CONCRETE BRIDGE DECK CORROSION

IN ALASKA

FINAL REPORT

by

Matthew K. Reckard
Research Engineer

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STATE OF ALASKA
DEPARTMENT OF TRANSPORTATION
DIVISION OF PLANNING
RESEARCH SECTION
2301 Peger Road
Fairbanks, Alaska 99701-6394

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FOREWORD

The premature deterioration of concrete bridge decks due to salt-induced corrosion of reinforcing steel (rebar) has become a major highway maintenance problem in the United States. Evidence of this type of damage has appeared on some Alaskan bridge decks, some of which have required expensive repair work.

The Bridge Deck Corrosion Project was undertaken to gain a better understanding of this problem in Alaska and to recommend actions which the Department of Transportation and Public Facilities (DOT&PF) can take to protect Alaska's investment in highway bridges. The conclusions of the project are presented in Chapter 1 of this report.

As part of the project, a literature review was made of the mechanism of deck corrosion problems and the past or proposed methods of their prevention and repair. This is presented in Chapter 3 of this report.

Chapter 4 contains a discussion of bridge deck repairs which have been made in Alaska, their costs, and the performance of these repairs since they were made.

Detailed inspections were made on a number of bridge decks throughout Alaska in order to assess the severity of the corrosion problem in the state. The results of the tests are presented in Chapter 5. The interpretation of test results, the limitations of specific tests, and potential difficulties in testing programs are discussed in Appendix A.

Appendix B contains unit cost information for concrete bridge decks and for systems to prevent and repair corrosion problems in those decks. This information was used in developing the recommendations in this report, and should be useful in estimating the costs of future deck construction and repair projects.

IMPLEMENTATION

Implementation of this report's recommendations will be straightforward as it does not involve large departures from current practices. This is due to this report's findings that few bridge decks in Alaska have severe corrosion problems and because current design procedures are for the most part adequate.

Remaining funds appropriated for this study should be adequate to train and equip personnel from the Bridge Design Section for deck testing. It should also be sufficient to perform tests on most of the highest priority bridges.

The above work, coupled with distribution of this report, should allow for further deck testing, as warranted, by bridge inspection personnel without significant changes in organization or policy.

Recommendations 5 and 6, which involve changes in allowable protection systems in particular circumstances, can be included in the special provisions of individual projects where applicable.

Scheduling of deck repair work in the Anchorage area should be made by Central Region Planning in consultation with the Bridge Design Section.

Developments in the field of deck corrosion prevention and repairs will continue to be monitored by the Research Section, and important findings will be relayed to the appropriate sections within DOT&PF.

CHAPTER 1
CONCLUSIONS AND RECOMMENDATIONS

The following conclusions have been reached from the work on this project:

1. Deck corrosion problems are less serious in Alaska then in most states. This is probably a result of the following factors:

   - Deicing salts are used less in Alaskan cities and towns than in many parts of the U.S.; outside of cities and towns such use is almost non-existent in Alaska.
   - The Alaskan climate is colder than other parts of the U.S. "Corrosion activity . . . is said to double for each ten degree increase in temperature" (ref. 1, p. 4-4).
   - Coastal areas in Alaska, which are exposed to airborne salts from the ocean, generally receive high rainfall which helps to flush these salts from bridge deck surfaces.

2. The State of Alaska should not be complacent towards deck corrosion problems, despite conclusion No. 1 above. Corrosion of rebar has caused severe damage to certain bridge decks in Alaska.

3. Corrosion problems on Alaskan bridge decks have in nearly all cases been in areas where there was less concrete cover over rebar than that specified in the bridge plans.

4. The slower progress of deck corrosion in Alaska means that repairs, in general, will be more durable and cost-effective than elsewhere. The retrofit of waterproof membranes and asphalt overlays, for example, will generally be effective after a longer period of unprotected exposure in Alaska than elsewhere.

5. Deterioration of deck surfaces due to frost action and traffic wear affects more Alaskan bridges than does corrosion of the rebars. Much of this may be due to overfinishing of the concrete during

construction, which may adversely affect the water content, aggregate gradation, and air entrainment in the near-surface concrete. Deck repair programs should be designed with these problems of surface deterioration in mind.

6. Alaskan deck corrosion problems appear to be most severe in the Central Region in general and in Anchorage in particular. This conclusion is based on a limited amount of testing done for this project, and should not be construed to mean such problems don't exist elsewhere.

7. The major deck repair projects performed on Glenn Highway bridges in 1973 and Ketchikan viaducts in 1974 have been effective. All of the repaired decks are in better condition now than prior to these repairs. It is too soon to judge the effectiveness of deck repairs made in Fairbanks in 1982 and 1983, but all of the decks are currently in very good condition.

8. Changes in deck construction procedures and specifications in the past decade have been worthwhile. These include the use of Class "A-A" concrete, which has more cement, a lower water/cement ratio, and more entrained air than normal structural concrete. Deck protection systems are also now required on all new federal-aid bridges. A third improvement is the explicit requirement to check the clearance between the screed of the laydown machine and the top rebar mat, which was added in the 1981 Standard Specifications. This has undoubtedly already prevented problems with inadequate concrete cover which were previously common.

The following actions and procedures are recommended:

1. Alaska DOT&PF's Bridge Design Section should be provided with equipment and training to enable them to perform detailed deck corrosion testing.

2. Deck corrosion testing should become an established component of the bridge inspection and inventory program. It should not, however, be made a part of the routine biannual inspections made by Bridge Design Section personnel.

3. High priority for deck repairs should be assigned to:

   - new, unprotected decks which are not yet salt contaminated,
   - decks with severe existing problems,
   - decks which form part of the main bridge support system (e.g. bulb-tees),
   - decks with high traffic volumes and/or on major intercity routes.

   Priorities are discussed in more detail in Chapter 2, and a suggested system is tabulated in Table 2-4.

4. Special care should be taken during construction to ensure that the specified minimum concrete cover is attained and that deck concrete is not overfinished. The latter point is more important in preventing frost and traffic wear damage than in preventing rebar corrosion.

