,801	934
		high	6.0	0.33	CY	72	0.5	4	33.93	1,221	3	660.21	660	3	243.84	1,463	3,344	3,585	597
Abutments	Topical Structural Treatments: #422. Quick-Set Hydraulic Mortar/Concrete Repairs (deep).	low	1.2	0.13	CY	72	0.5	4	33.93	1,221	3	660.21	660	4	115.44	139	2,020	2,165	1,805
		medium	3.0	0.33	CY	72	0.5	4	33.93	1,221	3	660.21	660	4	115.44	346	2,227	2,387	796
		high	6.0	0.67	CY	72	0.5	4	33.93	1,637	3	660.21	885	4	115.44	693	3,215	3,446	574
Abutments	Areal Structural Treatments: #510 Encase (Jacket) Abutment With Portland Cement Concrete.	low	15.0	3.33	CY	48	0.5	1	30.90	4,939	4	576.55	3,840	6	82.27	1,234	10,013	10,734	716
		medium	25.0	5.56	CY	48	0.5	1	30.90	8,247	4	576.55	6,411	6	82.27	2,057	16,715	17,918	717
		high	50.0	11.11	CY	48	0.5	1	30.90	16,478	4	576.55	12,811	6	82.27	4,114	33,403	35,808	716
Wingwalls	Topical Structural Treatments: #431. Polymer Mortar/Concrete Repairs (shallow).	low	0.7	0.02	CY	6	4	3	32.70	785	4	576.55	577	1	90.73	64	1,426	1,518	2,169
		medium	1.8	0.04	CY	6	4	3	32.70	785	4	576.55	577	1	90.73	163	1,525	1,635	908
		high	3.6	0.08	CY	6	4	3	32.70	785	4	576.55	577	1	90.73	327	1,689	1,810	503
Wingwalls	Topical Structural Treatments: #421. Quick-Set Hydraulic Mortar/Concrete Repairs (shallow).	low	0.7	0.04	CY	6	4	3	32.70	785	4	576.55	577	2	61.12	43	1,405	1,506	2,152
		medium	1.8	0.10	CY	6	4	3	32.70	785	4	576.55	577	2	61.12	110	1,472	1,578	877
		high	3.6	0.20	CY	6	4	3	32.70	785	4	576.55	577	2	61.12	220	1,582	1,696	471

(continued)

Table B-1. Computation of estimated unit costs.

(1) Concrete Member Type	(2) Treatment	(3) Repair Range	(4) Repair Area, SY	(5) Repair Volume, CY	(6) Performance Units	(7) Performance Standard, MH/ Unit	(8) Production Planning, Units/ day	(9) Crew No.	(10) Crew Rate, $/MH	(11) Crew Cost, $	(12) Equipment Group No.	(13) Equipment Cost, $/day	(14) Equipment Cost, $	(15) Material Group No.	(16) Material Cost, $/SY	(17) Material Cost, $	(18) Total Cost, $	(19) Including Mobilization & Engr., $	(20) Grand Total Unit Cost, $/SY
Wingwalls	Topical Structural Treatments: #432. Polymer Mortar/Concrete Repairs (deep).	low	0.7	0.04	CY	6	4	3	32.70	785	4	576.55	577	3	243.84	171	1,533	1,643	2,348
		medium	1.8	0.10	CY	6	4	3	32.70	785	4	576.55	577	3	243.84	439	1,801	1,931	1,073
		high	3.6	0.20	CY	6	4	3	32.70	785	4	576.55	577	3	243.84	878	2,240	2,401	667
Wingwalls	Topical Structural Treatments: #422. Quick-Set Hydraulic Mortar/Concrete Repairs (deep).	low	0.7	0.08	CY	6	4	3	32.70	785	4	576.55	577	4	115.44	81	1,443	1,547	2,210
		medium	1.8	0.20	CY	6	4	3	32.70	785	4	576.55	577	4	115.44	208	1,570	1,683	935
		high	3.6	0.40	CY	6	4	3	32.70	785	4	576.55	577	4	115.44	416	1,778	1,906	529

Note: $(\$/m^2) = (\$/SY) * 1.196$
$m^2 = (SY) * 0.836$
$m^3 = (CY) * 0.7646$

Table B-2. Key to computations in Table B-1.

Column No.	Column Identification	Column Information Source(s)
(1)	Concrete Member type	Input Data
(2)	Treatment	Input Data
(3)	Repair Range	Input Data
(4)	Repair Area, SY	Tables B-3 through B-5
(5)	Repair Volume, CY	Factor from Table B-6 x Col. (4); Tables B-4 and B-5
(6)	Performance Units	Table B-7
(7)	Performance Standard, MH/Unit	Table B-7
(8)	Production Planning, Units/day	Table B-7
(9)	Crew No.	Table B-8
(10)	Crew Rate, $/MH	Table B-8
(11)	Crew Cost, $	(a)For beams and diaphragms, assume that all repair is done on one member. For this case: Col. (11) = Col. (7) x Col. (10) (b)For the other bridge components: Col. (11) = Col. (5) x Col. (7) x Col. (10), <u>except that</u> the <u>minimum</u> cost is one day of crew time [= Col. (7) x Col. (8) x Col. (10)].
(12)	Equipment Group No.	Table B-9
(13)	Equipment Cost, $/day	Table B-9
(14)	Equipment Cost, $	(a) For beams and diaphragms, where it is assumed that all repair is done on one member and where the production rates all equal 1 unit per day [see Col. (8)]: Col. (14) = Col. (13) x 1 day (b) For the other bridge components: $\text{Col. (14)} = \frac{\text{Col. (5) x Col. (13)}}{\text{Col. (8)}}$ <u>except</u> <u>that</u> the <u>minimum</u> cost is one day of equipment time [= Col. (13) x 1 day].
(15)	Material Group No.	Table B-10
(16)	Material Cost, $/SY	Table B-11
(17)	Material Cost, $	Col. (17) = Col. (4) x Col. (16)
(18)	Total Cost, $	Col. (18) = col. (11) + Col. (14) + Col. (17)
(19)	Including Mobilization and Engr.	Col. (19) = Col. (18) x 1.072
(20)	Grand Total Unit Cost, $/SY	Col. (20) = Col. (19) ÷ Col. (4)

Note: ($/$m^2$) = ($/SY) * .96
m^2 = (SY) * 0.836
m^3 = (CY) * 0.7646

Table B-3. Repair area ranges for a typical concrete bridge.

Concrete Bridge Member	Total Exposed Concrete Area, SY	Repair Area Ranges					
		Low		Medium		High	
		%	SY	%	SY	%	SY
Beams[a]	1,310	0.5	6.6	1.0	13.1	2.0	26.2
Diaphragms	93	1.0	0.9	2.0	1.9	3.0	2.8
Backwalls	30	5.0	1.5	10.0	3.0	40.0	12.0
Abutments[b]	60	2.0	1.2	5.0	3.0	10.0	6.0
Wingwalls	36	2.0	0.7	5.0	1.8	10.0	3.6
Piers[c]	132	2.0	2.6	5.0	6.6	10.0	13.2
Pier Caps	100	5.0	5.0	10.0	10.0	40.0	40.0

[a] Percent deteriorated areas are lower for beams because, typically, problems occur only at the bottom flange and usually at the ends of the outside (facia) beams.

[b] Abutments should be repaired by jacketing if deteriorated areas exceed 10%. See Ref. (14).

[c] Piers should be repaired by encasement if deteriorated areas exceed 10%.

Note: $m^2 = (SY) * 0.836$

Table B-4. Repair area and volume ranges for abutment jackets.

Range	Abutment Height, ft	Repair Area, SY	Repair Vol., CY*
Low	3	15	3.33
Medium	5	25	5.56
High	10	50	11.11

*Average thickness = 8 in (20 cm).

Note: $m = (ft) * 0.3048$

$m^2 = (SY) * 0.836$

$m^3 = (CY) * 0.7646$

Table B-5. Repair area and volume ranges for pier encasement.

Range	Number of Piers Affected	Encasement Height, ft	Average Repair Area, SY*	Repair Vol. CY*
Low	1	5	7.8	.3
Medium	3	10	46.7	7.78
High	6	15	140.0	23.33

Assumes 3 ft x 3 ft (0. 0.9 m) square piers and 6 in (15 cm) thick jackets.

Note: m = (ft) * 0.30
m^2 = (SY) * 0.836
m^3 = (CY) * 0.7646

Table B-6. Factors for estimating repair volumes from repair area quantities.

Repair Depth Range, in	Factor CY/SY	Treatments
< 1	0.0208	#431
1-3	0.0556	#421; #432
> 3	0.1111	#422

Note: cm = (in) * 2.54
m^2 = (SY) * 0.836
m^3 = (CY) * 0.7646

Table B-7. Performance and production rates[a].

Concrete Bridge Member	Procedure	Performance Units	Performance Standard MH/Unit	Production Rate Units/hr	Production Planning Units/day
Beams	Patching	Each	24	0.17	1
Diaphragms	Patching	Each	24	0.17	1
Backwalls	Patching	CY	36	0.17	1
Abutments	Patching	CY	72	0.08	0.5
Abutments	Jacketing	CY	48	0.08	0.5
Wingwalls	Patching	CY	6	0.67	4
Piers	Patching	CY	30[b]	0.17	1
Piers	Encasing	CY	30	0.17	1
Pier Caps	Patching	CY	30[b]	0.17	1

[a] Source: Ref. (13)
[b] 36 MH/Unit for shallow polymer mortar patches (#431).
Note: $m^3 = (CY) * 0.7646$

Table B-8. Crew compositions and cost rates [a].

Crew No.	Crew Composition					Crew Cost, $/hr	Avg. Cost, $/MH
	Foreman-outside ($39.60/hr)	Laborer ($28.00/hr)	Welder ($44.80/hr)	Equipment Operator Medium ($35.20/hr)	Cement Finisher ($33.60/hr)		
1	1	3				123.60	30.90
2	1	3	1			168.40	33.68
3	1	2		1		130.80	32.70
4	1	3	1	1		203.60	33.93
5	1	4			1	185.20	30.87

[a] Position/Trade hourly rates include wage burden and contractor overhead and profit [source: Ref. (8), pg. 447].

Table B-9. Equipment group numbers and costs.

Equipment Item	Equipment Item Costs*				Equipment Group No.						
	Equip. Rent. $/day	Oper. Cost, $/hr	Est. % Use	Total Cost: per 6 hr day	1	2	3	4	5	6	7
250 cfm air compressor (w/accessories)	89.72	5.41	60	109.20	X	X	X	X	X	X	X
15 lb air hammer	15.00	0.10	40	15.24	X	X	X	X	X	X	X
Concrete drill (1½ in dia)	24.65	0.11	20	24.78	X	X	X	X	X		X
Concrete mixer	47.00	0.95	20	48.14	X	X	X	X	X		X
Aerial lift (to 25 ft high; 2000 lb cap.)	130.00	1.50	100	139.00	X				X	X	X
Backhoe, wheel mounted (5/8 CY)	195.00	6.40	25	204.60		X	X	X			
Jacks (2) -- cost each	18.35	0.15	100	38.50			X		X		
Roller	110.00	2.60	10	111.56		X	X	X			
Welding equipment	43.00	1.80	20	45.16		X	X		X		X
Concrete saw (12 in)	62.00	2.65	20	65.18					X		
Sandblast & accessories (6 cf cap.)	62.0	0.32	20	63.03	X	X	X	X	X	X	X
EQUIPMENT GROUP COSTS, $/day					399.39	621.71	660.21	576.55	548.23	326.47	444.55

*Source: Ref. (8)
Conversion Factors: (m^3/min) = (cfm) * 0.02832; kg = (lb) * 0.4536; (mm) = (in) * 25.4; m= (ft) * 0.03048; m^3 = (CY) * 0.7646; (cm) = (in) * 2.54; m^3 = (cf) * 0.02832

Table B-10. Material groups.

Material Group No.	Description
1	Topical Structural Treatment: Polymer Mortar/Concrete Repairs (shallow) (#431)
2	Topical Structural Treatment: Quick-Set Hydraulic Mortar/Concrete Repairs (shallow) (#421)
3	Topical Structural Treatment: Polymer Mortar/Concrete Repairs (deep) (#432)
4	Topical Structural Treatment: Quick-Set Hydraulic Mortar/Concrete Repairs (deep) (#422)
5	Areal Structural Treatment: Encase Piers with Portland Cement Concrete (#510)
6	Areal Structural Treatment: Jacket Abutments with Portland Cement Concrete (#510)

Table B-11. Material group unit costs.

			Unit Cost $/SY	Equipment Group No.					
				1	2	3	4	5	6
Forms		Abut. Jack & Pier Encase.	56.25					X	X
Reinforcement	Rebar Repl.	1-3 in (2.5 - 7.6 cm) depth	1.90		X	X			
		> 3 in (7.6 cm) depth	3.80				X		
	Pier Encase. Rebar Cage		12.93					X	
	Abutment Jacket Reinforcement		4.05						X
Epoxy Bonding Compound			6.81		X		X	X	X
Port. Cem. Concrete		Pier Encasement	11.37					X	
		Abutment Jacket	15.16						X
Patching Material	Rapid Set Hyd. M/C	1-3 in (2.5 - 7.6 cm) deep	52.41		X				
		> 3 in (7.6 cm) deep	104.83				X		
	Poly-mer M/C	< 1 in (2.5 cm) deep	90.73	X					
		1-3 in (2.5 - 7.6 cm) deep	241.94			X			
Group Costs, $/SY				90.73	61.12	243.84	115.44	87.36	82.27

Note: ($/m²) = ($/SY) * 1.196

Development of Materials Unit Costs

The unit costs for materials presented in Table B-11 are developed below:

A. Reinforcing Steel

1. For the replacement of individual rebars during patching operations.
   Cost data [Source: Ref. (8) pg. 64]

   Assumptions:
   - (a) Grade 60 steel
   - (b) Epoxy coated rebar and tie wire
   - (c) #5 (16 mm) rebars; 16 ga. (1.65 mm) tie wire
   - (d) Tie wire 1% by wt of bar
   - (e) Prices include O&P

Rebar base price (incl. freight) = $ 305/ton ($336/mt)

Epoxy coating @ $17.95/cwt ($39.57/100kg) = $ 359/ton ($396/mt)

#5 (16 mm) bar size, extra = $ 33/ton ($36/mt)

Quantity from mill under 20 ton (18 mt), extra = $ 3.30/ton ($3.6/mt)

Tie wire:

Base price	$81.00/cwt ($178.61/100 kg)
Epoxy coating	$17.95/cwt ($39.57/100 kg)
Subtotal	$98.95/cwt ($218.18/100 kg)

1% by wt of rebar = $(0.01)(2{,}000)\frac{(\$98.95)}{100}$ = $ 19.79/ton ($21.80/mt)

Total = $ 720.09/ton ($793.23/mt)

= $ 0.36/lb ($0.79/kg)

#5 (16 mm) rebar weighs 1.043 lb/ft (1.552 kg/m);

therefore, cost/ft = (1.043)(0.36) = \$ 0.38/ft (\$1.25/m)

Estimated rebar replacement requirements and costs:

Patch Thickness, in	Rebar Replacement ft/SY	Cost \$/SY
< 1 (2.5 cm)	0	0.00
1-3 (2.5 - 7.6 cm)	5 (1.8 m/m^2)	1.90 (\$2.27/m^2)
> 3 (7.6 cm)	10 (3.6 m/m^2)	3.80 (\$4.54/m^2)

2. Reinforcement cage for pier encasement

Assumptions

(a) Cage consists of #5 (16 mm) bars on 6 in (15 cm) centers vertically and #4 (13 mm) tie bars on 9 in (23 cm) centers

(b) Overall cage dimensions: (pier width + 6 in (15 cm)) x encasement height

(c) 3 ft x 3 ft (0.9 m x 0.9 m) square original pier cross-section

Calculations

(a) Wt of cage/ft of encasement height: = (28 - #5 bars) x (1.043 lb/ft) x (1 ft/bar) +

$$(1\ \text{ft})\frac{(12\ \text{in/ft})}{(9\ \text{in/\#4 bars})} \times (0.668\ \text{lb/ft}) \times (3.5)\,(4)\ \text{ft/bar} = 41.67\ \text{lb/ft}\ (62.00\ \text{kg/m})$$

(b) Costs [Source: Ref. (8), pg. 64]
- Grade 60 steel
- Epoxy coated rebar and tie wire
- Tie wire 1% by wt. of bar
- Prices include O&P

Basic price: cut, bent & delivered = \$ 545/ton (\$600/mt)

Epoxy coating @ \$17.95/cwt (\$39.57/100 kg) = \$ 359/ton (\$395/mt)

#4 (13 mm) & #5 (16 mm) bar sizes, extra (avg.) = \$ 38.5/ton (42.4/mt)

Quantity from mill under 20 ton, extra = \$ 3.3/ton (\$3.6/mt)

Tie wire, epoxy coated,
1% @ \$98.95/cwt (\$218.18/100 kg) = \$ 19.79/ton (\$21.80/mt)

Total = \$ 965.59/ton (\$1,062.80/mt)

$$\text{Cost/SY} = \frac{(41.67\text{ lb/ft})\ (\$965.59/\text{ton})\ (9\text{ ft}^2/\text{SY})}{(2000\text{ lb/ton})\ (3.5\text{ ft})\ (4)} = \$12.93/\text{SY}\ (\$14.15/\text{m}^2)$$

3. Reinforcement for abutment jackets

Assumptions

(a) Min. thickness = 6 in (15 cm) (assume avg. thickness = 8 in (20 cm))

(b) 1½ in (38 mm) ϕ tyscrus and lagstuds on 20 in (51 cm) centers to support forms & WWF

(c) 6 x 6 6/6 WWF, epoxy coated

Calculations

(a) $$\text{No. lagstuds/SY} = \frac{9\text{SF/SY}}{\left(\frac{20}{12}\right)^2 \text{SF/stud}} = 3.24\text{ lagstuds/SY } (3.99/\text{m}^2$$