5. Three inches (3") of concrete cover should be allowed as an alternative to other deck protection systems on bridges located in areas expected to remain rural throughout the design life of the bridge.

6. The use of waterproof membranes with asphalt overlays should be discouraged on new decks where rapid wear of the overlay is likely. This includes bridges with high traffic volumes, areas where tire chains are frequently used, and bridges on unpaved roads.

7. Deck repair work should be scheduled for the Spenard Overpass on Minnesota Avenue in Anchorage. Further testing of bridge decks in Anchorage should precede this work so that other decks can be repaired under the same contract if warranted.

8. Developments in the field of concrete deck protection and repair should be monitored as there is a great deal of research being conducted in this area.

CHAPTER 2

DECK RATINGS AND REPAIR PRIORITIES

The Federal Highway Administration (FHWA) has developed a deck condition rating system which is summarized in Table 2-1. This rating system has proved to be a useful tool for analysis, and it has gained wide acceptance in other states. The "electrical potential" mentioned in the table is that measured with respect to a copper-copper sulfate half-cell; the figure 0.35 in the table refers to a negative voltage. Chloride contents are found by chemical analysis of concrete samples taken from the deck. "Contaminated" concrete is defined as that with an electrical potential more negative than -0.35V and/or a chloride ion content greater than two pounds per cubic yard. More detailed explanations of the tests used to produce data for this rating system can be found in Appendix A and reference 2.

Table 2-2 lists what are currently judged to be the best reconstruction techniques for a common range of deck conditions. The table is adapted from the list of procedures accepted by the FHWA prior to February 1984. It has been adjusted to reflect new knowledge and techniques and the greater flexibility afforded by the new FHWA regulations.

Several options are listed for each deck condition category. Even technique "F" (the only one listed for uncontaminated decks) actually offers a choice of four types of protective systems. Unique conditions at each site will affect the relative merits of different reconstruction techniques.

Factors which affect the relative costs and performance of various repair techniques are discussed in some detail in Chapter 3. The most important, of course, is the condition of the deck. The type of deck construction, the deck's age and functional adequacy, traffic characteristics, and the severity of salt exposure may also influence the choice of repairs.

Certain conditions not specifically related to the deck itself can also influence the choice of repair techniques. Among these are the condition of other parts of the bridge, the impact of lane closures, possible alternate routes around the bridge, and whether or not the adjoining road system is paved.

There is a great deal of research in the field of deck repairs, and Table 2-2 will need to be updated as increased experience and knowledge is gained. "Deep polymer impregnation," for example, is a promising method for halting ongoing corrosion activity (see Chapter 3). If faster and cheaper construction methods can be developed, this technique could be used where cathodic protection is now the only accepted repair method. Similarly, high pressure water systems may make concrete removal and preparation for overlays cheaper, quicker, and simpler.

In general, the earlier a deck receives attention, the cheaper it will be to prevent or repair corrosion damage. Installing a protection system into a new deck is cheaper than repairing it later. Repairing minor damage (and preventing further salt contamination) is generally cheaper in the long run than allowing a deck to deteriorate.

Permanent reconstruction (which will prevent further corrosion damage) is typically a more favorable solution on lightly damaged and/or newer decks. On older and/or more severely damaged decks, "cost-effective" repairs (which extend the life of a deck but don't permanently halt corrosion) are likely to be the most cost-effective treatment.

Faced with numerous bridge decks in various conditions and a limited budget, priorities must be set for repair work. Table 2-3 shows a system of priorities established by the Minnesota Department of Transportation in 1976. The deck condition categories in Table 2-3 correspond roughly to those of the FHWA shown in Table 2-1. Both the repair systems and the priorities were set by "a task force made up of personnel from the Office of Bridge Design and Construction, Materials, Research and Standards" after an extensive inspection and analysis program.

The assignment of priorities in this table shows an interesting repair strategy. While well-traveled bridge decks in critical condition receive the highest priority, attention next shifts to decks with only slight deterioration. This resulted from cost-benefit analyses which showed permanent restoration of these decks would be more cost effective -- by a factor of two or three -- than salvage efforts on decks where corrosion was already well underway. "An ounce of prevention," in other words, "would in fact be worth a pound of cure." Although absolute costs are higher in

Alaska than in Minnesota, the relative cost effectiveness of the various deck repair techniques is similar, and thus this ranking of repair priorities should be applicable to Alaska.

Some exceptions were made to the priority ranking listed in Table 2-3. One of these deals with "bridges in which the deck is a portion of the main structural support member"; within any traffic volume category these bridges "should receive priority over all other bridges." Other exceptions involved matters of practicality; a lower-priority bridge might be repaired along with higher priority ones in the same vicinity under the same contract, or repair of a high priority deck might be delayed if it was needed as a detour around another bridge under construction.

The Minnesota program seems well thought out, and the effort and experience that went into it can be used to advantage in Alaska. There are differences between the two states, however, which need to be recognized.

One of these is that categorizing bridges by traffic volume alone is inadvisable in Alaska. Few Alaskan bridges outside of urban areas carry over 2,000 vehicles per day, yet many are part of intercity highways which are vital to the state's transportation system. High priority should be given to all bridges on these routes. Few of Alaska's rural bridges, fortunately, seem to have serious deck corrosion problems (see Chapter 5).

Corrosion problems in Alaska appear to be less severe, and to develop less rapidly, then in most other states. As a result, the double protection systems recommended for Minnesota's high-traffic-volume bridges (epoxy coated rebars and special concrete overlays) are probably unnecessary in Alaska. In fact, the 3 inch minimum cover of dense concrete recommended for Minnesota's low-traffic-volume bridges should adequately protect any Alaskan bridge deck.

With these thoughts in mind, a repair priority matrix for Alaska was developed and is presented in Table 2-4. This is intended as a guideline; practical considerations may warrant that exceptions be made (e.g. including a lower priority deck in the same project as a nearby high priority deck).