(b) Costs [Source: Ref. (8), pgs. 51, 64, & 66]

$$\text{lagstuds: } \frac{(\$58)\ (8\text{ in})}{(100\text{ ft})\ (12\text{ in/ft})} = \$0.39\text{ each (incl. O\&P)}$$

$$\text{lagnuts} = \frac{\$23}{100}\text{ (incl. O\&P)} = \$0.23\text{ each}$$

(\$0.39 + \$0.23) (3.24/SY) = \$2.01/SY (\$2.40/m^2)

WWF Bare Mat'l. Cost = \$13.80/CSF (\$1.48/m^2)

wt. of WWF = 42 lb/CSF (2.05 kg/m^2)

Epoxy coating @ \$16.30/CWT (bare cost) = (42 lb/CSF) x

$$\frac{\$16.30}{100\text{ lb}} = \$6.85\text{ CSF }(\$0.74/\text{m}^2)$$

Epoxy Coated WWF (incl. O&P)/SY =

$$\frac{\$(13.80 + 6.85)\ (1.1)\ (9)}{100\text{ SF}} = \$2.04/\text{SY }(\$2.44/\text{m}^2)$$

Total reinf. cost (incl. O&P) = \$2.01 + \$2.04 = <u>\$4.05/SY</u> (\$4.84/m^2)

B. <u>Portland Cement Concrete for Abutment Jackets and Pier Encasement</u>

Unit cost [Source: Ref. (8), pg. 69] = \$62/CY (4500 psi) (\$81/m^3)

Abutment Jackets (8 in (20 cm) avg. thick), assuming 10% waste = (62) (1.1) (8/36) = <u>\$15.16/SY</u> (\$18.13/m^2)

Pier casings (6 in thickness), assuming 10% waste = (62) (1.1) (6/36) = <u>\$11.37/SY</u> (\$13.60/m^2)

C. <u>Epoxy Bonding Compound</u>

Cost (avg. of quotations on three brands obtained 3/27/92) = \$46.92/gal. (\$12.40/L)

10% markup for O&P = (1.1) (46.92) = \$51.61/gal (\$13.64/L)

$$\text{Cost/SY, assuming 10\% waste} = \frac{\$(51.61)\ (1.1)/\text{gal}}{75\text{ ft}^2/\text{gal}} \times 9\text{ ft}^2/\text{SY} = \underline{\$6.81/\text{SY}}\ (\$8.14/\text{m}^2)$$

D. Rapid Setting Hydraulic Mortar/Concrete

Based on:

- Quotations on three brands obtained 3/27/92
- Add 10% markup for O&P
- Assume 10% waste
- Extend with 3/8 in agg. per mfg. recommendations
- Cost of 3/8 in agg. (incl. O&P) = \$12.05/ton = \$0.006/lb (\$0.013/kg) [Source: Ref. (8), pg. 67]

Material	Yield, CF/Unit	Cost, \$/Unit	Cost, \$/SY	
			1-3 in	> 3"
A (extended w/agg.)	0.78	19.22	40.66	81.31
B (extended w/agg.)	0.78	18.67	39.49	78.99
C (extended w/agg.)	0.83	38.78	77.09	154.19
Averages			52.41	104.83

Note: (\$/m^2) = (\$/SY) * 1.196
(cm) = (in) * 2.54
m^3 = (CF) * 0.0283

Sample Calculation for above table:

Material A (extended w/agg.), 1-3 in (2.5 - 7.6 cm) thickness:
Data: \$17.20/50 lb bag (\$17.20/22.68 kg bag)

yield = 0.78 CF/bag (22.1 L/bag) when extended w/50 lb (22.68 kg) agg.

Cost/unit = (\$17.20) (1.1) + (\$0.006/lb) (50 lb) = \$19.22/unit

$$\text{Cost/SY} = (1.1)\left(\frac{2\ \text{in}}{36\ \text{in/yd}}\right)\left(\frac{\$19.22/\text{unit}}{0.78\ \text{CF/unit}}\right)(27\ \text{CF/CY}) = \underline{\$40.66/\text{SY}}\ (\$48.63/\text{m}^2)$$

E. Form Work for Jacketing Abutments and Encasing Piers

Assume:
Job built plyform wall forms to 8 ft (2.44 m) high, single use.

Cost, installed (incl. O&P) = \$6.25/SF (\$67.25/m^2) [Source: Ref. (8), pg. 59]

Cost/SY = (\$6.25) (9) = $\underline{\$56.25/\text{SY}}$ (\$67.25/m^2)

F. Polymer Mortar/Concrete

Material price quote (3/27/92) = \$133.30/cu ft unit (\$4.71/L)

Assume 10% markup for O&P and 10% waste

For shallow repair (< 1 in (2.4 cm), say 3/4 in (1.9 cm) avg.):

$$\text{Cost} = \left[\frac{(1.1)\ (\$133.30)/\text{CF}\ (0.75\ \text{in})\ (9\text{SF/SY})}{12\ \text{in/ft}}\right] \times (1.1) = \underline{\$90.73/\text{SY}}\ (\$108.51/\text{m}^2)$$

For deep repair (1-3 in (2.5 - 7.6 cm), say 2 in (5 cm) avg.):

$$\text{Cost} = \left[\frac{(1.1)\ (133.30)\ (2)\ (9)}{12}\right] \times (1.1) = \underline{\$241.94/\text{SY}}\ (\$289.36/\text{m}^2)$$

MOBILIZATION AND ENGINEERING COSTS

From ENR "Unit Prices" feature for highway and bridge construction bids during the period 1980 - 1987*, mobilization costs as a percentage of bid cost were tallied with the following results:

Mean (weighted by contract amount) = 5.00%
no. of observations = 164

*Note: ENR stopped producing this feature after 1987.

Per Means [Ref. (8), pg. 1], engineering costs range from 1% to 2.5% of project cost. Average = 1.75%

Therefore, the factor for including mobilization and engineering costs into the total cost is:

$$\frac{1}{\left[1-\left(\frac{5.00 + 1.75}{100}\right)\right]} = \underline{\underline{1.072}}$$

Appendix C

Detailed Calculations and Documentation for Cost Determinations Using Engineering Estimating Procedures for New Techniques Developed Under SHRP Contract C-103.

Cost Calculations - SHRP C-103

1. General

1.1 Definition of "typical" bridge for estimating purposes:

- three span: 100 ft. (30.5 m) center span; two 50 ft. (15.2 m) end spans.
- roadway width 44 ft (13.4 m)
- superstructure: P/S concrete I-beam
  -center span: five AASHTO type V I-beams
  -end spans: five AASHTO type II I-beams
- piers: 3 ft x 3 ft (0.9 x 0.9 m) square, 16.5 ft (5.0 m) high; two bents, three piers per bent

1.2 Interest rate used for discounting investments in capital equipment = 10%

1.3 Cost conversion factors (to mid-1991 national average values) use indexes from Table 3.4 (pp. 40-46) and 3.5 (p. 47), for geographic area and time, respectively.

1.4 Use cost estimating procedures and data presented in "Means Concrete Cost Data - 1992" (Ref. 8), except as noted.

1.5 Mobilization and engineering costs = 5.00% and 1.75%, respectively, of total cost. (See pp. 177-178).

1.6 Insurance on capital equipment = 1.64% of equipment first cost (Ref. 16).

1.7 Surety bonds - 0.5% of project cost (Ref. 16).

1.8 Traffic maintenance and protection costs = 2.3% of project cost (Ref. 16).

1.9 Contractor overhead and profit: 10% add-on to base costs for all labor, equipment (amortization and rental), and materials. (See Ref. 8).

1.10 Wage rates (including wage burden and contractor profit and overhead:

(a) Construction Superintendent

- basic (incl. burden) (1985): $6,563/mo (Ref. 16)
- escalation factor (to mid-1991): 1.172
- contractor overhead profit factor: 1.10 (Ref. 8)

Est. current rate:

$$\frac{(\$6{,}563/mo)(1.172)(1.1)}{172\ m\text{-}h/mo.} = \$49.19/m\text{-}h$$

(b) Foreman-outside: $39.60/m-h (Ref. 8)
(c) Common labor: $28.00/m-h (Ref. 8)
(d) Welder: $44.80/m-h (Ref. 8)
(e) Equip. Operator - Medium: $35.20/m-h (Ref. 8)
(f) Equip. Operator - light: $33.80/m-h (Ref. 8)
(g) Cement finisher: $33.60/m-h (Ref. 8)
(h) Carpenter: $35.55/m-h (Ref. 8)
(i) Truckdriver - heavy: $29.00/m-h (Ref. 8)

1.11 Materials Quotations

1.11.1 <u>Calcium Nitrite Inhibitor System</u>

1.11.1.1 <u>Spray and Impregnant</u>: "Postrite" (15% Calcium nitrite solution with chemical enhancers for promoting impregnation). <u>$30.00/gal</u> (per phone quotation from W. R. Grace, 8/3/92).

1.11.1.2 <u>Admixture</u>: "DCI" (30% calcium nitrite solution used as inhibiting admixture in concrete/mortar for patching and groove-filling or overlaying). <u>$6.00/gal</u> (per phone quotation from W. R. Grace, 8/3/92).

1.11.2 <u>Cortec Inhibitor System</u>

1.11.2.1 <u>Spray and Impregnant</u>: "MCI 2020"

In 5 Gal Containers		In 55 Gal Drums	
Qty	Cost, $/gal	Qty	Cost, $/gal
1	62.43	1-4	54.53
2-7	56.75	5-9	49.57
8-14	52.55	10-19	45.90
15-24	48.67	20+	42.50
25+	45.07		

(Per Cortec Corp. written quotation, 5/22/91)

1.11.2.2 Admixture: "MCI 2000"

In 5 Gal. Containers		In 55 Gal. Drums	
Qty	Cost, $/gal	Qty	Cost, $/gal
1	97.57	1-4	83.76
2-7	88.70	5-9	76.15
8-14	82.13	10-19	70.50
15-24	76.05	20+	65.28
25+	70.41		

(Per Cortec Corp. written quotation, 5/22/91).

1.11.3 Alox inhibitor System

1.11.3.1 Spray Impregnant (not used with deep grooving method). Consists of 4.7% by weight Alox in denatured ethanol.

- Alox: $0.82/lb. (Sp. Gr. = 0.934) (per memo from B. D. Prowell, 6/5/92)
- Denatured ethanol: $7.10/gal in 55 gal. drum lots (per phone quotation from Fisher Scientific, 7/22/92 to M. Conroy - PSU Dept. of Purchases). Est. Sp. Gr. = 0.789.

1.11.3.2 Admixtures: Not used.

1.11.4 Concrete Admixtures

1.11.4.1 Special: for overlay concrete containing DCI inhibitor, the following admixtures are used:

- High Range Water Reducer: "Daracem-100" $6.00/gal (per phone quotation from W. R. Grace, 8/13/92)
- Retarder: "Daratard-17" $5.00/gal (per phone quotation from W. R. Grace, 8/3/92)

1.11.4.2 Air-Entrainment $5.25/gal (per Ref. 8)

1.11.5 Resin Modified Asphaltic Concrete

1.11.5.1 Resin Additive (PL7): $3.50/lb (per memo from B. D. Prowell, 6/5/92)

1.11.5.2 Job Unit Costs from Alyan Corp.

Job	Pavement Depth (in.)	Area SY*	Unit Cost ($/SY)	Year*
Tampa Airport	2	10,000	14.50	1991
Miami Airport	2	10,000	10.95	1991
Tampcon Airport (Bahamas)	2.5	10,000	10.95	1988
Macord AFB (Seattle)	1.5	40,000	10.50	1992
Fort Campbell	2	10,000	10.90	1991
	2	10,000	14.00	1992
Means	2.0 in.		11.97/SY	

•Data per memo from B. D. Prowell, 6/3/92

*Per telecom w/Ibrahim Murr (Alyan Corp.) 8/6/92

2. Case Definitions

TABLE C-1. SCENARIOS - FACTORS AND LEVELS

Case	Location		Deep Impreg (Grooving)			Corr. Inhib. Spray-On Overlay			Drying		Resin Mod. B.C. System	Concrete Removal		Percent Deterioration			
	Deck	Subst/ Super	Polymer	Inhibitor		Cortec	Ca-Ni	Alox	No	Yes		I	II	0	5	10	20
				CaNi	Cortec												
1	X		X											X			
2(a)	X		X												X		
2(b)	X		X													X	
2(c)	X		X														X
3	X			X										X			
4	X				X									X			
5(a)	X			X											X		
5(b)	X			X												X	
5(c)	X			X													X
6(a)	X				X										X		
6(b)	X				X											X	
6(c)	X				X												X
7(a)	X					X			X					X			
7(b)	X					X			X						X		
7(c)	X					X			X							X	
7(d)	X					X			X								X
8(a)	X						X		X					X			
8(b)	X						X		X						X		
8(c)	X						X		X							X	
8(d)	X						X		X								X
9(a)	X							X	X					X			

TABLE C-1. SCENARIOS - FACTORS AND LEVELS

Case	Location		Deep Impreg (Grooving)			Corr. Inhib. Spray-On Overlay			Drying		Resin Mod. B.C. System	Concrete Removal		Percent Deterioration			
	Deck	Subst/ Super	Polymer	Inhibitor		Cortec	Ca-Ni	Alox	No	Yes		I	II	0	5	10	20
				CaNi	Cortec												
9(b)	X							X	X						X		
9(c)	X							X	X							X	
9(d)	X							X	X								X
10(a)	X					X				X				X			
10(b)	X					X				X					X		
10(c)	X					X				X						X	
10(d)	X					X				X							X
11(a)	X						X			X				X			
11(b)	X						X			X					X		
11(c)	X						X			X						X	
11(d)	X						X			X							X
12(a)	X							X		X				X			
12(b)	X							X		X					X		
12(c)	X							X		X						X	
12(d)	X							X		X							X
13	X										X						
14		X										X					
15		X											X				

3. Cost Estimates

3.1 Case 1: Deep polymer impregnation of concrete bridge decks using the grooving technique (sound decks)

3.1.1 Approach: Use information and cost data from earlier work (see Ref. 16) updated for consistency with revised scenario and cost estimating procedures used.

3.1.2 Amortization Costs for the Specialized Equipment Needed for Deep Impregnation: The unit cost of this procedure will vary significantly with the volume of work of this type performed by the contractor per year because of the need to amortize large capital investments for the specialized equipment needed to carry out this activity. Therefore, this analysis will examine three levels of contractor's annual average activity in this area; one, four, and ten "typical" (see item 1.1) bridge decks per year.

3.1.3 Labor Costs: Based on data and information compiled in Ref. 16, the labor crew requirements for the various phases of this technique are presented in Table 2.

Table C-2. Labor Crew Requirements for Deep Polymer Impregnation of a "Typical" Bridge Deck

Job Phase	Days	Shifts Per Day	Crew Make-Up		Comments
			Laborers	Foremen	
Preliminary/Set-up	2	1	11	1	1/2 of crew
Cut & Clean Grooves	3	2	7	1	Use 4 Machines
		1	7	*	
Install Weather Protection Install Thermocouples Assemble Heating Units	1.5	1	21	2	Carry out simultaneously
Drying	5	2	4	1	•Use 10' Advance •1/2 of Crew
		1	4	*	
Impregnation	1	1	11	1	
		1	10	1*	
Polymerization	1	2	7	1	3 heats
		1	7	*	
Groove Filling	1	1	21	2	
Curing; Clean up	2	1	11	1	1/2 of crew

Total Days 16.5

* The construction superintendent will act as a third foreman, as needed.

Man hours:

$$\text{Laborers} = 8[(2)(11)+(3)(2)(7)+(3)(7)+(15)(21)+(5)(2)(4)+(5)(4)+ 11+10+(2)(7)+7+21+(2)(11)] = \underline{2{,}092\text{ m-h}}$$

$$\text{Foremen} = 8[2+(3)(2)+(1.5)(2)+(5)(2)+1+1+2+2+2] = \underline{232\text{ m-h}}$$

$$\text{Constr. Supt.} = (16.5\text{ days})(8\text{ hrs/day}) = \underline{132\text{ m-h}}$$

$$\text{Total est. labor cost} = (2{,}092)(28.00)+(232)(39.60)+(132)(49.19) = \underline{\underline{\$74{,}256}}$$

Unit Labor Cost =

$$\frac{\$74{,}256}{(200)(44)sf}$$

= $\underline{\underline{\$8.44/\text{sf}}}$ = $\underline{\underline{\$75.94/\text{SY}}}$ = $\underline{\underline{\$90.83/\text{m}^2}}$

3.1.4 Equipment, Materials, & Services Costs

3.1.4.1 Grooving

- Use standard self-propelled 30 hp concrete saw, groove cutting rate = 120 lineal ft. per hr. (= 30 sf/hr). Use 4 machines at a time (Ref 16).
- Machine first cost (each) = \$9,260 (1985) est. current cost = (\$9,260)(1.172) = \$10,853 ea.
- 10 year amortization @ 10% discount rate.
- Contractors Overhead & profit = 10%
- Annual cost = (4)(1.1)(10,853)(0.16275/NP,10%,10) = \$7,772/yr
- Insurance = (0.064)(4)(10,853) = \$712/yr
- Total Annual Cost = 7,772 + 712 = <u>\$8,484/yr</u>

- <u>Alternatively</u>, rent machines (Ref. 8, pg. 11) (Note: includes contr. O & P) Rental = \$97/day, or \$290/wk (each)
- Time requirements for rental:

$$\frac{(200\ X\ 44)sf}{(30\ sf/hr/machine)(4\ machines)} = 73.3\ hr.$$

3 shifts (24 hour)/day use (see Table 2)

$$\therefore\ \frac{73.3\ hr}{24\ hr/day} = 3.05\ days\ use$$

weekly rate for 1 week, i.e. \$290/machine
\$290 x 4 = <u>\$1,160</u>

- Breakeven between purchase and rental:

$$\frac{\$8{,}484/yr}{\$1{,}160/bridge} = 7.3\ bridges/year$$

(i.e. for cases of 7 or fewer bridges per year, rent saws. For 8 or more bridges per year, buy.)

- Saw Blades: Heavy duty 14 in. diamond set; two diamond blades sandwiching on abrasive cut-off blade (see Ref 16).

  -1985 cost = (2)(448) + 20 = \$916/blade set

  -Mid-1991 estimated cost = (1.1)(916)(1.172) = \$1,181/saw

  -Blade life estimate: 5280 sq of deck (see Ref. 16). ∴ use on equivalent of (200)(44)/5,280 = 1.67 blade sets per bridge, or an average cost for blades of (1,181)(1.67) = \$1,972/bridge

- Saw Operating Costs (incl. contr. O&P) (see Ref. 8, p. 11) = \$5.00/hr = (5.00)(73.3) = \$367/bridge

- Water and tanker truck rental: \$100/shift (1985)
  ∴ (\$100/shift)(3 shifts/day)(3 days)(1.172)(1.1) = \$1,160/bridge

- Flushing & Cleaning Grooves: \$500 for 120 t. bridge deck in 1985 (Ref. 16).
  ∴ for mid-1991:
  (1.1)(500)(200/120)(1.172) = \$1,074 for 200 ft. bridge deck in 1991

- Summary: Equipment Costs (incl. Operating) for Grooving

  -Rental (7 or fewer bridges/yr) 1,160+1,074+1,160+1,1972+367 = \$,733/bridge = 5,733/(200)(44) = \$0.65/sf = \$5.85/SY = \$7.01/m^2

  -Purchase (8 or more bridges/yr) for 10 bridges/yr, amortization + insurance = \$8,484/10 = \$848/bridge
  ∴Cost = 1,160+1,074+848+1,972+367 = \$5,421/bridge = 5,421/8800 = \$0.62/sf = 5.54/SY = 6.63/m^2

3.1.4.2 Drying

- Propane-fired IR drying equipment capable of treating the full deck width for a longitudinal distance of 10 ft. at a time was estimated to cost $40,000 in 1985. This equipment is not available or rental, and is assumed to have a 10 year life. (See Ref 16).

- Mid-1991 estimated cost = (1.172)(40,000) = $46,880

- Capitol Recovery (incl. Contractors O&P) = (1.1)(46,880)(A/P, 10%, 10) = $8,393/yr.

- Insurance = (46,880)(0.0164) = $769/yr

No. Bridges Treated Per Year	C.R. & Insurance Cost, $	
	Per Bridge	Per SY
1	9,162	9.37
4	2,291	2.34
10	916	0.94

- Fuel (Propane) Consumption @ 90% thermal efficiency = 0.54 gal/sf (Ref. 16).

- Propane Cost (incl. delivery and load of 1,000 gal tanks) = $0.87/gal (1985)
  Est. mid-1991 cost = (1.172)(0.87) = $1.02/gal
  ∴Fuel cost (incl. contractor O&P) = (1.1)($1.02/gal)(0.54 gal/sf) = 0.61/sf = 5.45/sy = 6.52/m^2

- Summary - Drying Equipment & Material Costs

No. Bridges Treated Per Year	Cost, $/SY			Cost, $/m^2
	CR & Ins	Fuel	Total	
1	9.37	5.45	14.82	17.72
4	2.34	5.45	7.79	9.32
10	0.94	5.45	6.39	7.64

3.1.4.3 Weather Protection

- Per Ref. 16, the estimated cost for a tent covering a 44 ft wide x 120 ft long (with 10 ft overhand on each end for a total length of 140 ft) = $30,000 (1985). Therefore, for a 200 ft. long deck (220 ft. long tent), the mid-1991 cost is estimated at: (220/140)(1.172)(30,000) = $55,251, say $56,000

- As per Ref 16, assume that 50% of the cost is for frame, hardware, tracks, etc. (life = 10 yr) and 50% is for the cover material (life = 3 yr)

- Capital Recovery (incl. Contractors O&P) = (1.1)(56,000)(0.5)[(A/P, 10%, 3) + (A/P, 10%, 10)] = $17,398/yr

- Insurance = (56,000)(0.0164) = $918/yr

- Summary: Weather Protection Equipment Costs

No. of Bridges Treated Per Year	C.R & Insurance, $		Per m^2
	Per Bridge	Per SY	
1	18,316	18.73	22.40
4	4,579	4.68	5.60
10	1,832	1.87	2.24

3.1.4.4 Impregnation

- Material (Monomer) Costs: Per Ref. 16, 1985 cost for MMA:

TMPTMA:AZO mixture at 100:10:0.5 = \$0.89/lb.

- At an impregnation rate of 1.9 lb/sf, mid-1991 estimated cost (incl. contractor O&P) is:
  (1.1)(\$0.89/lb)(1.172)(1.9 lb/sf)(9 sf/sy) = \$19.62/sy
  (\$23.47/m^2)

- Equipment: Per Ref. 16, 1985 costs for treating 120 ft. long deck = \$4,000 for capitol equipment items (5-year life) and \$2,000/bridge for expendable supplies. Estimated mid-1991 costs are: Cap. Rec. + Ins. (incl. contr. O&P)
  = (200/120)(4,000)(1.172)[(0.0164)+(1.1)(A/P, 10%, 5)] =
  \$2,395/yr

  Expendable supplies (incl. Contr. O&P) =
  (1.1)(200/120)(2,000)(1.172) = \$4,279/bridge

- Tarpaulin: Per Ref. 16, 1985 cost = \$0.50/sf (life = 3 yr). Therefore, estimated mid-1991 cost for 8800 sf "typical" bridge deck = (0.50)(1.172)(8800) = \$5,157

  Capital Recovery & Insurance (incl. Contractor's O&P) =
  (5,157)[(0.0164)+(1.1)(A/P, 10%, 3)] = \$2,366/yr

- <u>Summary - Equipment and Materials for Impregnation</u>

No. Bridges Treated Per Year	Monomer (\$/SY)	C.R. & Insur.		Expendable Supplies		Total \$/sy	Total \$/m^2
		\$/YR	\$/SY	\$/Bridge	\$/SY		
1	19.62	4,761	4.87	4,279	4.38	28.87	39.53
4	19.62	4,761	1.22	4,279	4.38	25.22	30.16
10	19.62	4,761	0.49	4,279	4.38	24.49	29.29

3.1.4.5 Polymerization

- Per Ref. 16, 1985 est. Cost for electric blankets for polymerization step = \$18.00/sf (life = 10 yr)

- Capital Recovery + Interest for mid-1991 (incl. Contractor's

O&P) = (18.00)(1.172)[10.0164+(1.1)(A/P, 10%, 10)] = $4.12/sf/yr

- Using 3 heats (i.e. heating one-third of the deck area at a time) the annual cost becomes: $4.12/3 = $1.37/sf/yr = $12.36/sy/yr

- Power Requirements (see Ref 16): 3 heats = 8800/3 = 2,933 sf/heat Power requirements @ 100 watts/sf and 90% efficiency

$$= \frac{(2{,}933)(100)}{(0.9)(1{,}000)} = 326 \; kw$$

- Generator Rental (see Ref. 8, p. 14)

2 days/bridge (incl. pick up and delivery) Operating time = 6 hr/heat (Ref. 16).

Gen. Size	Qty	Rental for 2d	Operating Time	Operating Cost		Total Cost $	
				Unit	Total	Per Br.	Per SY
100 kw	1	$300	18 H	$11.13/H	$200	500	0.51
250 kw	1	$520	18 H	$26.50/H	$477	997	1.02
TOTALS 350 kw		$820			$677	$1,497	$1.53/SY

(NOTE: Costs include Contractor's O&P)

- Insulation: R-19 unbacked glass wool (single use). 1985 est. cost $0.27/sf (Ref. 16). Therefore, mid-1991 est. cost (incl. contractor's O&P) = (1.1)($0.27/sf)(1.172)(8800 sf/3 heats) = $1,021/bridge = $1,021/8800 x 9 sf/sy = $1.04/sy of deck

- <u>Summary Equipment and Materials for Polymerization</u>

No. Bridges Treated Per Year	Elec. Blankets C.R. & Ins. ($/SY)	Power ($/SY)	Insulation ($/SY)	Total ($/SY)	Total ($/m^2)
1	12.36	1.53	1.04	14.93	17.86
4	3.09	1.53	1.04	5.66	6.77
10	1.24	1.53	1.04	3.81	4.56

3.1.4.6 Groove Filling

- Latex Modified Mortar: For 0.75 in x 1.5 in grooves on 3-in centers, need 6.11 cy per 5280 sf deck surface (see Ref. 16).

  Therefore, for 8800 sf deck surface and 10% waste:

  $$\frac{(6.11\ cy)\left(\frac{8800}{5280}\right)}{0.9} = 11.3\ cy$$

  Cost of 7cy latex modified mortar in 1985 = $1,336 (see Ref. 16). Therefore, est. cost of 11.3 cy of LMM in mid-1991 (incl. contractor's O&P) =

  (1.1)(1.172)(1,336)(11.3/7) = $2.780/bridge = $2.84/sy

- <u>Curing Materials</u>
  Bur-lene: $0.12/sf (1985). Therefore, est. current price (incl. Contractor's O&P) = (1.1)(0.12)(1.172) = $.15/sf = $1.39/sy

- <u>Mixer Rental</u> (see Ref. 8, p. 11)

16 cf portable mixer, 1d @ $77 =	$77
<u>Oper. Cost 8 h @ $1.40 =</u>	<u>$11</u>
Total (incl. Contr. O&P) =	$88/bridge
=	$0.09/sy

- <u>Summary - Equipment and Materials for Groove Filling</u>

  = 2.84 + 1.39 + 0.09 = $4.32/sy (5.17/m^2)

3.1.4.7 Process Control and Monitoring

- Equipment

  --Multipoint thermocouple recorder - \$2000 (Ref. 16, 1985 cost); 10-yr life. Capital recovery & Insur. @ est. mid-1991 prices (incl. contractor's O&P) = (2000)(1.172)[(0.0164)+(1.1)(A/P, 10%, 10)] = \$458/yr

  --Six Pad-Type Surface Thermocouples - \$56 each (Ref. 16, 1985 cost); 2 yr life. Capital Recovery & Insur. @ est. mid-1991 prices (incl. contractor's O&P) = (6)(56)(1.172)[(0.0164)+(1.1)(A/P, 10%, 2)] = \$256/yr

  Total - capital equipment

No. Bridges Per Year	Capital Recovery & Insurance		
	\$/yr	\$/Bridge	\$/sy
1	714	714	0.73
4	714	179	0.18
10	714	71	0.07

- Materials

  Thermocouple wire (non-reusable), Est. cost for 5280 sf deck surface in 1985 (see Ref. 16) = \$768. Therefore, mid-1991 est. cost (incl. contractor's O&P) =

$$\frac{(1.1)(1.172)(768)}{(5280)} = \$0.19/sf = \$1.69/sy$$

- Summary - Equipment and Materials for Process Control and Monitoring

No. Bridges Treated Per Year	Cap. Rec. & Insurance (\$/sy)	Expend. Mat'l (T/C wire) (\$/sy)	Total (\$/SY)	Total (\$/m^2
1	0.73	1.69	2.42	2.89
4	0.18	1.69	1.87	2.24
10	0.07	1.69	1.76	2.10

3.1.4.8Fire Protection

Est. 1985 cost (see Ref 16) = \$2,400/bridge (based on 120 ft bridge). Therefore, est. mid-1991 cost for 200 ft. bridge (incl. contractor's O&P) =

$$(1.1)\left(\frac{200}{120}\right)(1.172)(2{,}400)=\$5{,}157/bridge$$

$$=\frac{(\$5{,}157)(9sf/sy)}{(8800sf)}=\$4.27/sy(\$6.30/m^2)$$

3.1.4.9Lighting and Electric Power Generation (except for polymerization electric heating blankets): Per Ref. 16, two lighting units consisting of four 1000 W lamps on a tilting boom and attendant generator for 120 ft. deck, 1985 est. cost (incl. generator operating cost) = \$2,858 (rental).

$$=\frac{(2858)(9)}{(120)(44)}=\$4.87/SY$$

Therefore, est. mid-1991 rental cost (incl. contractor's O&P) = (1.1)(4.87)(1.172) = \$6.28/sy = (\$7.51/m^2)

3.1.5 Costs of Traffic Maintenance & Protection (TMP) Mobilization, Engineering, and Surety Bonds

Item	% of Project Cost
Traffic Maintenance & Protection (Ref. 16)	2.30
Mobilization	5.00
Engineering	1.75
Surety Bonds (Ref. 16)	0.50
Total	9.55

Est. \$ amt of total = Project subtotal x [9.55/(100-9.55)]

3.1.6 Total Cost - Deep Polymer Impregnation

Item	Estimated Cost $/sy		
	1 Br/yr	4 Br/yr	10 Br/yr
Labor	75.94	75.94	75.94
Equip. & Mat'l: Grooving	5.86	5.86	5.54
Equip. & Mat'l: Drying	14.82	7.79	6.39
Equip. & Mat'l: Weather Prot.	18.73	4.68	1.87
Equip. & Mat'l: Impregnation	28.87	25.22	24.49
Equip. & Mat'l: Polymerization	14.93	5.66	3.81
Equip. & Mat'l: Groove Filling	4.32	4.32	4.32
Equip. & Mat'l: Proc. Cont. & Mon.	2.42	1.87	1.76
Fire Protection Services	5.27	5.27	5.27
Lighting & Power	6.28	6.28	6.28
Subtotal	177.44	142.89	135.67
TMP, Mobiliz., Engr., Bonds	18.74	15.09	14.33
Est. Total Cost, $/sy	196.18	157.98	150.00
($/m^2)	234.63	188.94	179.40

3.2 Case 2: Deep Polymer Impregnation of concrete bridge decks using the grooving technique (Deteriorated decks)

3.2.1 Approach: Damaged areas repaired by removal of deteriorated concrete and patching with portland cement concrete. Deep polymer impregnation then carried out as per Case 1. Therefore, cost equals cost of deep polymer impregnation plus cost of repairing the deteriorated areas. Three sub-cases, involving deterioration levels of 5%, 10%, and 20% of the deck area, will be investigated.

3.2.2 Repair Costs: The basis for the repair cost will be Treatment Item 111, "Topical Deck Treatments, P.C.C. Patch Repairs -- Partial Depth" carried out earlier under Task 1C of SHRP Contract C-103. The best regression equation ($R^2 = 0.607$) found uses the factor (quantity * number of bidders) as the independent variable (see Table 4-1). However, since the number of bidders is unknown, the second best regression equation ($R^2 = 0.447$), in which the independent variable is quantity alone, will be used. Actually, both equations give almost exactly the same results (within ± 2%) for four bidders.

The regression equation is: $y = 134.4 + 0.00460X + 316{,}200/X^{3.345}$

Where: y = cost for partial-depth patch repair of concrete bridge decks using portland cement concrete, $/sy

X = repair quantity, sy

Deterioration Level (%)	X = Repair Area per Deck (sy)	Y = Repair Cost per Unit Area of Patches ($/sy)	Repair Cost Per Unit Area of Deck ($/sy)	Incl. TM&P, Mobiliz., Engr. & Bonds (Factor = 1.1056) $/sy
5%	48.9	135.33	6.76	7.47
10%	97.8	134.92	13.49	14.91
20%	195.6	135.31	27.07	29.93

3.2.3 Estimated Total Costs

Case	Deterioration Level	Bridge Decks Treated Per Year	Repair Cost per Unit Area of Deck ($/sy)	Deep Polymer Impregnation Cost ($/sy)	Total Cost ($/sy)	Total Cost ($/m^2)
2(a)	5%	1	7.47	196.18	203.65	243.56
		4	7.47	157.98	165.45	197.88
		10	7.47	150.00	157.47	188.33
2(b)	10%	1	14.91	196.18	211.09	252.46
		4	14.91	157.98	172.89	206.77
		10	14.91	150.00	164.91	197.23
2(c)	20%	1	29.93	196.18	226.11	270.42
		4	29.93	157.98	187.91	224.74
		10	29.93	150.00	179.93	215.19

3.3 Case 3: Deep Inhibitor Impregnation Using Grooving Method (Calcium Nitrite Inhibitor) -- Sound Concrete Deck.

3.3.1 Inhibitor: "Postrite" (15% solution of calcium nitrite in water used as the impregnant). Groove back filling mortar to contain DCI (30% calcium nitrite solution) at the rate of 6 gal/cy.