TABLE 2-1 - CONCRETE BRIDGE DECK EVALUATION

Category Classification	Rating	Condition Indicators (% deck area): Spalls	Delaminations	Electrical Potential	Chloride Content #/CY
	9	none	none	0	0
Category #3 Light Deterioration	8	none	none	none > 0.35	none > 1.0
	7	none	< 2%	95% < 0.35	none > 2.0
Category #2 Moderate Deterioration	6	< 2% spalls *or* sum of all deteriorated and/or contaminated deck concrete < 20%			
	5	< 5% spalls *or* sum of all deteriorated and/or contaminated deck concrete 20 to 40%			
Category #1 Extensive Deterioration	4	> 5% spalls *or* sum of all deteriorated and/or contaminated deck concrete 40 to 60%			
	3	> 5% spalls *or* sum of all deteriorated and/or contaminated deck concrete > 60%			
Structurally Inadequate Deck	2	Deck structural capacity grossly inadequate			
	1	Deck has failed completely. Repairable by replacement only			
	0	Holes in deck - danger of other sections of deck failing			

From: "Recording and Coding Guide for the Structural Inventory and Appraisal of the Nation's Bridges," FHWA, January 1979.

TABLE 2-2 RECONSTRUCTION OPTIONS

Deck Condition	Permanent Reconstruction (stops corrosion)	Cost-effective Repairs (extends deck life)
Structurally Inadequate	A, B	
Extensive Deck Deterioration	A, B, C	D
Moderate Deck Deterioration	A, B, C, E	D
Light Deck Deterioration	C, E	D, F
Uncontaminated Deck	F	

RESTORATION WORK:

A: Complete deck replacement with Protective Systems I, II, or III.
B: Pour new deck on top of old with Protective Systems I, II, or III.
C: Remove and replace deteriorated concrete, install Protective System IV.
D: Remove and replace deteriorated concrete, install Protective System I or III.
E: Remove and replace all contaminated concrete, install Protective System I or III.
F: Install Protective System I or III.

PROTECTIVE SYSTEMS:

I: Waterproof membrane and asphalt concrete overlay.
II: Epoxy-coated rebars.
III: Polymer, polymer-modified (e.g. latex-modified), or two-coarse dense (Iowa system) concrete overlay.
IV: Cathodic protection system.

TABLE 2-3 - MINNESOTA DOT DECK REPAIR SYSTEMS AND PRIORITIES

Deck Condition	TRAFFIC VOLUME (VPD) > 10,000	2,000-10,000	< 2,000
Slight Deterioration	Priority 3 Spot removal and concrete overlay	Priority 4 Spot removal and concrete overlay or membrane and bituminous overlay	Priority 10 Spot removal and concrete overlay or membrane and bituminous overlay
Moderate Deterioration	Priority 6 Spot removal and concrete overlay	Priority 7 Spot removal and concrete overlay	Priority 11 Spot removal and concrete overlay or membrane and bituminous overlay
Severe Deterioration	Priority 8 Total removal to rebars with minimum spot removal below bars - concrete overlay	Priority 9 Total removal to rebars with minimum spot removal below bars - concrete overlay	Priority 12 Total removal to rebars and minimum spot removal below bars - concrete overlay
Critical	Priority 1 Program new deck: epoxy-coated rebars and special concrete overlay	Priority 2 Program new deck: epoxy-coated rebars or special concrete overlay or membrane and bituminous overlay	Priority 5 Program new deck: minimum water/cement ratio concrete and 3 inches clear cover

Adapted from Robert G. Tracy, "Scheduling the Bridge Deck Repair Program," in Public Works, January 1980.

TABLE 2-4 RECOMMENDED ALASKAN DECK REPAIR PRIORITIES

Deck Condition	> 10,000 vpd or on major Intercity Route	2,000-10,000 vpd	< 2,000 vpd
Uncontaminated	3	4	8
Slight Deterioration	5	6	13
Moderate Deterioration	9	10	14
Severe Deterioration	11	12	15
Critical	1	2	7

Notes: Major intercity routes include the following highways: Alaska, Dalton, Glenn, Parks, Richardson, Seward, Sterling, and Tok Cutoff.

Exceptions should be made for bridges whose decks are part of the main structural support (e.g. bulb-tees). These bridges should receive priority over all other bridges in their traffic volume category.

CHAPTER 3: BRIDGE DECK CORROSION PREVENTION AND REPAIR TECHNIQUES

The mechanism of bridge deck corrosion is discussed in detail in the literature and will not be described at length here. Briefly, concrete which has become contaminated with chloride ions from deicing salts or seawater becomes an effective electrolyte enabling galvanic corrosion cells to become established between different parts of the steel. Corrosion products (rust) produced at the anodic areas of steel occupy a larger volume than the original steel and therefore exert high pressures on the surrounding concrete. Cracks then form and grow in the concrete, a process accelerated by freeze/thaw cycles of any water in the cracks. Eventually, the concrete cover above the top mat of reinforcing steel spalls off. This results in poor riding quality, higher maintenance costs, and ultimately in structural damage to the bridge.

Strategies for coping with this problem fall into two broad categories; prevention and cure.

Protection Systems for New Decks

Preventative measures are usually designed to keep the concrete surrounding the rebars free of chloride contamination. These include the following:

- insuring good drainage from the deck to avoid ponding of water and salts.
- reducing or eliminating the use of deicing salts.
- increasing the thickness of the concrete cover over the rebars.
- placement of a waterproof membrane and bituminous riding surface over the deck.
- use of special, water resistant concretes to cover the top mat of rebar.

There are several types of concrete in the latter group, the most common of which are dense concrete with high cement content and a low water/cement ration (the "Iowa system"), latex-modified concrete, and polymer concrete.

Another preventative measure is the use of epoxy-coated steel in the upper portions of the deck. Instead of preventing chloride contamination of the concrete, this method attempts to electrically isolate the steel from the concrete, thus preventing galvanic reactions. Yet another method which has been tried experimentally is the use of concrete containing corrosion inhibiters (e.g. calcium nitrite).