3.3.2 Cost Components

- Cost for deep polymer impregnation using the grooving technique (see Case 1):

Bridge Decks Treated per year	Polymer Impregnation ($/sy)
1	196.18
4	157.98
10	150.00

- Less cost of MMA impregnant (see 3.1.4.4) = (-$19.62/sy)

- Plus cost of 15% Calcium Nitrite inhibitor impregnant ("Postrite") Sp.Gr. MMA/TMPTMA/AZO System =

$$\frac{(0.938)(100)+(1.058)(10)}{110}(approx) = 0.949$$

$$\therefore @1.9\ lb/sf:\ \frac{(1.9\ lb/sf)(7.48\ gal/cf)}{(62.4\ lb/cf)(0.949)} = 0.24\ gal/sf$$

check (should approx. = groove vol.):

$$\frac{(4\ ft/sf)(0.75\ in)(1.5\ in)(7.48\ gal/cf)}{144\ in^2/sf} = 0.23\ gal/sf$$

Impregnant cost = $30.00/gal (see 1.11.1.1) Unit Cost = ($30.00/gal)(0.24 gal/sf)(9 sf/sy) = $64.80/sy

- Less Cost of Polymerization Step

labor: $\{[(2)(7)+(1)(7)](28.00)(8)+(2)(1)(39.60)(8)+(1)(8)(49.19)\} \div 977.8$sy (see 3.1.3) = (-$5.86/sy)

Equipment & Materials:

No. Bridges Per Year	Cost Polymerization
1	-\$20.79/sy
4	-\$11.52/sy
10	-\$ 9.67/sy

- Plus sandblasting grooves before backfilling:

  Light sandblasting concrete surfaces -- total unit cost (incl. contractor's O&P) (Ref. 8) = \$0.92/sf

  Area of grooves/unit area of deck =

$$(4\ ft/sf)\left[\frac{0.75\ in + (2)(1.5\ in)}{12\ in/ft}\right] = 1.25\ sf\ groove\ area\ /sf\ deck\ area$$

$$\therefore\ Unit\ Cost = (1.25)(0.92)(9\ sf/sy) = \$10.35/sy$$

- Plus DCI inhibitor in latex-modified mortar for backfilling grooves

  6 gal DCI/cy @ \$6.00/gal (see 1.11.1.2) = \$36.00/cy
  Unit cost (incl. contr. O&P) =

$$\frac{(1.1)(11.3\ cy)(\$36.00/cy)}{977.8\ sy} = \$0.46/sy$$

- Less fire protection costs

  (see 3.1.6) = (\$5.27/sy)

3.3.3 Total Cost Determination for Case 3

Bridges Per yr.	Deep Polymer Impreg. ($/sy)	Changes ($/SY)								TOTAL COST	
		Impregnant		Polymer-ization	Sand-Blast Grooves	Fire Protec-tion	DCI for LMM	Sub. Tot. for Changes	Δ(TM&P, Mob., Eng., Bonds)*	($/SY)	($/m^2)
		MMA	Postrite								
1	196.18	(-19.62)	64.80	(-20.79)	10.35	(-5.27)	0.46	29.93	3.16	229.27	274.20
4	157.98	(-19.62)	64.80	(-11.52)	10.35	(-5.27)	0.46	39.20	4.14	201.32	240.78
10	150.00	(-19.62)	64.80	(- 9.67)	10.35	(-5.27)	0.46	41.05	4.33	195.38	233.67

$$* \ \mathit{FACTOR} = \frac{9.55}{100 - 9.55} = 0.10558$$

3.4 Case 4: Deep Inhibitor Impregnation Using Grooving Method (Cortec Inhibitor -- Sound Concrete Deck.

3.4.1 Cost Components

- Cost for deep polymer impregnation using the grooving technique (see Case 1):

Bridge Decks Treated Per Year	Polymer Impregnation ($/SY)
1	196.18
4	157.98
10	150.00

- Less cost of MMA impregnant (see 3.1.4.4) = (-$19.62/sy)

- Plus cost of Cortec 2020 inhibitor impregnant:

  @ 0.24 gal/sf, qty/bridge = (8800)(0.24) = 2,112 gal/bridge = 2,112/55 = 39 drums

  Per quotation from Cortec (see 1.11.2.1), cost/55 gal drum in lots of 20 or more drums = $42.50/gal. Therefore, mid-1991 est cost (incl. contractor's O&P) = (1.1)(42.50)(0.24)(9 sf/sy) = $100.98/sy

- Less cost of polymerization step (see Case 3)

Bridge Decks Treated Per Year	Cost of Polymerization
1	(-$20.79/sy)
4	(-$11.52/sy)
10	(-$ 9.67/sy)

- Plus Sandblasting grooves before backfilling (see Case 3) = $10.3[illegible]y

- Plus Cortec 2000 inhibitor in Latex-modified mortar for backfilling grooves

  Dosage: 2 pints/cy

$$\frac{(11.3\ cy/bridge)(2\ pts/cy)}{(8\ pts/gal)} = 2.825\ gal/bridge$$

Per quotation from Cortec (see 1.11.2.2) $97.57/gal
Therefore, est. mid-1991 cost (incl. contractor's O&P) =

$$\frac{(1.1)(97.57)(2.825)}{977.8\ sy} = \$0.31/sy$$

- Less Fire Protection Costs - (see Sect. 3.1.6) = (-$5.27/sy)

3.4.2 TOTAL COST DETERMINATION FOR CASE 4.

Bridges Per yr.	Deep Polymer Impreg. ($/sy)	Changes ($/SY)								TOTAL COST	
		Impregnant		Polymer-ization	Sand-Blast Grooves	Fire Protec-tion	Cortec 2000 for LMM	Sub. Tot. for Changes	Δ(TM&P, Mob., Eng., Bonds)*	($/SY)	($/m²)
		MMA	Cortec 2020								
1	196.18	(-19.62)	64.80	(-20.79)	10.35	(-5.27)	0.31	65.96	6.96	269.10	321.84
4	157.98	(-19.62)	64.80	(-11.52)	10.35	(-5.27)	0.31	75.23	7.94	241.15	288.41
10	150.00	(-19.62)	64.80	(- 9.67)	10.35	(-5.27)	0.31	77.08	8.14	235.22	281.32

$$* \ FACTOR = \frac{9.55}{100 - 9.55} = 0.10558$$

3.5 Case 5: Deep impregnation w/calcium nitrite inhibitor - grooving technique (deteriorated decks). [NOTE: same as Case 2, except use calcium nitrite instead of MMA as impregnant, i.e. combination of Case 2 and 3.]

3.5.1 Cost Components

- PIC Cost per Case 2

Sub-case	Deterioration Level	Bridge Decks Per Year	Cost ($/SY)
2 (a)	5%	1 4 10	203.65 165.45 157.47
2 (b)	10%	1 4 10	211.09 172.89 164.91
2 (c)	20%	1 4 10	226.11 187.91 179.93

- Less cost of MMA impregnant (see 3.1.4.4): = (-$19.62/sy)

- Plus cost of 15% calcium nitrite inhibitor impregnant (see Case 3): = $64.80/sy

- Plus cost of DCI inhibitor in patch concrete

DCI dosage = 6 gal/cy. Assume avg. 3 in. repair depth unit cost (see Case 3) = $36.00/cy. Therefore, est DCI cost (+10% waste and contractor's O&P):
5% Deterioration Level:

$$(1.1)(1.1)\left(\frac{3\ in}{36\ in/yd}\right)(0.05)(36.00) = \$0.18/sy$$

10% Deterioration Level:

$$(2)(\$0.18) = \$0.36/SY$$

20% Deterioration Level:

$$(4)(\$0.18) = \$0.72/SY$$

- Less Cost of Polymerization Step (see Case 3)

Bridge Decks Treated Per Year	Cost of Polymerization
1	(-$20.79/sy)
4	(-$11.52/sy)
10	(-$ 9.67/sy)

- Plus cost of sandblasting grooves before backfilling (see Case 3): = $10.35/sy

- Plus cost of DCI in latex-modified mortar for backfilling grooves (see Case 3). = $0.46/sy

- Less Fire Protection - (see Section 3.1.6) = (-$5.27/sy)

3.52 Total Cost Determination for Case 5

Sub-Case	Deterior-ation Level	Bridge Decks Per Year	PIC (per Case 2) ($/SY)	CHANGES, ($/SY)								Δ(TM&P, MOB, ENGR, BONDS)* ($/SY)	TOTAL COST	
				Impregnant		DCI in Patch Concrete	Polymer-ization Step	Sand-Blast Grooves	Fire Protec-tion	DCI in LMM	Sub-Tot. Changes		($/CY)	($/M^2)
				MMA	Cal. Nitr.									
5(a)	5%	1	203.65	(-19.62)	64.80	0.18	(-20.79)	10.35	(-5.27)	0.46	30.11	3.18	236.94	283.38
		4	165.45	(-19.62)	64.80	0.18	(-11.52)	10.35	(-5.27)	0.46	39.38	4.16	208.99	249.95
		10	157.47	(-19.62)	64.80	0.18	(- 9.67)	10.35	(-5.27)	0.46	41.23	4.35	203.05	242.84
5(b)	10%	1	211.09	(-19.62)	64.80	0.36	(-20.79)	10.35	(-5.27)	0.46	30.29	3.20	244.58	292.51
		4	172.89	(-19.62)	64.80	0.36	(-11.52)	10.35	(-5.27)	0.46	39.56	4.18	216.63	259.09
		10	164.91	(-19.62)	64.80	0.36	(- 9.67)	10.35	(-5.27)	0.46	41.41	4.37	210.69	251.98
5(c)	20%	1	226.11	(-19.62)	64.80	0.72	(-20.79)	10.35	(-5.27)	0.46	30.65	3.24	260.00	310.96
		4	187.91	(-19.62)	64.80	0.72	(-11.52)	10.35	(-5.27)	0.46	39.92	4.21	232.04	277.52
		10	179.93	(-19.62)	64.80	0.72	(- 9.67)	10.35	(-5.27)	0.46	41.77	4.41	226.11	270.42

$$* \ FACTOR = \frac{9.55}{100 - 9.55} = 0.10558$$

3.6 Case 6: Deep impregnation w/Cortec 2020 inhibitor - grooving technique (deteriorated decks). [NOTE: Same as Case 2, except use Cortec MCI 2020 instead of MMA as impregnant, i.e. combination of Cases 2 and 4.]

3.6.1 Cost Components

- PIC Cost Per Case 2

Sub-Case	Deterioration Level	Bridge Decks Per Year	Cost ($/SY)
2 (a)	5%	1 4 10	203.65 165.45 157.47
2 (b)	10%	1 4 10	211.09 172.89 164.91
2 (c)	20%	1 4 10	226.11 187.91 179.93

- Less Cost of MMA impregnant (see 3.1.4.4) = (-$19.62/sy)

- Plus cost of Cortec 2020 inhibitor impregnant (see Case 4): = $100.98/SY

- Plus cost of Cortec 2000 inhibitor in patch concrete - Dosage = 2 pints/cy; cost = $65.28/gal (see 1.11.2.2) = (2 pts/cy/8 pts/gal)($65.28/gal) = $16.32/cy

  Therefore, est. Cortec 2000 cost (incl. 10% waste and contractor's O&P):

  5% Deterioration Level:

  (1.1)(1.1)(3 in/36 in/yd)(0.05)(16.32) = $0.08/sy

  10% Deterioration Level:

  (2)(0.08) = $0.16/sy

20% Deterioration Level:

(4)(0.08) = $0.32/sy

- Less Cost of Polymerization Step (See Case 3)

Bridge Decks Treated Per Year	Cost of Polymerization
1	(-$20.79/sy)
4	(-$11.52/sy)
10	(-$ 9.67/sy)

- Plus cost of sandlasting grooves before backfilling (See Case 3) = $10.35/sy

- Plus cost of Cortec 2000 in latex-modified mortar for backfilling grooves (See Case 4) = $0.31/sy

- Less fire Protection (See Section 3.1.6) = (-$5.27/sy)

3.6.2 Total Cost Determination for Case 6

Sub-Case	Deterior-ation Level	Bridge Decks Per Year	PIC (per Case 2) ($/SY)	CHANGES, ($/SY)								Δ(TM&P, MOB, ENGR, BONDS)* ($/SY)	TOTAL COST	
				Impregnant		Cortec 2000 in Patch Concrete	Polymer-ization Step	Sand-Blast Grooves	Fire Protec-tion	Cortec 2000 in LMM	Sub-Tot. Changes		($/CY)	($/M²)
				MMA	Cortec 2020									
6(a)	5%	1	203.65	(-19.62)	100.98	0.08	(-20.79)	10.35	(-5.27)	0.31	66.04	6.97	276.66	330.88
		4	165.45	(-19.62)	100.98	0.08	(-11.52)	10.35	(-5.27)	0.31	75.31	7.95	248.71	297.45
		10	157.47	(-19.62)	100.98	0.08	(- 9.67)	10.35	(-5.27)	0.31	77.16	8.15	242.78	290.36
6(b)	10%	1	211.09	(-19.62)	100.98	0.16	(-20.79)	10.35	(-5.27)	0.31	66.12	6.98	284.19	339.89
		4	172.89	(-19.62)	100.98	0.16	(-11.52)	10.35	(-5.27)	0.31	75.39	7.96	256.24	306.46
		10	164.91	(-19.62)	100.98	0.16	(- 9.67)	10.35	(-5.27)	0.31	77.24	8.15	250.30	299.36
6(c)	20%	1	226.11	(-19.62)	100.98	0.32	(-20.79)	10.35	(-5.27)	0.31	66.28	7.00	299.39	358.07
		4	187.91	(-19.62)	100.98	0.32	(-11.52)	10.35	(-5.27)	0.31	75.55	7.98	271.44	324.64
		10	179.93	(-19.62)	100.98	0.32	(- 9.67)	10.35	(-5.27)	0.31	77.40	8.17	265.50	317.53

$$* \ FACTOR = \frac{9.55}{100 - 9.55} = 0.10558$$

3.7 Corrosion Inhibitor Spray-On Overlay System: Cases 7 through 12 - General

3.7.1 See Table C-3 for details of subcases

3.7.2 Concrete Removal Procedures

3.7.2.1 General

- Milling is the lowest cost method for removal of deck concrete above the level of the top rebar mat (Ref. 4).

- In cases where no drying is used (cases 7 through 12), hydrodemolition cannot be employed (would necessitate subsequent drying). Therefore, it is necessary to investigate hydrodemolition plus drying (i.e. obviates cases 7-9) versus uses of pneumatic breakers to remove deteriorated concrete (for cases 7-9).

- Since the economics of methods for removing deteriorated concrete may be a function of the quantity of deteriorated concrete four levels of deterioration will be examined: 0%, 5%, 10%, and 20% of the deck area.

- Assume the max. size of aggregate in patching concrete is 3/8 in. ("pea gravel").

- Assumed "typical" bridge deck section as follows:

Table C-3. Corrosion Inhibitor Spray-On Overlay System -- Activities by Case

ACTIVITY	7				8				9				10				11				12			
	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
Weather Prot	X	X	X	X	X	X	X	X	X	X	X	X												
Scarification to Rebars	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Remove Deteriorated Concrete		X	X	X		X	X	X		X	X	X		X	X	X		X	X	X		X	X	X
Rem. Particulate Fines	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Sandblast Rebars*		X	X	X		X	X	X		X	X	X		X	X	X		X	X	X		X	X	X
Patch Deterior. Areas		X	X	X		X	X	X		X	X	X		X	X	X		X	X	X		X	X	X
Weather Protection Install Thermocouples Assemble Heating Units													X	X	X	X	X	X	X	X	X	X	X	X
Dry Concrete w/IR Heat													X	X	X	X	X	X	X	X	X	X	X	X
Spray-on Inhibitor	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Lightly Sandblast Surf.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Rem. Particulate Fines	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Apply Bonding Grout	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Overlay w/inh.-mod. Concrete	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

7 = Cortec Inhibitor, no drying
8 = Postrite Inhibitor, no drying
9 = Alox Inhibitor, no drying
10= Cortec Inhibitor, dried
11= Postrite Inhibitor, dried
12= Alox inhibitor, dried
    A = 0% deteriorated
    B = 5% deteriorated
    C = 10% deteriorated
    D = 20% deteriorated

*not needed for hydrodemolition

3.7.2.2Milling

- Use cost prediction equation from Ref. 1. (See Treatment Item #251, "Scarification of Concrete Deck Surface - Milling or Unspecified Method")

  -Regression equation (See equation (4-1), pg. 90 and Table 4-11, pg. 102):
  Cost (\$/sy) = $6.952 + 2.38 \times 10^{-5}Q + 68{,}770/Q^{1.8294}$
  where: Q = work quantity in sy (Note: n = 1,808; $R^2 = 0.921$) for 8,800 sf = 977.8 sy,
  Cost = $6.952 + (2.38 \times 10^{-5})(977.8) + 68{,}770/(977.8)^{1.8294}$ = 7.12/sy (incl. removal of fines)

  With traffic maint, & protection (TMP), mobilization, engineering, and surety bonds (see section 3.1.5), Est. Cost = (\$7.21/sy)(1.1056) = \$7.97/sy

3.7.2.3Removal of Deteriorated Concrete Using Pneumatic Breakers and Patching with Portland Cement Concrete Containing Inhibitors

- Use Treatment Item #111 (See section 3.2.2 for details.)

Costs for Removal of Deteriorated Concrete Using Pneumatic Breakers and Patching With Portland Cement Concrete Containing Inhibitors

Deterior-ation Level (%)	Repair Area per Deck (sy)	Repair Cost/Unit Area of Patches ($/sy)*	Inhibitor Cost (See Sect. 3.5.1 & 3.6.1) ($/sy)**			Subtotal ($/sy)			x 1.1056 = Total Cost Incl. TMP, Mobiliz., Engr., & Bonds ($/sy)			Total Cost Per Unit Area of Bridge Deck ($/sy)		
			DCI	Cortec 2000	Alox	DCI	Cortec 2000	Alox	DCI	Cortec 2000	Alox	DCI	Cortec 2000	Alox
5%	48.9	135.33	0.18	0.08	0.00	135.51	135.41	135.33	149.82	149.71	149.62	7.49	7.49	7.48
10%	97.8	134.92	0.36	0.16	0.00	135.28	135.08	134.92	149.57	149.34	149.17	14.96	14.93	14.92
20%	195.6	135.31	0.72	0.32	0.00	136.03	135.63	135.31	150.39	149.95	149.60	30.08	29.99	29.92

* from Section 3.2.2

** Two-ti of costs in Section 3.5.1 and 3.6.1 (2 in. vs. 3 in. depth)

3.7.2.4 Removal of Deteriorated Concrete Using Hydrodemolition and Patching With Portland Cement Concrete Containing Inhibitors

- Productivity:
  Data in Table 4.2, pg. 55 of Ref. 18 covering actual reported hydrodemolition production rates gives the following regression equation:

  $$P = \frac{304.4 - 1.8d}{12} \qquad (R^2 = 0.896)$$

  Where: P = productivity, cf/hr. d = depth of scarification, in. (range: 0.5 to 6.0 in)

  for the 2 in depth assumed here (see sketch under 3.7.2.1):

  $$P = \frac{304.4 - (1.8)(2)}{12} = \underline{25.07\ cf/hr}$$

- Equipment reliability factor = 0.75 to 0.95 (Ref. 18); assume avg. = 0.85

- Instantaneous productivity modification factors (Ref. 18):

  Range
  -Small size patches; scattered patches 0.4-0.8
  -entire surface scarification 0.8-1.0

- Presuming that the data in Table 4.2 of Ref. 18 was based on entire surface scarification and "average" conditions, the estimated instantaneous productivity for the 2 in. deep removal

  $$= \frac{25.07\ cf/hr}{(0.85)(0.90)} = \underline{32.77\ cf/hr}$$

- Equipment Purchase Price (Single Pump Pack System) = \$330,000 - \$750,000 (Ref. 18). Therefore, assume mean value (mid-1991) price =

  $$(1.026)\left(\frac{330{,}000 + 750{,}000}{2}\right) = \underline{\$554{,}040}$$

- Expected equipment life (Ref. 18): 5 yr. (no salvage value)

- Contractors expect hydrodemolition equipment to operate 200-250 days/yr (say 225 average) where a working day is defined as <u>one</u> shift of 10 hr or less. (Ref. 18).