None of these methods will guarantee that corrosion will never occur on the deck, but all should result in lengthening the amount of time before corrosion begins. If the contamination can be delayed long enough - past the useful life of the bridge as a whole - the corrosion problem is effectively solved. Most new concrete decks in Alaska are built with either waterproof membranes or epoxy-coated rebars. In general, the use of either of these or polymer-modified concrete (PMC) in the top 1 1/2 inches of the deck is allowed in Alaska contracts, with the choice left up to the contractor. There is a large amount of literature on the relative merits of these techniques; the best method may well depend on the specific circumstances of a particular deck. Some states now use two protective systems on the same deck if it is thought to be particularly vulnerable to corrosion.

Waterproof membranes with asphalt concrete (AC) overlays are very effective when correctly installed. The membrane, however, can be punctured during installation or improperly cured by placing the overlay at an incorrect temperature; it is difficult to be certain if these errors have been made. The AC overlay is relatively soft and can be worn off by traffic, particularly if chains are heavily used. The Water Street and Tongass Avenue Viaducts in Ketchikan, for example, have had three AC wearing courses in ten years; on some bridges in mountainous parts of California AC overlays have lasted only two years (reference 3). While they wear readily, AC overlays can also be renewed easily, at least if done before the membrane has been damaged. Mobilizing equipment to overlay a deck located far from the paved road system, however, may be very costly. AC overlays make later deck condition surveys (chain dragging and half-cell testing) more difficult and less accurate, and deck concrete sampling for chloride analysis cannot be done without puncturing the membrane.

Polymer-modified concrete surfaces are subject to wear too. Although the wear is slower than for AC concrete, PMC overlay replacement is more difficult. Bridge inspection records indicate that traffic wear is a problem on many Alaskan concrete decks, particularly on unpaved roads. This is probably due to the grinding of loose gravel under the wheels of traffic. One solution to this is to maintain an asphaltic wearing course on the deck, which can be renewed as necessary. Even so, the protection given by a PMC surface may be compromised by cracks, which can allow salts to penetrate to rebar level.

Given the uncertainties of the various deck protection techniques, the current policy of allowing the contractor a choice of systems is a good one. As more experience is gained, both in Alaska and elsewhere, this may change. The choice of protection system in Alaska is probably not as critical as in many other parts of the U.S. which have more severe corrosion problems.

Increasing the thickness of concrete cover over the top rebars could be added to the list of contractor options. Deck inspections in Alaska have shown little or no damage in deck areas with two or more inches of cover. Research by the New York State DOT indicated that 2 1/2 inches of cover should provide at least 30 years of protection against spalling, compared to only 10 years with 2 inches cover and 5 years with 1 1/2 inches. The increase in dead load from the added cover should not exceed that added by membranes with asphalt overlays.

Membranes and asphalt overlays are by far the most common type of deck protection in Alaska. The average cost of these is about $24 per square yard in 1982 dollars. Extreme cases have cost as little as half and as much as twice this amount. Estimates of cost for increasing cover thickness or using a PMC layer are in the same general range, although experience with both in Alaska is inadequate to confirm this.

The literature indicates that epoxy-coated rebars should be cheaper than other deck protection methods. Here too there has not been enough experience in Alaska to confirm this. Recent research with laboratory-scale concrete slabs subjected to accelerated salt contamination and weathering have shown very encouraging results with epoxy-coated rebars (reference 4). This was true even when the coating had more defects ("holidays") than allowed by AASHTO or ASTM specifications. Epoxy-coated rebar, of course, does not increase dead loads as do asphalt overlays or increased concrete cover. These factors indicate that for both costs and performance reasons, the use of epoxy-coated rebars may increase in the future.

Calcium nitrite added to deck concrete during mixing has also been very effective at inhibiting corrosion under experimental conditions (reference 4). There is no long term field experience with this technique, however. The amount of inhibiter required is quite small (a few pounds per cubic yard of concrete). This simple protection procedure is very promising.

Deck protection systems are worthwhile features on new concrete decks. Their cost typically adds less than 10% to the cost of the deck itself, and is much less than the cost of major deck repair work.

Existing Uncontaminated Decks

The best course of action for existing decks without corrosion protection features depends upon their condition. If the concrete has not been contaminated with salt, preventive measures can still be taken. Waterproof membranes with asphalt overlays are probably the most practical measure at this point. Grease, skid marks, painted markings, etc., may create bonding problems with concrete overlays. Thin scarification of the deck may be advisable if an "Iowa system" or PMC concrete overlay is attempted on an existing deck, although overlays on sandblasted decks have in at least some cases performed well.

Sandblasting existing decks and applying a waterproof membrane and asphalt overlay will typically cost about $35-40 per square yard. Overlaying sandblasted decks with 1" of latex-modified concrete will probably cost about $10 per square yard more. The cost of the same procedure using dense ("Iowa method") concrete will probably lie somewhere in between, although there is no Alaskan experience with this material. Thin scarification of a deck, rather than sandblasting, will probably add about $10 to these costs. Mobilization, traffic control, and any incidental work may significantly increase the above costs. It is thus advantageous to combine this type of work where possible with other bridge or highway work in the area.

Contaminated Deck With No Delamination

If a condition survey reveals a deck which has sufficient salt contamination to initiate corrosion but where delamination has not begun, four options should be considered. These options are (1) install a cathodic protection system, (2) install a deck protection system, (3) remove and replace the contaminated concrete and install a deck protection system, and (4) do nothing.

Doing nothing is appropriate where there are reasons to expect that the deck (or the whole bridge) will be replaced in the near future. In such a case, the expense of the other options may not be justifiable. On older bridges doing nothing may be appropriate even if their replacement is not imminent. If the corrosion process on an older deck has been progressing slowly for many years it may continue to do so and damage, if it occurs in the future, may be slight and slow to develop. Good judgement is required here, taking into consideration such things as recent or expected changes in the amount of deicing salts used.

The installation of a deck protection system without removing contaminated concrete will not prevent corrosion from occurring. By preventing further salt intrusion, however, it may prevent the rate of corrosion from increasing. Some experimental evidence indicates that corrosion activity is proportional to the amount of chloride in excess of a threshold value of about 1.8 pounds per cubic yard of concrete (reference 4). Prevention of further salt contamination may thus extend deck life by restraining the rate at which corrosion occurs. Other sources, however, contradict this, maintaining that once the threshold has been reached, further chlorides will have little effect and other factors (e.g. oxygen availability) will determine corrosion rates.