- Equipment operating cost (Ref. 18): \$75-\$95 per nozzle-hr for single pump pack system. Therefore, assume mean value (mid-1991) price =

$$\left(\frac{75 + 95}{2}\right)(1.026) = \underline{\$87.21/nozzle\text{-}hr}$$

- NOTE: Use of hydrodemolition deviates need to sandblast rebars.

- Estimated Costs

Item	Deck Deterioration Level		
	5%	10%	20%
(1) Depth of removal, in.	2	2	2
(2) Total area of removal (8,800 sf deck), sf	440	880	60
(3) Instantaneous Productivity Rate, cf/nozzle-hr	32.77	32.77	32.77
(4) Instantaneous Productivity Rate, sf/nozzle hr	196.62	196.62	196.62
(5) Equipment Reliability Factor	0.85	0.85	0.85
(6) Productivity Modification Factor	0.40	0.50	0.60
(7) Hourly Production Estimate (4)x(5)x(6), sf/hr	66.85	83.56	100.28
(8) Nozzle-hr to complete work: (2), ÷ (4)	2.24	4.48	8.95
(9) Hours to complete work: (2) ÷ (7)	6.58	10.53	17.55
(10) Equipment use (@ one 8-hr shift/day), days	1	2	[illegible]
(11) Capital recovery hydrodemolition equip. @ 10% discount rate: $\frac{[line\ (10)]}{[line\ (2)]} \times \frac{(\$554{,}040)(A/P,10\%,5)/yr}{225\ days/yr}$, \$/sf	1.48	1.48	1.11

Item		Deck Deterioration Level		
		5%	10%	20%
(12) Rental of Auxiliary Equipment (Ref. 8) $/d				
Tractor loader	$285			
Dump truck (12 ton)	$305			
Air Compressor (160 cfm)	$ 63			
Pneumatic breaker (30 lb)	$ 17			
Auxiliary Pump (1 1/2 in)	$ 19			
TOTAL	$689/d			
X[line (10) = Total, $		689	1,378	2,067
÷[line (2) = unit cost, $/sf		1.57	1.57	1.17
(13) Operating Costs				
Hydrodemolition Equip.	$87.21/hr			
Tractor loader	$ 7.95/hr			
Dump truck	$15.65/hr			
Air compressor	$ 6.25/hr			
Pneumatic breaker (dental work)	$ 0.10/hr			
Auxiliary Pump	$ 0.38/hr			
TOTAL	$117.54/hr			
÷[line (4)], $/sf		0.59	0.59	0.59
(14) Labor Costs (incl. contractor O&P) (Ref. 8)				
Operator - hydrodemolition machine	$35.20/hr			
Operator - loader	$33.80/hr			
Foreman - Outside	$39.60/hr			
Truck Driver - dump truck	$29.00/hr			
Truck Driver - water tank truck	$29.00/hr			
5 Laborers @ $28.00/hr	$140.00/hr			
TOTAL	$306.60/hr			
÷[line (7)], $/sf		4.59	3.67	3.06
(15) Materials & Supplies (Ref. 18)				
Additional Safety Shield, $		100.00	100.00	100.00
Plug deck drains, $		250.00	250.00	250.00
Hay bales, 30 @ $1.00 ea, $		30.00	30.00	30.00
Water: assume 40 gpm for hydrodemolition + flushing @ $2/1000 gal. =				
$\frac{(40\ gal/\underline{min})(\$2)(60\ \underline{min}/hr)[line(2)]}{(1{,}000\ gal)[line(4)]}\ \$$		10.74	21.48	42.97
TOTALS, $		90.74	401.48	422.97
÷[line(2)], $/sf		0.89	0.46	0.24

Item		Deck Deterioration Level		
		5%	10%	20%
(16) Concrete Patching (Ref. 8)				
Costs/cy:				
Concrete, 4500 psi, HES	$62.70/cy			
<u>Placing & Finishing</u>	<u>$21.90/cy</u>			
TOTAL	$84.60/cy			
for 2 in. thick (avg) patch (10% waste): =				
$\frac{(1.1)(\$84.60/cy)(2\ in)}{(36\ in/y)(9\ sf/sy)}$, $/sf		0.52	0.52	0.52
Inhibitor (See Section 3.7.2.3), $/sf				
DCI		0.02	0.04	0.08
Cortec 2020		0.01	0.02	0.04
Alox		0.00	0.00	0.00
TOTALS, #/sf				
DCI		0.54	0.56	0.60
Cortec 2020		0.53	0.54	0.56
Alox		0.52	0.52	0.52
(17) TOTALS, #/sf of Deteriorated Area				
Capital Recovery [item (11)]		1.48	1.48	1.11
Rental of Aux. Equip. [item (12)]		1.57	1.57	1.17
Operating Costs [item (13)]		0.59	0.59	0.59
Materials & Supplies [item (15)]		0.89	0.46	0.24
Concrete Patching [item (16)]				
DCI		0.54	0.56	0.60
Cortec 2020		0.53	0.54	0.56
Alox		0.52	0.52	0.52
Subtotals, $/sf Det. Area				
DCI		5.07	4.66	3.71
Cortec 2020		5.06	4.64	3.67
Alox		5.05	4.62	3.63
Plus Contractor's O&P @ 10%				
DCI		5.58	5.13	4.08
Cortec 2020		5.57	5.10	4.04
Alox		5.56	5.08	3.99
Labor (incl. contr. O&P) [item (14)]		4.59	3.67	3.06
Totals, $/sf Det. Area				
DCI		10.17	8.80	7.14
Cortec 2020		10.16	8.77	7.10
Alox		10.15	8.75	7.05

Item	Deck Deterioration Level		
	5%	10%	20%
(18) TOTALS, $/sy of Deck Area (incl. TMP, Mobilization, Engineering, Surety Bonds) = $\frac{[item\ (17)](\%\ Det.)(1.1056)(9\ sf/sy)}{(100)} =$			
DCI	5.06	8.76	14.21
Cortec 2020	5.05	8.73	14.13
Alox	5.05	8.71	14.03

3.7.3 Application of Inhibitor

3.7.3.1Inhibitor Costs

- Application Rates & Times

Inhibitor	Without Drying (Cases 7-9)		With Drying (Cases 10-12)	
	Appl. Rate sf/gal	Appl. Times, hours	Appl. Rate sf/gal.	Appl. Times, hours
Postrite (15% Ca-Nitr).	150	0, 1, 8	150	0, 1, 8
Cortec 2020	225	0, 2, 12	225	0, 1, 8
Alox (4.5& by wt/Sol'n in denat. ethanol)	70	0, 1, 4	70	0, 1, 4

- Material Quantities (+10% waste), per "typical" bridge deck
  -Postrite: 15% Calcium Nitrite solution.

$$\frac{(1.1)(8{,}800\ sf)(3\ appl.)}{(150\ sf/gal/appl.)} = \underline{193.6\ GAL.}$$

-Cortec MCI 2020:

$$\frac{(1.1)(8{,}800\ sf)(3\ appl.)}{(225\ sf/gal/appl.)} = \underline{129.1\ GAL.}$$

-Alox (without drying - 3 applications)

$$\frac{(1.1)(8{,}800\ sf)(3\ appl.)}{(70\ sf/gal/appl.)} = \underline{414.9\ GAL.}$$

-Alox (with drying - 4 applications)

$$\frac{(1.1)(8{,}800\ sf)(4\ appl.)}{(70\ sf/gal/appl.)} = \underline{553.1\ GAL.}$$

- Material Costs

-Basic Costs

Postrite (15% calcium-nitrite solution): $30.00/gal (See section 1.11.1.1).

Cortec MCI-2020: Depends on Quantity (See section 1.11.2.1). For 129.1 Gal. needed: 2-55 gal. drums + 4-5 gal containers, (2)(55)(54.53)+(4)(5)(56.75) = $7,133.30 OR, 26 - 5 gal containers, (26)(5)(45.07) = $5,859.10 ($45.07/gal).

Alox: 4.7% by wt. solution in denatured ethanol. Alox costs $0.82/lb and has Sp. Gr. 0.934 (See section 1.11.3). Ethanol (denatured) $7.10/gal in 55 gal. drum lots (50 gr = 0.789). (See Section 1.11.3). 1 lb. Alox makes 1/0.047 = 21.28 lb solution requiring 21.28 -1.00 = 20.28 lb. ethanol.

$$1\ lb.\ Alox = \frac{(1\ lb)(7.48\ gal/cf)}{(62.4\ lb/cf)(0.934)} = 0.128\ gal$$

$$20.28\ lb\ Ethanol = \frac{(20.28)(7.48)}{(62.4)(0.789)} = 3.081\ gal$$

$$Solution = 0.128 + 3.081 = 3.209\ gal.$$

$$\therefore\ One\ Gal.\ Solution\ Requires:$$

$$\frac{1}{3.209} = 0.312\ lb.\ Alox\ and\ \frac{3.081}{3.209} = 0.960\ gal\ ethanol$$

Therefore, cost/gal/ of Alox Solution = (0.960 gal)($7.10/gal) + (0.312 lb)($0.82/lb) = $7.07/gal.

- Square yard basis (incl. Contractors O&P + TMP, etc.)

Postrite:

$$\left[\frac{(193.6\ gal)(\$30.00/gal)}{(8{,}800\ sf)}\right](1.1)(1.1056)(9\ sf/sy) = \$7.22/sy$$

Cortec MCI-2020:

$$\left[\frac{(129.1\ gal)(\$45.07/gal)}{(8{,}800\ sf)}\right](1.1)(1.1056)(9\ sf/sy) = \$7.24/sy$$

Alox - 3 applications (not dried)

$$\left[\frac{(414.9\ gal)(\$7.07/gal)}{(8{,}800\ sf)}\right](1.1)(1.1056)(9\ sf/sy) = \$3.65/sy$$

Alox - 4 applications (dried deck)

$$\left[\frac{(553.1\ gal)(\$7.07/gal)}{(8{,}800\ sf)}\right](1.1)(1.1056)(9\ sf/sy) = \$4.86/sy$$

NOTE: The Alox/ethanol mixture constitutes a major fire and health hazard due to the volatility, flammability, and toxicity of the ethanol. Therefore, special provisions must be made for the application of this mixture (see Section 3.7.3.3, below).

3.7.3.2Equipment Costs (Postrite & Cortec 2020 Applications)

- Emulsion Sprayer, 200 gal, 5 hp engine: (Ref. 8)
  Rental $49.00/day
  Operating Cost $0.45/hr

- Assume spray rate = 5 gpm = 300 gph

- <u>Postrite</u>:

$$\frac{193.6\ \mathit{gal}}{3\ \mathit{appl.}} = 64.5\ \mathit{gal/appl.}$$

$$\frac{64.5\ \mathit{gal/appl}}{300\ \mathit{gal/h}} = 0.22\ \mathit{h/appl.}$$

- <u>Cortec 020:</u>

$$\frac{129.1\ \mathit{gal}}{3\ \mathit{appl.}} = 43.0\ \mathit{gal/appl.}$$

$$\frac{43.0\ \mathit{gal/appl.}}{300\ \mathit{gal/h}} = 0.14\ \mathit{h/appl.}$$

- Total Equipment Costs (incl. contractor's O&P & TMP, etc.)
  <u>Postrite</u>

$$[(\$49.00/\mathit{d})(1\mathit{d}) + (0.22\ \mathit{h/appl.})(3\ \mathit{appl.})(\$0.45/\mathit{h})]\ X\ (1.1)(1.1056)(9\ \mathit{sf/sy}) \div (8{,}800\ \mathit{sf}) =$$

- <u>Cortec 2020</u>

$$[(\$49.00/\mathit{d})(1\mathit{d}) + (0.14\ \mathit{h/appl.})(3\ \mathit{appl.})(\$0.45/\mathit{h})]\ X\ (1.1)(1.1056)(9\ \mathit{sf/sy}) \div (8{,}800\ \mathit{sf}) =$$

3.7.3.3 Equipment Costs (Alox Applications)

- Because of the potential fire/explosion hazards associated with the large volumes of ethanol used as a diluent, it is assumed that the Alox will be applied using handheld pneumatic sprayer.

- Estimated production rate:

  Ref. 8, pg. 117 gives 830 sf/m-d for 15.6 sf/gal coverage rate.

$$\frac{414.9\ gal}{3\ appl.} = 138.3\ gal/appl.$$

$$\frac{830\ sf/m\text{-}d}{(25.6\ sf/gal)(8\ h/d)} = 4.05\ gal/m\text{-}h$$

$$\frac{138.3\ gal/appl.}{4.05\ gal/m\text{-}h} = 34.1\ m\text{-}h/appl.$$

Since time available for application is one hour or less (see "application times" in Section 3.7.3.1),

$$\frac{34.1\ m\text{-}h/appl.}{1\ h/appl.} = 35\ men(sprayers),\ \underline{minimum}$$

- Assume use of insecticide-type portable had sprayers @ \$20.00 each. Because of the small cost and expected short lives of these sprayers, consider them to be "expendable" equipment items rather than "Capital" equipment. Assuming the average they will last through 10 bridges.

$$cost/bridge = \frac{(\$20.00/unit)(35\ units)}{(10\ bridges)} = \$70.00/bridge$$

- Unit Cost incl. contractors O&P & TMP, etc.

$$= \frac{(1.1)(1.1056)(\$70.00/bridge)(9\ sf/sy)}{(8{,}800\ sf/bridge)} = \$0.09/sy$$

- Fire Protection

  Fire protection: Assume need same as for MMA in deep impregnation using grooving method (See Section 3.1.4.8) = \$5.27/sy (incl. contractor's O&P) Including TMP, etc: (\$5.27/sy)(1.1056) = \$5.83/sy

- Total Equipment & Services for Alox Application = \$0.09/sy +\$5.83/sy = \$5.92/sy

5.7.3.4Labor Costs for Spray Applications

- <u>Postrite</u>

0.22 h/appl., say 1 hr/appl. with preparation, etc. Wage rates (incl contr. O&P) (Section 1.10):

1 equip, operator - light:	$33.80/h
1 laborer:	$28.00/h
Subtotal	$61.80/h

Unit labor cost (incl. TMP, etc.) =

$$\frac{(1.1056)(3\ appl.)(1\ h/appl.)(\$61.80/h)(9\ sf/sy)}{(8{,}800\ sf)} = \$0.21/sy$$

- Cortec 2020

  0.14 h/appl., say 0.75 h/appl. with preparation, etc. Wage rate (same as for Postrite) = $61.80/h. Unit labor cost (incl. TMP, etc.) =

$$\frac{(1.1056)(3\ appl.)(0.75\ h/appl)(\$61.80/h)(9\ sf/sy)}{(8{,}800\ sf)} = \$0.16/sy$$

- Alox

  Application time = 34.1 m-h/appl. ÷ 35 m = 0.97 h/appl., say 1.5 h/appl. to incl. preparation time, etc. Wage cost (incl. Contr. O&P) (Section 1.10): laborers: $28,00/hr (35 required - minimum). Unit labor cost for 3 applications (incl. TMP, etc)

$$\frac{(1.1056)(3\ appl.)(1.5\ h/appl.)(35\ m)(\$28.00/mh)(9\ sf/sy)}{(8{,}800\ sf)} = \$4.99/sy\ \ (for\ 3\ applications)$$

For 4 applications: (4/3)($4.99/sy) = $6.65/sy (for 4 applications)

3.7.3.5 Total Costs for Application of Inhibitor (Incl. Contractor's O&P & TMP, etc.)

Inhibitor System	No. Applic.	Costs, \$/sy (\$/m²)				
		Inhibitor	Equip.	Labor	Total	Total (m²)
Postrite	3	7.22	0.06	0.21	7.49	8.96
Cortec 2020	3	7.24	0.06	0.16	7.46	8.92
Alox	3	3.65	5.92*	4.99	14.56	17.41
Alox	4	4.86	5.92*	6.65	17.43	20.85

* Incl. Fire Protection

3.7.4 Overlay Application

3.7.4.1Sandblasting

Light sandblasting of concrete surfaces - total cost (incl. contractor's O&P) = \$0.92/sf (Ref. 8). Therefore, cost/sy (& TMP, etc.) = (\$0.92/sf)(9 sf/sy)(1.1056) = \$8.74/sy

3.7.4.2Removal of Particulate Matter

Blow away using air wand. Estimate 2 laborers for 1 hour and 1 hour rental and operating cost for air compressor. Wage rate (incl. contr. O&P) = \$28.00/mh (Section 1.10) 60 cfm air compressor; \$48.00/day (oper. cost = \$4.70/h) (Ref. 8). Unit cost (incl. Contr. O&P & TMP, etc.) =

$$\frac{(1.1056)\left((12m)(\$28.00/mh) + (1.1)\left[\left(\frac{\$48.00/d}{8\ h/d}\right) + \$4.70/h\right]\right)(1h)(9\ sf/sy)}{(8{,}800\ sf)} = \$0.08/sf$$

3.7.4.3Application of Bending Grout

- Material Cost

  Grout proportions (assumed - based on the mortar fraction of typical bridge deck concrete):

Ingredient	lb per ct Mortar
Portland Cement	42
Water	19
Sand	61
(Air = 11%)	
	122 lb/cf

Solid unit wt. of CA used in concrete = (2.70)(62.4) = 168 lb/cf

let x = vol fraction of mortar. If assumed unit wt. of concrete = 145 lb/cf: 122X + 168 (1-x) = 145 x = 0.50

Therefore, inhibitor does in mortar = 1/0.50 = 2 times does in concrete

For Postrite: dosage =

$$\frac{(2)(6\ gal/cy)}{27\ cf/cy} = 0.44\ gal/cf$$

And for Cortec 2020, dosage =

$$\frac{(2)(2pts/cy)}{27\ cf/cy} = 0.15\ pts/cf$$

None for Alox

Unit Cost:

Cement:

$$\frac{\$6.70/bag}{94\ lb/bag} = \$0.0713/lb\ (Ref. 8)$$

Sand:

$$\frac{\$9.45/ton}{2{,}000\ lb/ton} = \$0.0047/lb\ (Ref.\ 8)$$

Postrite: $30.00/gal (Section 1.11.1.1)

Cortec 2000: $70.41/gal (in 5-gal containers in lots of 25 or more - Section 1.11.2.2).