The other two options are both designed to permanently solve the corrosion problem. The choice between them will be made primarily on the basis of economics.

If there is sufficient concrete cover over the rebars (as revealed by a pachometer survey), anode wires for a cathodic protection system can be grouted into slots cut in the existing deck. No overlay is necessary in this case, although an asphalt wearing course might be advisable if heavy wear is anticipated. If insufficient (less than 1") cover exists anywhere on the deck, at least a partial overlay will be needed just to provide clearance for the anode slots. This occurred on the Wendell Street Bridge in Fairbanks, adding an estimated 70% to the cost of the cathodic protection system, despite the fact that mobilization for overlay equipment and materials had already been paid (reference 5, p. 66).

Cathodic protection systems of this type operate by driving a DC current (from an external source) between the steel to be protected and the anode wires through the deck concrete. Where some of the steel was previously anodic (and thus corroding), it is now all forced to be cathodic, and thus protected from corrosion. There are extensive descriptions of such systems in the literature (see, for example, references 6 and 7).

Cathodic protection systems are still a new technology for bridge deck protection, and costs are hard to predict accurately. Indications are that, if no overlay is needed, they may cost about $40-50 per square yard in 1982 dollars. Mobilization, traffic control, and incidentals will probably add 50% or more to this; these costs are highly variable.

Cathodic protection systems also have operational costs, primarily for electricity. Electricity use will vary depending on deck size, chloride levels and other factors. The Wendell Street system in Fairbanks used an average of over 300 kwh per month in its first year (which was more than expected). The systems must also be checked periodically to ensure they are working, although this only takes a few minutes. Little or no maintenance has been needed on these systems to date.

Removing and replacing all contaminated concrete and installing a deck protection system (e.g. a waterproof membrane with asphalt overlay) will give permanent deck protection without operating costs. If the amount of contaminated concrete is very large, however, these repairs may cost much more than a cathodic protection system. This is due to the difficulty of removing salty but otherwise sound concrete without damaging rebars or uncontaminated concrete. This may be a good option, however, if the amount of contaminated concrete is relatively small or if cathodic protection systems would be expensive (e.g. if a concrete overlay would be required or if no ready source of electricity is available).

Hand chipping to completely expose top rebars, cleaning the rebars, and patching with a polymer concrete may cost about $450 per square yard for intact concrete in the small quantities likely to be treated under this kind of repair. Assuming 5-6% of the deck required such treatment, this is equivalent to about $25 per square yard of total deck area. Subsequent sandblasting of the deck and applications of a waterproof membrane and asphalt overlay may cost about $35 per square yard. Mobilization, traffic control, and incidentals might add about $25, for a total of about $85 per square yard of total deck area.

These costs are quite variable; under good circumstances on a deck with little contaminated concrete a project of this type might cost as little as $55 per square yard. At the other extreme, costs of this type of deck restoration could easily be high enough to make it impractical.

Improved systems for removing concrete rapidly with high-pressure water are under development (reference 8). Such systems may clean rebar sufficiently so that overlay material can be placed without sandblasting or wire brushing. The net effect may be to make many deck repairs worthwhile in situations where they are not cost effective using current procedures.

Decks with Delaminated Concrete

As the extent of corrosion damage to decks increases, repair options and their costs change. If a deck has delaminated areas, for example, cathodic protection systems cannot be installed without first repairing the damaged concrete. Removal of all salty concrete from severely contaminated decks may be impractically expensive. In such cases, repairs intended to extend the life of a deck, but not expected to permanently halt corrosion problems, may be the best alternative.

These repairs have been termed "experimental cost-effective reconstruction" by the Federal Highway Administration. Most of the major deck repair work in Alaska has been of this type. The repairs entail first scarifying the deck and removing delaminated concrete. Further concrete removal is limited to excavating around rebars which have been exposed and to concrete immediately adjacent to delaminated areas. The latter is done to ensure no delaminations or rusted rebar are overlooked and to provide a clean joint with the overlay to follow. Before placing the overlay, both the exposed rebar and all concrete surfaces are cleaned by sandblasting and/or wire brushing. Overlay material is one of the special, relatively impervious concretes, and may be placed in one or more layers.

These repairs will not prevent future corrosion damage in those parts of the deck where salty but intact concrete was allowed to remain. They should, however, slow or halt salt intrusion and thus limit the areas where future delamination and spalling may occur.

This is the type of repair which was made to Ketchikan viaducts in 1974 and to Fairbanks bridge decks in 1982 and 1983. A cathodic protection system was also installed on one of the decks (Wendell Street Bridge) in Fairbanks. The use of the cathodic protection system should mean that the Wendell Street deck is permanently protected from corrosion damage (as contrasted with the extended life afforded the others).

The deck repairs in Ketchikan cost about $139 per square yard in 1982 dollars; those in Fairbanks cost about $132 per square yard, not counting the cost of cathodic protection. The repairs done to Glenn Highway bridge decks in 1973 had a similar unit cost of about $137 per square yard (1982 dollars).

These costs are not as consistent as they seem, since they do not represent exactly the same type of work and materials. Costs for individual bridges - as opposed to the project averages listed above - range from a low of about $106 per square yard (Illinois Street, Fairbanks) to $210 per square yard (Eagle River Bridge, Glenn Highway). These repairs and their costs are more fully described in Chapter 4.

Estimated costs of this type of deck repair work are summarized in Table 3-1. Details on unit costs are given in Appendix B. The typical costs shown in the table are for a project of a least moderate size (over 1000 square yards) in an easily accessible urban or suburban setting, using a concrete similar to that used in the Ketchikan and Glenn Highway projects for overlays. It assumes removal of concrete, most of it delaminated, from about 15% of the total deck area, and excavation around rebars more than 50% exposed by other work. The excavation around exposed rebars will probably comprise most of the actual work. High pressure water systems under development, mentioned above, may be able to cut the costs of concrete removal and deck cleaning in half. This could cut the total cost of a typical project by about 15%.