∴ Unit cost of mortar containing Postrite (incl. contr. O&P & TMP, etc.)

$$=(1.1)(1.1056)[(\$0.0713/lb)(42\ lb/cf)+(\$0.0047/lb)(61\ lb/cf)+(30.00/gal)(0.44\ gal/cf)]= \$20.04/cf$$

Assuming 0.1 in third coat and 10% waste, cost/sy =

$$\frac{(\$20.04/cf)(0.1\ in)(9\ sf/sy)(1.1)}{12\ in/f} = \$1.65/sy\ (for\ Postrite)$$

And unit cost of mortar containing Cortec 2000 (incl. contr. O&P & TMP, etc.) =

$$=(1.1)(1.1056)\left[(\$0.713/lb)(42\ lb/cf)+(\$0.0047/lb)(61\ lb/cf)+\frac{(\$70.41/gal)(0.15\ pts/cf)}{(8\ pts/gal)}\right]=$$

Assuming 0.1 in thick coat and 10% waste, cost/sy:

$$\frac{(\$5.60/cf)(0.1\ in)(9\ sf/sy)(1.1)}{(12\ in/f)}=\$0.46/sy\ \textit{for Cortec}\ 2000$$

And for Alox (no inhibitor in grout or overlay), unit cost of mortar (incl. contr. O&P & TMP, etc.) =

$$(1.1)(1.1056)[(\$0.0713/\text{lb})\ (42\ \text{lb/cf})+(\$0.0047/\text{lb})(61\ \text{lb/cf})]=\$3.99/\text{cf}$$

Assuming 0.1 in. thick coat and 10% waste, cost/sy =

$$\frac{(\$3.99/cf)(0.1\ in)(9\ sf/sy)(1.1)}{(12\ in/f)}=\$0.33/sy\ (\textit{for Alox})$$

- Labor Cost for Bonding Coat

Estimated application rate: full deck width by 25 ft in 2 hr by 3 man spreading crew.

$$\frac{200\ ft\ deck\ length}{25\ ft/crew\text{-}h}=8\ crew\text{-}h$$

Available time (working ahead of overlay paving crew) = 4 h (est. time for placement of overlay).

$$\therefore\ \frac{8\ crew\text{-}h}{4h}=2\ spreading\ crews\ needed$$

For batching and mixing, estimate one 3 man labor crew. ∴ Total 3-man labor crews; unit labor cost = \$28.00/mh (see Section 1.10). Estimated labor cost incl Contractor's O&P & TMP, etc.

$$=\frac{(1.1056)(4h)(3\ m/crew)(3\ crews)(\$28.00/mh)(9\ sf/sy)}{(8{,}800\ sf)}=\$1.14/sy$$

- Equipment Cost for Bonding Coat: 1 - 16 cf mixer:Rent \$77.00/d; operating cost \$1.40/hr (Ref. 8). 2-hand buggies, 150' haul:0,375 mh/cy: Equip. Cost \$1.98/cy (Ref. 8).

$$\therefore\ Equip.Cost = \frac{\$1.98/cy}{0.375\ mh/cy} = \$5.28/mh$$

$$(8\ crew\text{-}h)(3\ m/crew)(\$5.28/mh) = \$126.72$$

$$Unit\ Cost\ (incl.\ contr.\ O\&P\ \&\ TMP,\ etc.) =$$

$$\frac{(1.1)(1.1056)[\$126.72 + \$77.00 + (4h)(\$1.40/h)](9\ sf/sy)}{(8{,}800\ sf)} = \$0.26/sy$$

- Total cost for bonding coat (incl. contractor's O&P & TMP, etc.)

Inhibitor System	Cost, \$/sy (\$/m^2)				
	Materials	Labor	Equipment	Total	Total (m^2)
Postrite	1.65	1.14	0.26	3.05	3.65
Cortec 2000	0.46	1.14	0.26	1.86	2.22
Alox	0.33	1.14	0.26	1.73	2.07

3.7.4.4 Application of Overlay

- 1.75 in thick overlay (see 3.7.2.1) Extrapolation of cost data on pg. 38, Ref. 8, gives the following bare unit costs for placing, finishing, and curing a 1.75 in thick wearing surface:

Materials	\$3.67/sy
Equipment	\$0.30/sy
Labor	\$0.30/sy
Membrane Curing:	
Materials	\$0.16/sy
Labor	\$0.19/sy
Total Bare Cost (w/o inhib. & admixtures)	\$4.62/sy

- Admixtures

Inhibitor System	Admixtures				
	DCI	Daracem-100 (HRWR)	AEA	Daratard-17 Retarder	Cortec 2000
Postrite	6 gal/cy	12 fl oz/cwt cement	1.5 fl oz/cwt cement	6 fl. oz/cwt cement	
Cortec 2020				"	2 pts/cy
Alox				"	

Admixture Costs (bare)

<u>DCI</u>

Admix Cost = \$6.00/gal (see section 1.11.1.2)
Cost/cy = (\$6.00/gal)(6 gal/cy) = \$36.00/cy

$$Bare\ Unit\ Cost = \frac{(\$36.00/cy)(1.75\ in)}{(36\ in/yd)} = \$1.75/sy$$

<u>Cortec 2000</u>

Admix Cost = \$70.41/gal (in 5-gal containers in lots of 25 or more - see section 1.11.2.2)

$$Cost/cy = \frac{(\$70.41/gal)(2\ pts/cy)}{(8\ pts/gal)} = \$17.60/cy$$

$$Bare\ Unit\ Cost = \frac{(\$17.60/cy)(1.75\ in)}{36\ in/yd)} = \$0.86/sy$$

<u>Air Entraining Agent (AEA)</u>

Admixture Cost = \$5.25/gal (See Section 1.11.4.2)

$$Cost/cy = \frac{(\$5.25/gal)(1.5\ fl.\ oz./cwt\ p.c.)(7\ cwt\ p.c./cy)(1.75\ in)}{(128\ fl.\ oz./gal)(36\ in/yd)} = \$0.02/sy$$

<u>Retarder (Daratard-17)</u>

Admixture Cost = \$5.00/gal (See Section 1.11.4.1)

$$Cost/cy = \frac{(\$5.00/gal)(6\ fl.\ oz./cwt\ p.c.)(7\ cwt\ p.c./cy)(1.75\ in)}{(128\ fl.\ oz./gal)(36\ in/yd)} = \$0.08/sy$$

<u>High Range Water Reducer (Daracem-100)</u>

Admixture Cost = $6.00/gal (See Section 1.11.4.1)

$$Cost/cy = \frac{(\$6.00/gal)(12\ fl.\ oz./cwt\ p.c.)(7\ cwt\ p.c./cy)(1.75\ in)}{(128\ fl.\ oz./gal)(36\ in/yd)} = \$0.19/sy$$

Overlay Material and Installation Cost

Inhibitor System	Cost, \$/SY (\$/m^2)				
	Basic	Admix	Subtotal	Total*	Total (m^2)*
Postrite	4.62	2.04	6.66	8.10	9.69
Cortec 2020	4.62	0.88	5.50	6.69	8.00
Alox	4.62	0.02	4.64	5.64	6.75

*(incl. O&P & TMP, etc.); factor = (1.1)(1.1056) = 1.21616

3.7.4.5Total Estimated Cost for Overlay Application

Inhibitor System	Cost (incl. Contr. O&P & TMP, etc), \$/sy (\$/m^2)					
	Sandblast	Remove Particle Matter	Bonding Grout	Overlay	Total	Total (\$/m^2)
Postrite	8.74	0.08	3.05	8.10	19.97	23.88
Cortec 2020	8.74	0.08	1.86	6.69	17.37	20.77
Alox	8.74	0.08	1.73	5.64	16.19	19.36

3.7.5 Weather Protection (Non-Dried Condition)

- Capital equipment cost, incl. contractor's O&P (see section 3.1.4.3):

No. Bridged Treated/Yr	Cost, \$/sy
1	18.73
4	4.68
10	1.87

- Labor (see sections 3.1.3 and 1.10)
  [illegible] shifts; assume 15 of 21 laborers ($28.00/mh) and 1 of 2 foremen ($39.60/mh) are involved in assembling weather protection.

∴ Unit labor cost (incl. wage burden and contr. O&P) =

$$\frac{(9\ \mathit{sf/sy})(1.5\ \mathit{shifts})(8\ \mathit{h/shift})[(15\ \mathit{m})(\$28.00/\mathit{mh}) + (1\mathit{m})(\$39.60/\mathit{mh})]}{(8{,}800\ \mathit{ft})} = \$5.64/\mathit{sy}$$

- Total Cost for Weather Protection (Non-Dried)

No. Bridges Treated/Yr	Cost, \$,SY (\$/m²)				
	Capital Equipment	Labor	SubTotal	Total*	Total (m²)*
1	18.73	5.64	24.37	26.94	32.22
4	4.68	5.64	10.32	11.41	13.65
10	1.87	5.64	7.51	8.30	9.93

*(Incl. TMP, etc.); factor = 1.1056

3.7.6 Weather Protection, Install Thermocouples, Assemble Heaters (Dried Condition)

- Weather Protection Capital Equipment (see section 3.1.4.3):

No. Bridges Treated/yr	Cost Incl. Contr. O&P (\$/sy)
1	18.73
4	4.68
10	1.87

- Process Control Equipment & Materials (See Section 3.1.4.7):

No. Bridges Treated/yr	Cost Incl. Contr. O&P (\$/sy)
1	2.42
4	1.87
10	1.76

- Labor (see sections 3.1.3 and 1.10): 1.5 shifts, 21 laborers (\$28.00/m-h) and 2 foremen (\$39.60/m-h)

∴ Unit Labor cost (incl. wage burden and contractor's O&P):

$$\frac{(9\ \mathit{sf/sy})(1.5\ \mathit{shifts})(8\ \mathit{h/shift})[(21\ \mathit{m})(\$28.00/\mathit{m\text{-}h})+(2\ \mathit{m})(\$39.60/\mathit{m\text{-}h})]}{(8{,}800\ \mathit{sf})} = \$8.19/\mathit{sy}$$

- Total cost for weather protection, installing thermocouples, and assembling heaters (Dried Deck Condition)

No. Bridges Treated/Yr	Cost W.P., Inst. T/C, Assemb. Htr, (Dried Conditions); S/SY					
	Weather Proof Cap. Equip.	Proc. Control Equip.	Labor	Sub-Total	Total Cost (incl. TMP, etc.)*	Total Cost (m^2) (Incl. Tmp, etc.)*
1	18.73	2.42	8.19	29.34	32.44	35.87
4	4.68	1.87	8.19	14.74	16.30	18.02
10	1.87	1.76	8.19	11.82	13.07	14.45

*Factor = 1.1056

3.7.7 Drying Decks With IR Heaters

- Drying Capital Equipment and Materials Costs Incl. Contractor's O&P (See Section 3.1.4.2):

No. Bridges Treated/yr	Cost ($/sy)
1	14.82
4	7.79
10	6.39

- Labor (See Sections 3.1.3 and 1.10):

  5 days, 3 shifts/day, each consist of 4 laborers ($28.00/mh) and 1 foreman ($39.60/mh). (All rates incl. wage burden and contractor's O&P).

  ∴ Unit Labor Cost =

$$\frac{(9\ \mathit{sf/sy})(3\ \mathit{shifts/d})(5\mathit{d})(8\ \mathit{h/shift})[(4\ \mathit{m})(\$28.00/\mathit{m\text{-}h})+(1\ \mathit{m})(\$39.60/\mathit{m\text{-}h})]}{(8{,}800\ \mathit{sf})} = \$18.61/\mathit{sy}$$

- Total Cost - Drying Decks with IR Heaters

No. Bridges Treated/Yr	Costs - Drying Decks with IR Heaters, $/SY				
	Cap. Equip. & Materials	Labor	Sub-Total	Total (Incl. TMP, etc.)*	Total ($/m^2) (Incl. TMP, etc.)*
1	14.82	18.61	33.43	36.96	44.20
4	7.79	18.61	26.40	29.18	34.89
10	6.39	18.61	25.00	27.64	33.06

*Factor = 1.1056

3.7.8 Hydrodemolition Versus Pneumatic Breakers for Repair of Deteriorated Concrete

- For cases where deck is not dried: if using hydrodemolition, must add drying step.

Drying Cost	Costs, $/SY		
No. Bridges Treated/Yr	1	4	10
W.P., T/S's, Assembl. Htr. (see Sect. 3.7.6) Less. W.P. (See Section 3.7.5) Plus Drying Cost (See Section 3.7.7)	32.44 (-26.94) 36.96	16.30 (-11.41) 29.18	13.07 (-8.30) 27.64
Total = Drying & Related Costs	42.46	34.07	32.41

- Repair Using Hydrodemolition for Removal of Deteriorated Concrete (See Section 3.7.2.4)

Inhibitor System Deterioration Level	Cost, $/SY		
	Postrite	Cortec 2020	Alox
5%	5.06	5.05	5.05
10%	8.76	8.73	8.71
20%	14.21	14.13	14.03

- Plus subsequent drying cost:

Inhibitor System Deterioration Level	Cost (Range 1-10 Bridges/Yr), $/SY		
	Postrite	Cortec 2020	Alox
5% 10% 20%	37.47-47.52 41.17-51.22 46.62-56.67	37.46-47.51 41.14-51.19 46.54-56.59	37.46-47.51 41.12-51.17 46.44-56.49

- Repair Using Pneumatic Breakers (See 3.7.2.3)

Inhibitor System Deterioration Level	Cost Using Pneumatic Breaker, $/SY		
	Postrite	Cortec 2020	Alox
5% 10% 20%	7.49 14.96 30.08	7.49 14.93 29.99	7.48 14.92 29.92

- Conclusions:

  (1) Use hydrodemolition for removal of deteriorated concrete on <u>dried</u> decks only (Cases 10-12)
  (2) Use pneumatic breakers for removal of deteriorated concrete on non-dried decks only (cases 7-9).

3.7.9 Sandblasting Rebars

- Required when using pneumatic breakers for removing deteriorated concrete.

- Rebar surface area/unit area of bridge deck (top mat) -- assume #5 bars on 6 in centers and #4 bars on 9 in centers:
  4/3 #4 bars/sf; 2 #5 bars/sf

$$\#4: \frac{(0.5\pi)(12)(4/3)}{144} = 0.175\ sf/sf$$

$$\#5: \frac{(0.625\pi)(12)(2)}{144} = 0.327\ sf/sf$$

$$TOTAL = 0.502\ sf/sf$$

Say, 0.50 sf bar surface per sf deck surface

- Unit cost for sandblasting (heavy penetration) = $2.71/sf, incl. contractor's O&P (Ref. 8). Unit cost incl. TMP, etc. = (2.71/sf) (1.1056) = $3.00/sf

- Cost/sy repair area = (0.50)($3.00/sf)(9 sf/sy) = $13.50/sy repair area

Deterioration Level	Cost/Unit Deck Area, $/SY
5%	0.68
10%	1.35
20%	2.70

- Notice that these additional costs incurred when using pneumatic breakers are not nearly sufficient to reverse the conclusions presented at the end of Section 3.7.8.

3.8 Case 7. Corrosion Inhibitor Spray-On Overlay System - Cortec 2000 Inhibitor; No Drying

- Weather Protection (See Section 3.7.5)

No. Bridges Treated/Yr	1	4	10
Weather Protection Cost ($/SY)	26.94	11.41	8.30

- Scarification to Rebars (See Section 3.7.2.2) = $7.97/sy

- Remove Deteriorated Concrete (See Section 3.7.8)

Deterioration Level, %	Cost to Remove and Patch Deteriorated Concrete, $/SY*
0	0.00
5	7.49
10	14.93
20	29.99

*NOTE: Cost/sy of Total Deck Surface

- Remove Particulate Fines - Included in costs for scarification and deteriorated concrete removal.

- Sandblast Rebars (See Section 3.7.9)

Deterioration Level, %	Sandblast Rebar, $/SY*
0	0.00
5	0.68
10	1.35
20	2.70

*NOTE: Cost/sy of TOTAL Deck Surface

- Patch Deteriorated Concrete - Included in Section 3.7.8.