Substitution of latex-modified concrete for the overlay material can be expected to add $10-25 per square yard to these costs, with about $15 typical. "Iowa system" concrete would probably add something less than this to the cost shown in the table.

These costs are those for "cost-effective reconstruction." Permanent repairs would probably entail either the use of a cathodic protection system or the removal of all salty concrete, whether delaminated or not. The former, as stated before, is likely to cost $40-50 per square yard, plus continuing operational costs. The latter will vary in cost depending on the amount of contaminated deck concrete.

A rough guess is that removal of salty but physically intact concrete will cost 50-100% more than for a similar area of delaminated concrete. If any delamination has begun, there is probably enough contaminated concrete that the minimum cost of this type of permanent restoration will be $130 per square yard of total deck area; "typical" costs may approach $200 per square yard.

Deck replacement is the yardstick by which the economic feasibility of repairs will ultimately be made. Table 3-2 shows the costs of a typical new concrete deck as estimated for this report (details are in Appendix B). It is clear that even very extensive repairs can be made for less money than the $450-500 per square yard estimated for a new deck.

The California DOT has begun pouring entirely new decks on top of old ones as an alternative to removing and replacing them. The old decks are scarified to promote a good bond with the new concrete, and the new, epoxy coated rebar mats are tied into the existing girders. The new deck can be poured half-width at a time, allowing traffic to continue using the other half. The technique thus avoids the need for both new form work and detours. The cost is estimated to be one-fifth to one-third less than that of a new deck (reference 3 and 9).

A final deck repair procedure which deserves mention is deep polymer impregnation. This is a new, relatively untried technique. The most promising procedure reported (reference 10) is to first heat the deck (in order to dry it out), then pond methyl methacrylate (a monomer) and a thermocatalyst on the deck until it soaks to the level of the top rebars, and finally to initiate polymerization by heating the deck a second time. Repair of spalled and delaminated concrete is required before impregnation. The cutting of grooves in the deck or the removal of concrete to within 1/4 inch of the rebar mat has been suggested to speed the impregnation and improve its effectiveness. An overlay is required after impregnation if this is done. This technique has been shown experimentally to effectively encapsulate the rebar mat, halting the passage of electric current and thus preventing further corrosion. This could potentially be a very useful technique, especially for bridges where the deck forms part of the basic support structure (e.g. bulb-tee bridges). Cheaper and faster construction methods need to be developed.

TABLE 3-1: DECK REHABILITATION PROJECT COSTS

Item of Work	COST (1982 DOLLARS PER SQUARE YARD OF TOTAL DECK AREA) Typical	Range
Deck Scarification	15	10- 30
Hand Chipping (concrete removal)	30	10- 60
Deck Preparation (cleaning)	10	5- 15
Concrete Overlay	35	30- 55
Mobilization	10	5- 30
Traffic Control and incidentals	30	10- 65
TOTAL	130	70-255 (extreme) 110-150 (likely)

TABLE 3-2: TYPICAL DECK REPLACEMENT COSTS

Item of Work	Cost (1982 dollars per square yard)
New Deck	265
Removal of Old Deck	50
Mobilization	50
Traffic Control and Other Incidental Work	80
Deck Protection	25
TOTAL	470

CHAPTER 4: ALASKAN EXPERIENCE IN DECK REHABILITATION AND REPAIRS

Most of the repairs which have been made to Alaskan bridges have been either spot patching or bituminous overlays performed by maintenance crews. Patching has been done with asphaltic "cold patch" materials and with portland cement and epoxy concretes. These repairs have been intended to provide temporary improvements to ride quality and, consequently, to safety. They do nothing to protect the remainder of the deck from further damage.

Complete overlays have generally been either hot asphalt over a waterproof membrane or bituminous surface treatment ("chipping"). Both provide a good riding surface and give protection from traffic wear and, to some extent, frost action on the underlying concrete. They will not, however, stop corrosion damage of salt contaminated concrete, although membranes may prevent an increase in the rate of corrosion (see Chapter 3).

While they don't provide permanent protection, these repairs are not without merit. They are much cheaper than more extensive deck repairs, and can be made quickly in response to needs. They are particularly worthwhile where traffic wear and/or frost action, not corrosion, is the principal cause of damage.

Experience with these repairs will not be discussed in detail in this chapter, however. Instead, attention will be focused on three major rehabilitation projects undertaken in Alaska since 1973.

Glenn Highway Bridge Deck Reconstruction

This 1973 project included work on three bridge decks: Kings River (#544), Eagle River (#535), and Knik River (#1121). The major items of work included scarifying the top 1/4 inch of the concrete bridge decks, removal of damaged and contaminated concrete below that level, cleaning of the concrete surface and exposed rebars, and placement of an overlay of 8 sack, 3 inch maximum slump concrete (concrete mix details are given in Table B-5 in Appendix B). The overlay was thick enough to result in an increase in concrete cover over the reinforcing steel of 1 1/2 inches, some of which was previously found to have as little as 1/2 inch of cover.

Contaminated concrete (as shown by high half-cell readings) was removed even if it was not delaminated. This proved difficult, and the contractor maintained this was not required in the contract nor reflected in his bid prices. The engineer's cost estimate for this item - "Removal of Unsound Concrete" - was well over twice the amounts in any of the three lowest bids for the project. While it was eventually agreed that the contract did specify removal of contaminated but intact concrete, the use of the word "unsound" may have been confusing, and the contract price paid for this work was unusually low. Designers made a point of not using the word in the plans for repairs to Ketchikan viaducts, which were made the next year.

The concrete overlays developed extensive hairline cracks as they cured. It was felt that this might lead to spalling of the overlays and/or rapid reintrusion of salts into the deck, thus negating the value of the repair. This led to the deletion of work on a fourth bridge (Knik River #1123) which had been included in the original project plans.

Biannual inspection reports made by DOT&PF Bridge Design Section have not noted any spalling on the repaired decks in the ten years since work was completed. These reports, on the other hand, note continuing problems with the Knik River Bridge (#1123) deck which was not repaired. Spalled areas on that bridge have been patched with both epoxy concrete and asphaltic materials. Asphaltic seal coats have generally been maintained on the decks of all of these bridges as a wearing course.

Table 4-1 summarizes the costs of the repairs made to the Glenn Highway bridge decks. The high costs of traffic control are unusual even for this type of work. Despite the expense, a flagman was killed while working on the project. The costs are in 1973 dollars; the same work in 1982 would cost roughly twice as much.

Ketchikan Deck Reconstruction

This work, mostly completed in 1974, was principally intended to repair damage to the Tongass Avenue and Water Street Viaducts. The work included removal of damaged concrete, cleaning of concrete and exposed rebar surfaces, and placement of a concrete overlay similar to that used on the Glenn Highway repairs and finished one inch above the original grade. This work was limited to the center (driving) lanes of the viaducts; the entire decks including outer (parking) lanes also received a hot asphalt wearing course.

This project is a good example of the type of repairs under study in this report; the damage on the viaduct decks, however, was not principally the result of rebar corrosion. It was, instead, a result of wear on the concrete surface, which was as great as 1 1/4 inches in the wheelpaths and had exposed large areas of rebar in the deck slab (reference 11). In the parking lanes and along the roadway centerline wear was negligible. This explains why only the center part of the structure received a concrete overlay. The extreme wear was attributed to heavy traffic, soft aggregates (typical of the Ketchikan area), and common use of studded tires and chains.

Half-cell potential tests run on the viaducts in 1973 revealed almost no areas with high corrosion potential (i.e. potentials < -0.35V relative to copper-copper sulfate half-cell). Chemical analysis of concrete samples taken at the same time, however, revealed chloride levels of 1 to 3 lbs per cubic yard of concrete. These amounts of chloride are enough to sustain some level of corrosion, although they are not extremely high.

The repaired deck remains in much better condition then it was prior to the repairs. Recent chloride analyses and half-cell potential measurements, however, suggest that these viaducts currently have a moderate amount of corrosion activity (see Chapter 5). An extensive chain dragging survey performed in the summer of 1982 revealed a considerable amount of delaminations on the viaducts.

It seems likely, however, that most of the current delamination is not due to corrosion. The delaminated areas are principally around fixed joints (see Figure 4-1); these areas experienced problems even while the deck repairs were being made in 1974 and 1975. The project history notes that "patching resulted from not sawing or forming the fixed joints" and that "the small amounts of expansion at the fixed joint [was] enough to break the bond between the old and new concrete."

Figure 4-1: 1982 Delamination Survey
Tongass Avenue Viaduct

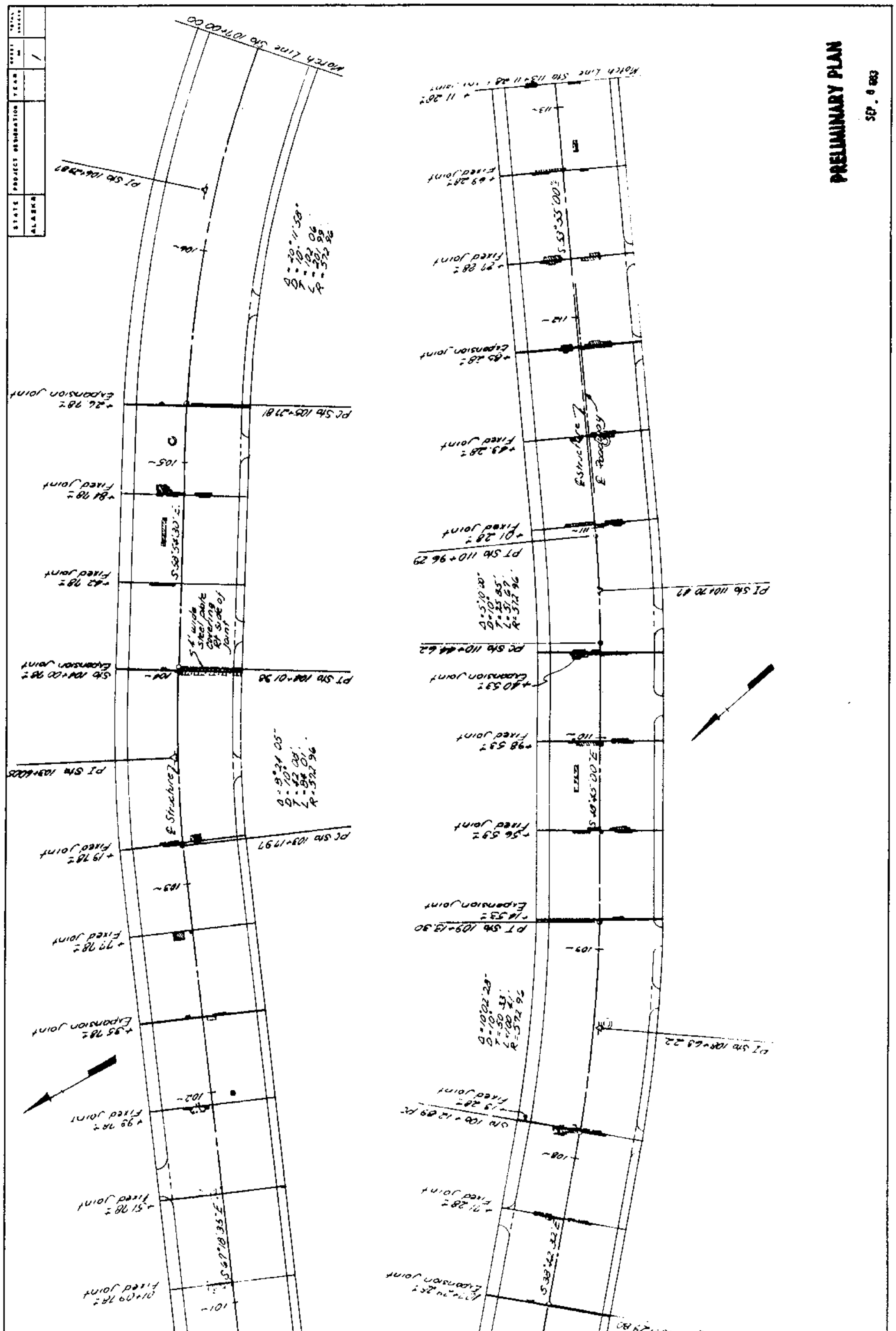


Table 4-2 presents data on both bid and final prices and quantities. This analysis is complicated by the fact that other work was done in Ketchikan under the same contract. The costs have been broken out as accurately as possible.