- Spray-on Inhibitor (See Section 3.7.3.5) = $7.46/sy (3 applications)

- Sandblast surface, remove particulate fines, apply bonding grout, and overlay with inhibitor - modified concrete (see section 3.7.4.5) = $17.37/sy

- Total Costs - Case 7

No. of Bridges Per Year	Total Cost, $/SY ($/m^2)		
Deterioration Level	1	4	10
0% 5% 10% 20%	59.74 (71.45) 67.91 (81.22) 76.02 (90.92) [illegible]3 (110.54)	44.21 (52.87) 52.38 (62.65) 60.49 (72.35) 76.90 (91.97)	41.10 (49.15) 49.27 (58.93) 57.38 (68.63) 73.79 (88.25)

3.9 Case 8: Corrosion Inhibitor Spray-On Overlay system - Postrite (15% Calcium Nitrite) Inhibitor; No Drying

- Weather Protection (See Section 3.7.5)

No. Bridges Treated Year	1	4	10
Weather Protection Cost, $/S	26.94	11.41	8.30

- Scarification to Rebars (See Section 3.7.2.2) = $7.97/SY

- Remove Deteriorated Concrete (See Section 3.7.8)

Deterioration Level, %	Cost to Remove & Patch Deteriorated Concrete, $/SY*
0	0.00
5	7.49
10	14.96
20	30.08

*NOTE: Cost/SY of TOTAL Deck Surface

- Remove Particulate Fines - Included in costs for scarification and deteriorated concrete removal.

- Sandblast Rebars (See Section 3.7.9)

Deterioration Level, %	Sandblast Rebar, $/SY*
0	0.00
5	0.68
10	1.35
20	2.70

*NOTE: Cost/SY of TOTAL Deck Surface

- Patch Deteriorated concrete - Included in Section 3.7.8

- Spray-on Inhibitor (See Section 3.7.3.5) = $7.49/SY (3 applications)

- Sandblast surface, remove particulate fines, apply bonding grout, and overlay with inhibitor - modified concrete (See Section 3.7.4.5) = $19.97/SY

- Total Costs - Case 8

No. Bridges Per Year	Total Cost $/SY ($/m^2)		
Deterioration Level	1	4	10
0%	62.37 (74.59)	46.84 (56.02)	43.73 (52.30)
5%	70.54 (84.36)	55.01 (65.79)	51.90 (62.07)
10%	78.68 (94.10)	63.15 (75.53)	60.04 (71.81)
20%	95.87 (114.66)	79.62 (95.22)	76.51 (91.50)

3.10 Case 9: Corrosion Inhibitor Spray-On Overlay System - Alox Inhibitor; No Drying

- Weather Protection (See Section 3.7.5)

No. Bridges Treated/Yr	1	4	10
Weather Protection (est, $/SY)	26.94	11.41	8.30

- Scarification to Rebars (See Section 3.7.2.2) = $7.97/SY

- Remove Deteriorated Concrete (See Section 3.7.8)

Deterioration Level, %	Cost to Remove & Patch Deteriorated Concrete, $/SY*
0	0.00
5	7.48
10	14.92
20	29.92

*NOTE: Cost/SY of TOTAL Deck Surface

- Remove Particulate Fines - Included in Costs of scarification and deteriorated concrete removal.

- Sandblast Rebars (See Section 3.7.9)

Deterioration Level, %	Sandblast Rebar, $/SY
0	0.00
5	0.68
10	1.35
20	2.70

*NOTE: Cost/SY of TOTAL Deck Area

- Patch Deteriorated Concrete - Included in Section 3.7.8.

- Spray-on Inhibitor (See Section 3.7.3.5) = $14.56 (3 applications). Includes cost of extensive fire protection required due to large quantity of ethanol exposed and need for hand-sprayed application of inhibitor.

- Sandblast surface, remove particulate fines, apply bonding grout, and overlay with inhibitor - modified concrete (see section 3.7.4.5) = $16.19/SY

- Total Costs - Case 9

No. Bridges Per Year	Total Cost $/SY ($/m^2)		
Deterioration Level	1	4	10
0% 5% 10% 20%	65.66 (78.53) 73.82 (88.29) 81.93 (97.99) 98.28 (117.54)	50.13 (59.95) 58.29 (69.71) 66.40 (79.41) 82.75 (98.97)	47.02 (56.23) 55.18 (65.99) 63.29 (75.69) 79.64 (95.25)

3.11. Case 10. Corrosion Inhibitor Spray-On Overlay System - Cortec 2020 Inhibitor, Dried Deck

- Scarification to Rebars (See Section 3.7.2.2) = $7.97/SY

- Remove Deteriorated Concrete (See Section 3.7.8)

Deterioration Level, %	Cost to Remove & Patch Deteriorated Concrete, $/SY*
0	0.00
5	5.05
10	8.73
20	14.13

*NOTE: Cost/SY of TOTAL Deck Surface

- Remove Particulate Fines - Included in costs for scarification and deteriorated concrete removal.

- Sandblast Rebars - Not required with hydrodemolition removal of deteriorated concrete.

- Patch Deteriorated Concrete - Included in Section 3.7.8.

- Weather protection, install thermocouples, assemble heaters, and dry deck (See Sections (3.7.6, and 3.7.7).

No. Bridges Treated/Year	1	4	10
Weather Protection, T/C's, # Assembl. Htrs., $/SY Dry Deck, $/SY	32.44 36.96	16.30 29.18	13.07 27.64
TOTAL, $/SY	69.40	45.48	40.71

- Spray-on Inhibitor (See Section 3.7.3.5) = $7.46/SY (3 applications).

Includes cost of extensive fire protection required due to large quantity of ethanol exposed and need for hand-sprayed application of inhibitor.

- Sandblast surface, remove particulate fines, apply bonding grout, and overlay with inhibitor - modified concrete (See Section 3.7.4.5) = $16.19/SY

- Total Costs - Case 12

No. Bridges Per Year	Total Cost $/SY ($m^2)		
Deterioration level	1	4	10
0%	110.99 (132.74)	87.07 (104.13)	82.30 (98.43)
5%	116.04 (138.78)	92.12 (110.17)	87.35 (104.47)
10%	119.70 (143.16)	95.78 (114.55)	91.01 (108.85)
20%	125.02 (149.52)	101.10 (120.91)	96.33 (115.21)

3.12. Case 11: Corrosion Inhibitor Spray-On Overlay System - Postrite (15% Calcium Nitrite) Inhibitor: Dried Deck

- Scarification to Rebars (See Section 3.7.2.2) = $7.97/SY

- Remove Deteriorated Concrete (See Section 3.7.8)

Deterioration Level, %	Cost to Remove & Patch Deteriorated Concrete, $/SY
0	0.00
5	5.06
10	8.76
20	14.21

*NOTE: Cost/SY of TOTAL Deck Surface

- Remove Particulate Fines - Included in costs for scarification and deteriorated concrete removal.

- Sandblast Rebars - Not required with hydrodemolition removal of deteriorated concrete.

- Patch Deteriorated Concrete - Included in Section 3.7.8.

- Weather Protection, Install Thermocouples,. Assemble Heaters, and Dry Deck (See Sections 3.7.6 and 3.7.7).

No. Bridges Treated/Year	1	4	10
Weather Protection, T/C's, # Assembl. Htrs., $/SY Dry Deck, $/SY	32.44 36.96	16.30 29.18	13.07 27.64
TOTAL, $/SY	69.40	45.48	40.71

- Spray-on Inhibitor (See Section 3.7.3.5) = $7.49/SY (3 applications).

- Sandblast surface, remove particulate fines, apply bonding grout, and overlay with inhibitor - modified concrete (See Section 3.7.4.5) = $19.97/SY

- Total Costs - Case 11

No. Bridges Per Year	Total Cost $/SY ($m^2)		
Deterioration level	1	4	10
0%	104.83 (125.38)	80.91 (96.77)	76.14 (91.06)
5%	109.89 (131.43)	85.97 (102.82)	81.20 (97.11)
10%	113.59 (135.85)	89.67 (107.24)	84.90 (101.54)
20%	119.04 (142.37)	95.12 (113.76)	90.35 (108.06)

3.13. Case 12: Corrosion Inhibitors - Spray-on Overlay System - Alox Inhibitor, Dried Deck

- Remove Particulate Fines - Included in costs for scarification and deteriorated concrete removal.

- Sandblast Rebars - Not required with hydrodemolition removal of deteriorated concrete.

- Patch Deteriorated Concrete - Included in Section 3.7.8.

- Weather Protection, Install Thermocouples,. Assemble Heaters, and Dry Deck (See Sections 3.7.6 and 3.7.7).

No. Bridges Treated/Year	1	4	10
Weather Protection, T/C's, # Assembl. Htrs., $/SY Dry Deck, $/SY	32.44 36.96	16.30 29.18	13.07 27.64
TOTAL, $/SY	69.40	45.48	40.71

- Scarification to Rebars (See Section 3.7.2.2) = $7.97/SY

- Remove Deteriorated Concrete (See Section 3.7.8)

Deterioration Level, %	Cost to Remove & Patch Deteriorated Concrete, $/SY
0	0.00
5	5.05
10	8.71
20	14.03

*NOTE: Cost/SY of TOTAL Deck Surface

- Remove Particulate Fines - Included in costs for scarification and deteriorated concrete removal.

- Sandblast surface, remove particulate fines, apply bonding grout, and overlay with inhibitor - modified concrete (See Section 3.7.4.5).

- Total Costs - Case 11

No. Bridges Per Year	Total Cost $/SY ($m^2)		
Deterioration level	1	4	10
0%	104.83 (125.38)	80.91 (96.77)	76.14 (91.06)
5%	109.89 (131.43)	85.97 (102.82)	81.20 (97.11)
10%	113.59 (135.85)	89.67 (107.24)	84.90 (101.54)
20%	119.[illegible] (142.37)	95.12 (113.76)	90.35 (108.06)

3.14 Case 13: Resin-Modified Bituminous Concrete System for Decks With Membranes

3.14.1 General Procedure

- Mill 1 1/2 in from existing bituminous concrete overlay, and remove particulate matter.

- Apply light tack coat of asphalt emulsion to milled surface.

- Apply 1 1/2 in open-graded bituminous concrete overlay (void content 25-30%).

- Apply slurry grout.

3.14.2 Milling and Clean up Cost

- Per Item #260, "Removal of Asphalt from Deck Surface", regression equation for cost is (see Table 4-12):

$$C = 6.906 - 7.3\ X\ 10^{-5}Q + \frac{1831.76}{977.8^{1.6280}}$$

$$(n = 446, R^2 = 0.164)$$

$$\textit{where}: C = Cost,\ \$/SY \qquad Q = Quantity, SY$$

$$\textit{for}\ Q = 8800\ sf\ (977.8\ sy),$$

$$C = 6.906 - (7.3\ X\ 106-5)(977.8) + \frac{1831.76}{977.8^{1.6280}} = \$6.86/SY$$

  With traffic maintenance and protection (TMP), mobilization, engineering, and surety bonds (see section 3.1.5), total cost = (1.1056)($6.86/sy) = $7.58/sy

- Ref. 8 gives the following cost estimates (bare 1990 costs) for cold planing asphalt 1-3 in.:

  25,000 sy or more: $1.00/sy
  5,000 - 10,000 sy: $1.50/sy

  Costs can be expected to vary as a function of 1/Q. Therefore, extrapolating the above data on the basis of 1/Q to 977.7 SY gives a cost figure of $6.26/sy. Converting to mid-1991 costs (factor = 1.026), that includes contractor's profit and overhead (factor = 1.1) and TMP, etc. (factor = 1.1056):

  est. total cost = (6.26)(1.026)(1.1)(1.1056) = $7.81/sy, very close to the $7.58/sy figure based on the regression equation.

3.14.3 Asphalt Emulsion Tack Coat Cost

- Per Ref. 19, 1990 estimated cost for tack coat, emulsion, 0.05 gal./sy, in quantity of 1,000 sy = $0.53/sy (total for labor, materials, and equipment, incl. contractor's O&P). Estimated mid-1991 total cost (factor = 1.026) incl. TMP, etc. (factor = 1.1056) =

  ($0.53/sy)(1.026)(1.1056) = $0.60/sy

3.14.4 1 1/2 in. Bituminous Concrete Overlay Cost

- Per Ref. 19, 1990 estimated cost for 1 1/2 in. wearing course asphalt overlay (total for labor, materials, equipment, and contractor's O&P) = $3.20/sy. Estimated mid-1991 total cost (factor = 1.026), incl. TMP, etc. (factor = 1.1056) =

  ($3.20/sy)(1.026)(1.1056) = $3.63/SY

3.14.5 Slurry Grout Cost

3.14.5.1 Materials

- Slurry Mix Proportions*

Ingredient	Weight %
Portland Cement	38.5
Filler (fly ash, limestone dust, rock flour)	19.2
Sand (#30-#200)	12.7
Water	26.8
Latex Resin Modifier (Prosalvia L7)	2.8

*Per Job Spec. from REW 6/9/92

- Material Specific Gravities

Ingredient	Sp. Gr.
Portland Cement	3.15 (typical)
Fly ash (filler)	2.10 (typical)
Sand	2.65 (typical)
Latex Resin Modifier	1.01*

*Mean of 0.980 - 1.040 range given in Material Safety Data Sheet supplied by REW 6/9/92

- Estimated Volumes/100 lb mix

Portland Cement	$\frac{(0.385)(100)}{(62.4)(3.15)} = 0.196\ cf$
Fly Ash	$\frac{(0.192)(100)}{(62.4)(2.10)} = 0.147\ cf$
Sand	$\frac{(0.217)(100)}{(62.4)(2.65)} = 0.077\ cf$
Water	$\frac{(0.268)(100)}{(62.4)(1.00)} = 0.429\ cf$
Latex Resin Modifier	$\frac{(0.028)(100)}{(62.4)(1.01)} = 0.044\ cf$
Subtotal	= 0.893 cf

Assume 1% air, total volume = 0.893/0.99 = 0.902 cf/100 lb.

- Unit Costs of Ingredients

Ingredient	Unit Cost $/lb	Cost Source
Portland Cement	0.07128	Ref. 8: $6.70/94 lb bag
Fly Ash (Filler)	0.0083	F. Campabianco - Centre Conc. $16.60/ton, delivered
Sand	0.00865	Ref. 8: $17.30/ton screened & washed
Water	0.00	
Latex Resin Modified	3.50	Memo from B. D. Prowell 6/5/92

- Estimated Quantities & Costs/cf of Mix

Ingredient	lb/cf mix	Cost	
		Unit, $/lb	$/cf mix
Portland Cement	38.5/0.902 = 42.7	0.07128	3.04
Fly ash	19.2/0.902 = 21.3	0.0083	0.18
Sand	12.7/0.902 = 14.1	0.00865	0.12
Water	26.8/0.902 = 29.7	0.00	0.00
Latex Resin Mod.	2.8/0.902 = 3.1	3.50	10.85
Totals	110.9 lb/cf		$14.19/cf

- Cost/Unit Deck Area

Assume 27.5% void volume in pavement filled with slurry (range = 25 - 30% per spec.). For the 1 1/2 in thick asphalt overlay, vol. voids/sy =

$$\frac{(9\ sf/sy)(1.5\ in)(0.275)}{(12\ in/f)} = 0.31\ cf/sy$$

Assuming 10% waste, bare material cost = (1.10)(0.31 cf/sy)($14.91/cf) = $4.84/sy Incl. contractor O&P and TMP, etc., estimated unit materials cost = ($4.84/sy)(1.1)(1.1056) = $5.89/sy

3.14.5.2 Equipment (Ref. 8)

- Unit Costs

Item	QTY	Bare Cost, each	
		Rental, $/day	Operating, $/hr
Concrete Mixer, 16 ct	2	77.00	1.40
Motorized Concrete Buggy, 18 cf	2	155.00	2.45

- Operating Time - use 4 spreading crews @ 500 sf/h/crew:

$$\frac{8{,}800\ sf}{(500\ sf/h/crew)(4\ crews)} = 4.4\ h$$

- Total Equipment Cost (incl. contractor's O&P plus TMP, etc.)

$$= \frac{(1.1)(1.1056)\{(2)[(77.00)+(1.40)(4.4)]+(2)[(155.00)+(2.45)(4.4)]\}}{(977.8\ sy)} = \$0.62/sy$$

3.14.5.3 Labor (see Section 1.10)

No.	Category	Wage (incl. burden & contr. O&P), $/hr	
		Unit	Total
18* 2 1	Laborers Light Equip (Buggy) Operators Foreman - Outside	28.00 33.80 39.60	504.00 67.60 39.60
	Total		$611.20/hr

* Four spreading crews of 3 laborers each and two batching/mixing crews of 3 laborers each. Time: 4.4 hr. (See Section 3.14.5.2); assume 6 hours including preparation and clean-up. ∴ Unit Labor Cost (Incl Tmp, etc.)

$$= \frac{(1.1056)(\$611.20/hr)(6\ hr)}{(977.8\ sy)} = \$4.15/sy$$

3.14.5.4 Total Cost for Slurry Grout = 5.89+0.62+4.15 = $10.66/sy

3.14.6 Case 13 - Total Cost

Step	Cost $/SY
Milling & Clean-Up Tack Coat Bituminous Overlay Slurry Grout	7.58 0.60 3.63 10.66
TOTAL	$22.47/SY

NOTE: Unit costs for jobs carried out mostly in 1991-2 per Alyan Corp. (See Section 1.11.5.2.) give an average cost of $11.97/sy for 2 in. average thickness. However, according to Mr. Ibrahim Murr of Alyan Corp., these figures do not include milling. If the milling cost is subtracted from the $22.47/sy total, the result is $14.89/sy. This is reasonable agreement, even with the thinner overlay (1 3/4 in), because the Alyan Corp. Figures are for airport pavements of much larger areas (typically 10,000 sy vs. approximately 1,000 sy here) reflecting an economy of scale.

3.15 Cases 14 and 15: Substructure/Superstructure Repairs Using Corrosion Inhibitor Modified Concrete and Corrosion Inhibitor Spray-on Patching System

3.15.1 Information Sources on Cost Data for Superstructure/Substructure Repairs

- Report prepared as part of the same project that this work is being carried out on - contains cost estimates on several "treatment items" closely related to this subject, as follows:

Treatment Item No.	Subject
411	Topical Structural Treatments - Portland Cement Concrete Patching (shallow repairs)
412	Topical Structural Treatments - Portland Cement Concrete Patching (deep repairs)
421	Topical Structural Treatments - Quick-Set Hydraulic Mortar/Concrete Patches (shallow repairs)
422	Topical Structural Treatments - Quick-Set Hydraulic Mortar/Concrete Patches (deep repairs)

Treatment items #411 and #412 were developed from regression of historical Highway DOT bid price data. Items #421 and #422 were prepared using engineering estimating procedures, since insufficient empirical data existed (see Appendix B). While both sets of information (#411/#412 and #421/#422) provide costs or a function of quantity (costs are extremely sensitive to low quantity uses such as patching), #421/#422 also give costs by individual superstructure/substructure bridge member. Also, #421/#422 gives breakdowns of cost by component, allowing simple arithmetic substitutions in arriving at estimates for the inhibited concrete cases. Therefore, treatment items #421/#422 were used as the basis for carrying out the estimates here.

Ref 8: (R.S. Means Concrete Cost Data) Gives Unit prices for patching concrete ranging from 3.41 to 10.75/sf, incl. contractor's overhead & profit (= $33.93 to $106.79/sy, incl. Traffic Maintenance & protection, etc.). However, these again do not take into account effects of quantity on price.

3.15.2 Descriptions of Procedures

3.15.2.1 Type I: Remove concrete to below rebar, and patch with corrosion inhibitor modified concrete.

- Outline area to be removed with 3/4" deep saw cut and remove concrete to a depth of 1.5X the maximum size aggregate in the patch concrete using pneumatic breakers.

- Sandblast exposed rebars

- Clean cavity - remove all particulate materials

- Apply concrete grout containing corrosion inhibitor

- Patch with inhibitor-modified concrete
  -Cortec 2000 (2 pts/cy)
  -DCI (6 gal/cy) (plus high range water reducer and a retarder)

- Moist cure 7 days (min) and air dry 24 hours (min).

- Apply penetrating sealer to repaired area

3.15.2.2 Type II: Remove concrete to rebar depth and apply corrosion inhibitor spray-on patch system.

- Outline area to be removed with 3/4" deep saw cut and remove concrete to the depth of the rebars using pneumatic breakers.

- Clean cavity - remove all particulate material

- Protect from rain and runoff

- Spray on corrosion inhibitor.
  - Cortec 2020 (225 sf/gal) @ 0,2,& 12 h
  -Postrite (15% calcium nitrite (150 sf/gal) @ 0,1,& 8 H
  -Alox: 4.7 wt% in ethanol (70 sf/gal) @ 0,1, & 4 h

- Lightly sandblast surface

- Remove particulate materials

- Apply concrete grout containing inhibitors

- Patch with inhibitor modified concrete
  - Cortec 2000 (2 pts/gal)
  - DCI (6 gal/cy) + HRWR + Retarder
  -Alox - None

- Moist cure 7 d (min) and air dry 24 h (min)

- Apply penetrating sealer. (Note: per phone discussion with REW 8/10/92, the entire structure sealed. Therefore, large area application, but in cost estimate only use area of patch.)

3.15.3 Approach

- The procedures and criteria for Treatment Items #422 and #421 (Section 3.15.1) are essentially the same as those outlined for Type I and Type II repairs, respectively, in Section 3.15.2. The only major difference is the use of different materials (spray-on corrosion inhibitors and corrosion inhibitor - modified concrete and bonding grout.

- Therefore, the approach will be to use the equipment and labor costs for Treatment Items #422 and #421 with material costs and other cost items related to the use of corrosion inhibitors in arriving at unit costs for the Type I and Type II repairs.

3.15.4 Equipment and Labor Costs (from Table B-1, pp. 161-165).

Bridge Member	Type Repair	Data From Table B-1				
		Treatment Item	Repair Range*	Repair Area (sy)**	Crew Cost ($)	Equip. Cost ($)
Beams	I	#422	Low	6.6	741.60	399.39
			Med	13.1	741.60	399.39
			High	26.2	741.60	399.39
	II	#421	Low	6.6	741.60	399.39
			Med	13.1	741.60	399.39
			High	26.2	741.60	399.39
Diaphragms	I	#422	Low	0.9	741.60	399.39
			Med	1.9	741.60	399.39
			High	2.8	741.60	399.39
	II	#421	Low	0.9	741.60	399.39
			Med	1.9	741.60	399.39
			High	2.8	741.60	399.39
Piers	I	#422	Low	2.6	1,010.40	548.23
			Med	6.6	1,010.40	548.23
			High	13.2	1,485.29	805.90
	II	#421	Low	2.6	1,010.40	548.23
			Med	6.6	1,010.40	548.23
			High	13.2	1,010.40	548.23
Pier Caps	I	#422	Low	5.0	1,010.40	548.23
			Med	10.0	1,121.54	608.54
			High	40.0	4,486.18	2,434.14

Bridge Member	Type Repair	Data From Table B-1				
		Treatment Item	Repair Range*	Repair Area (sy)**	Crew Cost ($)	Equip. Cost ($)
Pier Caps Cont'd	II	#421	Low	5.0	1,010.40	548.23
			Med	10.0	1,010.40	548.23
			High	40.0	2,243.09	1,217.07
Backwalls	I	#422	Low	1.5	1,221.48	621.71
			Med	3.0	1,221.48	621.71
			High	12.0	1,624.57	826.87
	II	#421	Low	1.5	1,221.48	621.71
			Med	3.0	1,221.48	621.71
			High	12.0	1,221.48	621.71
Abutments	I	#422	Low	1.2	1,221.48	660.21
			Med	3.0	1,221.48	660.21
			High	6.0	1,636.78	884.68
	II	#421	Low	1.2	1,221.48	660.21
			Med	3.0	1,221.48	660.21
			High	6.0	1,221.48	660.21
Wingwalls	I	#422	Low	0.7	784.86	576.55
			Med	1.8	784.86	576.55
			High	3.6	784.86	576.55
	II	#421	Low	0.7	784.86	576.55
			Med	1.8	784.86	576.55
			High	3.6	784.86	576.55

* Definition of Repairs Ranges in Terms of Percent of total surface area of Bridge member affected (See Table B-3, pg. 167).

Bridge Member	Repair Area %		
	Low	Med.	High
Beams	0.5	1.0	2.0
Diaphragms	1.0	2.0	3.0
Piers	2.0	5.0	10.0
Pier Caps	5.0	10.0	40.0
Backwalls	5.0	10.0	40.0
Abutments	2.0	5.0	10.0
Wingwalls	2.0	5.0	10.0

** Avg. Repair Depths

Treatment Item	Repair Type	Avg. Depth (in).
#422	I	4
#421	II	2

3.15.5 Material Costs & Related Cost Items

3.15.5.1 Type I Repair Procedure (Incl. Contractors Overhead & Profit plus Traffic Maintenance & Protection, Mobilization, Engineering, and Surety Bonds).

- Remove Concrete to below rebars: Covered under "Crew" and "Equipment" costs.

- Sandblast Exposed Rebars: Covered under "crew" and Equipment costs.

- Remove Particulate Materials: $0.08/sy (See Section 3.7.4.2).

- Apply Grout Containing Inhibitor: (See Section 3.7.4.3; materials only - equipment & labor included in "Crew" and "Equipment" costs).

Inhibitor	Cost, $/SY
DCI	1.65
Cortec 2000	0.46

- Patch With Inhibitor Modified Concrete (See Section 3.7.4.4; materials only - Equipment and labor included in "Crew" and "Equipment" costs.)

Inhibitor	1 3/4" Thick Patch, $/SY (Bare)			4" thick Patch (incl. Contr. O&P, TMP, etc.)
	Admix	Concr.	Total	
DCI	2.04	3.67	5.71	15.87
Cortec 2000	0.88	3.67	4.55	12.65

*Incl. inhibitor

**Factor = (4/1.75)(1.1)(1.1056) = 2.78

- Moist Cure 7d & Air Dry 24 h: Cost negligible.

- Apply Penetrating Sealer: Sealer will be applied to entire superstructure/substructure (per REW). Estimated total area for average bridge (See Table B-3, pg. 167) = 1,761 sy. Per REW use silane or siloxane type sealer. Regression equation for empirical cost data for silane/siloxane penetrating sealers (Treatment item #242/#522):

$$C = 8.652 + 7.04\ X10^{-5}Q + \frac{56.077}{Q^{1.2394}}$$

Where C = Cost, \$/SY (incl. Cont. O&P)
Where Q = Quantity, SY
∴ For Q = 1,761 SY:

$$C = 8.652 + (7.04\ X\ 10^{-5})(1,761) + \frac{56.077}{(1,761)^{1.2394}} = \$8.78/SY$$

Incl. TMP, etc. = (8.78)(1.1056) = \$9.71/SY

Total: Material Cost & Related Cost Items for Type I Repair Procedure:

DCI Inhibitor	=	\$27.31/SY
Cortec 2000 Inhibitor	=	\$22.90/SY

3.15.5.2 Type II Repair Procedure (Incl. Contractor's Overhead & Profit plus Traffic Maintenance & Protection, Mobilization, Engineering, and Surety Bonds.)

- Remove Concrete to rebars: Covered under "Crew" and "Equipment" costs.

- Remove Particulate Fines: \$0.08/SY (See Section 3.7.4.2)

- Weather Protection: Use polyethylene sheeting - cost negligible.

- Spray-on Corrosion Inhibitor (See Section 3.7.3.1) (Note: Labor & Equip, Negligible).

Inhibitor	Cost, \$/SY
Postrite	7.22
Cortec 2020	7.24
Alox	3.65

- Fire Protection (Alox only - ethanol diluent): Assume hand-held extinguisher @ rental cost (incl. Contractor's O&P & TMP, etc.) = $1.00/SY

- Lightly Sandblast Concrete Surface (See Section 3.7.4.1): $8.74/SY
- Remove Particulate Fines (See Section 3.7.4.2): $0.08/SY
- Apply Grout Containing Inhibitor (See Section 3.7.4.3)

Inhibitor System	Inhibitor in Grout	Material Cost, $/SY
Postrite	DCI	1.65
Cortec 2020	Cortec 2000	0.46
Alox	none	0.33

(NOTE: Material cost only - equipment & labor included in "Crew" and "Equipment" costs.)

- Patch with Inhibitor Modified Concrete (See Section 3.7.4.4; Material cost only - equipment & labor included in "Crew" and "Equipment" costs.)

Inhibitor	1 3/4" Thick Patch, $/SY (Bare)			2" thick Patch (incl. Contr. O&P, TMP, etc.)
	Admix	Concr.	Total	
DCI	2.04	3.67	5.71	7.94
Cortec 2000	0.88	3.67	4.55	6.32
none (Alox)	0.02	3.67	3.69	5.13
*Incl. inhibitor **Factor = (2/1.5)(1.1)(1.1056) = 1.39				

- Moist Cure 7d & Air Dry 24 h: Cost Negligible
- Apply Penetrating Sealer (See Section 3.15.5.1): $9.71/SY

Total: Material Cost & Related Cost Items for Type II Repair Procedure:

Postrite/DCI Inhibitor:	$35.42/SY
Cortec 2020/2000 Inhibitor:	$32.63/SY
Alox/More Inhibitor:	$28.72/SY

3.15.6 Cases 14 & 15 - Total Estimated Unit Costs: See Table next page
NOTE: These costs are per SY of repair area (not member area).

Bridge Member	Type Repair	Per Table B-1			Crew & Equip. Incl. TMP, etc., $/SY	Crew & Equip. Unit Cost $/SY	Mat'ls & Spl. Items for Inhib. Modified Conc., $/SY			Total Est. Cost, $/SY (of Rep. Area)		
		Deterioration		Crew & Equip. $			Ca-Ni	Cortec	Alox	Ca-Ni	Cortec	Alox
		Range (%)	Area, SY									
Beams	I	L (0.5)	6.6	1,140.99	1,261.48	191.13	27.31	22.90		218.44	214.03	
		M (1)	13.1	1,140.99	1,261.48	96.30	27.31	22.90		123.61	119.20	
		H (2)	26.2	1,140.99	1,261.48	48.15	27.31	22.90		75.46	71.05	
	II	L (0.5)	6.6	1,140.99	1,261.48	191.13	35.42	32.63	28.72	226.55	223.76	219.85
		M (1)	13.1	1,140.99	1,261.48	96.30	35.42	32.63	28.72	131.72	128.93	125.02
		H (2)	26.2	1,140.99	1,261.48	48.15	35.42	32.63	28.72	83.57	80.78	76.87
Diaph-ragms	I	L (1)	0.9	1,140.99	1,261.48	1,401.64	27.31	22.90		1,428.95	1,424.54	
		M (2)	1.9	1,140.99	1,261.48	663.94	27.31	22.90		691.25	686.84	
		H (3)	2.8	1,140.99	1,261.48	450.53	27.31	22.90		477.84	473.43	
	II	L (1)	0.9	1,140.99	1,261.48	1,401.64	35.42	32.63	28.72	1,437.06	1,434.27	1,430.36
		M (2)	1.9	1,140.99	1,261.48	663.94	35.42	32.63	28.72	699.36	696.57	692.66
		H (3)	2.8	1,140.99	1,261.48	450.53	35.42	32.63	28.72	485.95	483.16	479.25
Piers	I	L (2)	2.6	1,558.63	1,723.22	662.78	27.31	22.90		690.09	685.68	
		M (5)	6.6	1,558.63	1,723.22	261.09	27.31	22.90		288.40	283.99	
		H (10)	13.2	2,291.19	2,533.14	191.90	27.31	22.90		219.21	214.80	
	II	L (2)	2.6	1,558.63	1,723.22	662.78	35.42	32.63	28.72	698.20	695.41	691.50
		M (5)	6.6	1,558.63	1,723.22	261.09	35.42	32.63	28.72	296.51	293.72	289.81
		H (10)	13.2	1,558.63	1,723.22	130.55	35.42	32.63	28.72	165.97	163.18	159.27
Pier Caps	I	L (5)	5.0	1,558.63	1,723.22	344.64	27.31	22.90		371.95	367.54	
		M (10)	10.0	1,730.08	1,912.78	191.28	27.31	22.90		218.59	214.18	
		H (40)	40.0	6,920.32	7,651.11	191.28	27.31	22.90		218.59	214.18	
	II	L (5)	5.0	1,558.63	1,723.22	344.64	35.42	32.63	28.72	380.06	377.27	373.36
		M (10)	10.0	1,558.63	1,723.22	172.32	35.42	32.63	28.72	207.74	204.95	201.04
		H (40)	40.0	3,460.16	3,825.55	95.64	35.42	32.63	28.72	131.06	128.27	124.36

Bridge Member	Type Repair	Per Table B-1			Crew & Equip. Incl. TMP, etc., $/SY	Crew & Equip. Unit Cost $/SY	Mat'ls & Spl. Items for Inhib. Modified Conc., $/SY			Total Est. Cost, $/SY (of Rep. Area)		
		Deterioration		Crew & Equip. $			Ca-Ni	Cortec	Alox	Ca-Ni	Cortec	Alox
		Range (%)	Area, SY									
Back-walls	I	L (5)	1.5	1,848.19	2,037.83	1,358.55	27.31	22.90		1,385.86	1,381.45	
		M (10)	3.0	1,848.19	2,037.83	679.28	27.31	22.90		706.59	702.18	
		H (40)	12.0	2,451.44	2,710.31	225.86	27.31	22.90		253.17	248.76	
	II	L (5)	1.5	1,843.19	2,037.83	1,358.55	35.42	32.63	28.72	1,393.97	1,391.18	1,387.27
		M (10)	3.0	1,843.19	2,037.83	679.28	35.42	32.63	28.72	714.70	711.91	708.00
		H (40)	12.0	1,843.19	2,037.83	169.82	35.42	32.63	28.72	205.24	202.45	198.54
Abut-ments	I	L (2)	1.2	1,881.69	2,080.40	1,733.67	27.31	22.90		1,760.98	1,756.57	
		M (5)	3.0	1,881.69	2,080.40	693.47	27.31	22.90		720.78	716.37	
		H (10)	6.0	2,521.46	2,787.73	464.62	27.31	22.90		491.93	487.52	
	II	L (2)	1.2	1,881.69	2,080.40	1,733.67	35.42	32.63	28.72	1,769.09	1,766.30	1,762.39
		M (5)	3.0	1,881.69	2,080.40	693.47	35.42	32.63	28.72	728.89	726.10	722.19
		H (10)	6.0	1,881.69	2,080.40	346.73	35.42	32.63	28.72	382.15	379.36	375.45
Wing-Walls	I	L (2)	0.7	1,361.41	1,505.17	2,150.24	27.31	22.90		2,177.55	2,173.19	
		M (5)	1.8	1,361.41	1,505.17	836.21	27.31	22.90		863.52	859.11	
		H (10)	3.6	1,361.41	1,505.17	418.10	27.31	22.90		445.41	411.00	
	II	L (2)	0.7	1,361.41	1,505.17	2,150.24	35.42	32.63	28.72	2,185.66	2,182.87	2,178.96
		M (5)	1.8	1,361.41	1,505.17	836.21	35.42	32.63	28.72	871.63	868.84	864.93
		H (10)	3.6	1,361.41	1,505.17	418.10	35.42	32.63	28.72	453.52	450.73	446.82

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