Fairbanks Bridge Deck Repairs

These repairs were made in 1982 and 1983 to Fairbanks bridge decks on Minnie Street (built in 1951), Illinois Street (1952), Cushman Street (1959), and Wendell Street (1951). The decks, after preparation, were overlaid with latex-modified concrete. A cathodic protection system was also installed on the Wendell Street deck.

These repairs are described at length in another research report (reference 5). That report contains descriptions of the sequence of work and problems encountered, along with recommendations for design and construction of similar projects in the future.

Salt contamination at a given depth in the deck concrete was the worst on the Cushman Street Bridge. The severity of the problem was mitigated somewhat because the concrete cover over the rebar was greater, in general, on that deck than on the others. Nevertheless, it had the largest damaged areas and required the most preparation prior to the overlay.

Extensive removal of delaminated concrete was also required on the Minnie Street and Illinois Street decks. Minnie Street was the worst of the two, and was shown in 1980 tests to have greater salt contamination. Both the Minnie and Illinois Street decks had large areas with very thin concrete cover over the rebars. Delaminated concrete was almost entirely limited to these areas and, especially on Minnie Street, were primarily along the wheelpaths (see Figure 4-2).

The correlation between insufficient cover over rebars and concrete damage was most striking on the Wendell Street Bridge deck. Nearly all of the unsound concrete removed during repairs was located in an area, about sixty feet long, where cover was less than one inch (see Figure 4-3). The remainder of the deck, where cover in most places exceeded one inch, was in fairly good condition.

Figure 4-2: Concrete Cover Depth and Delaminations, Minnie Street Bridge

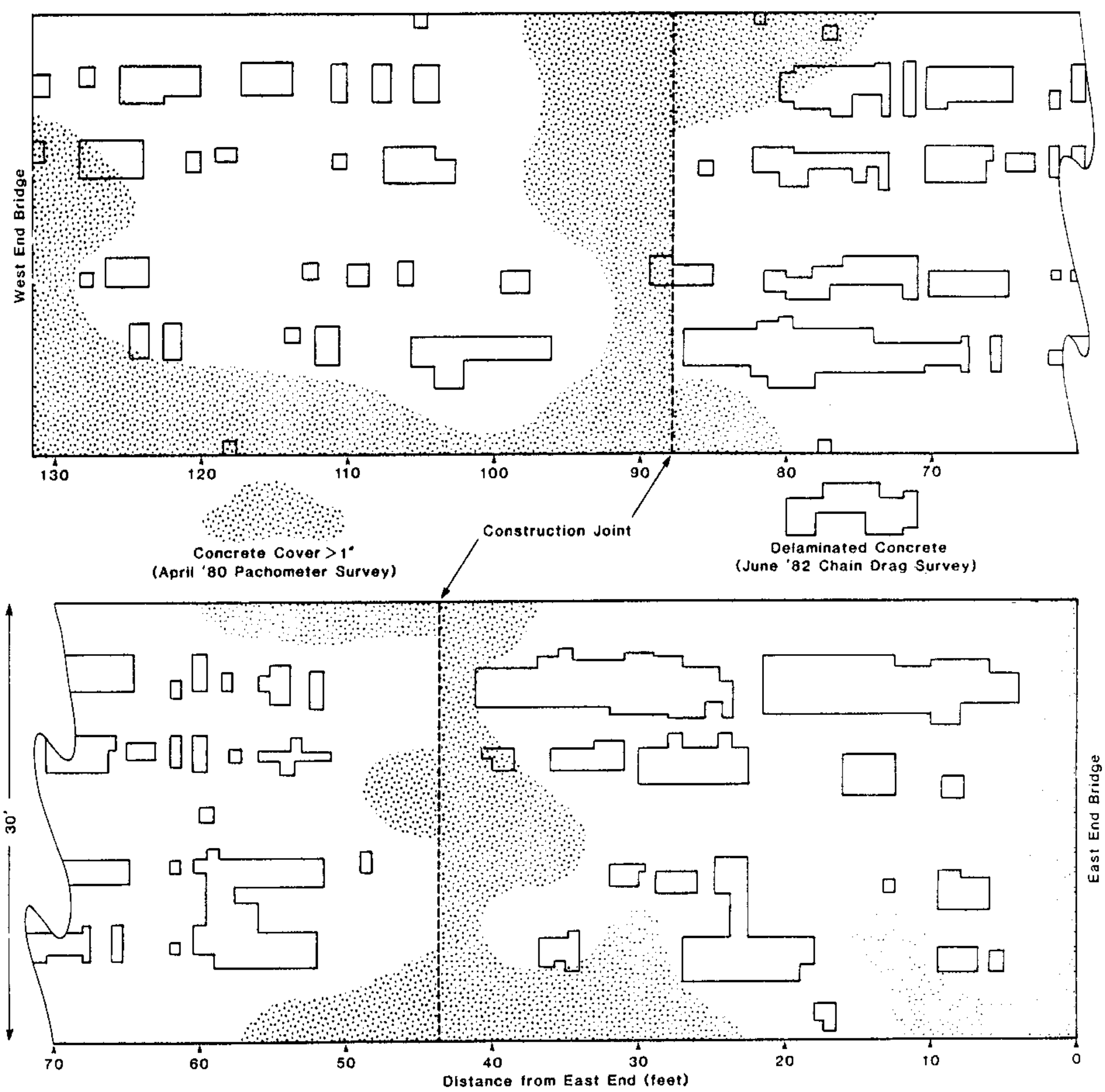
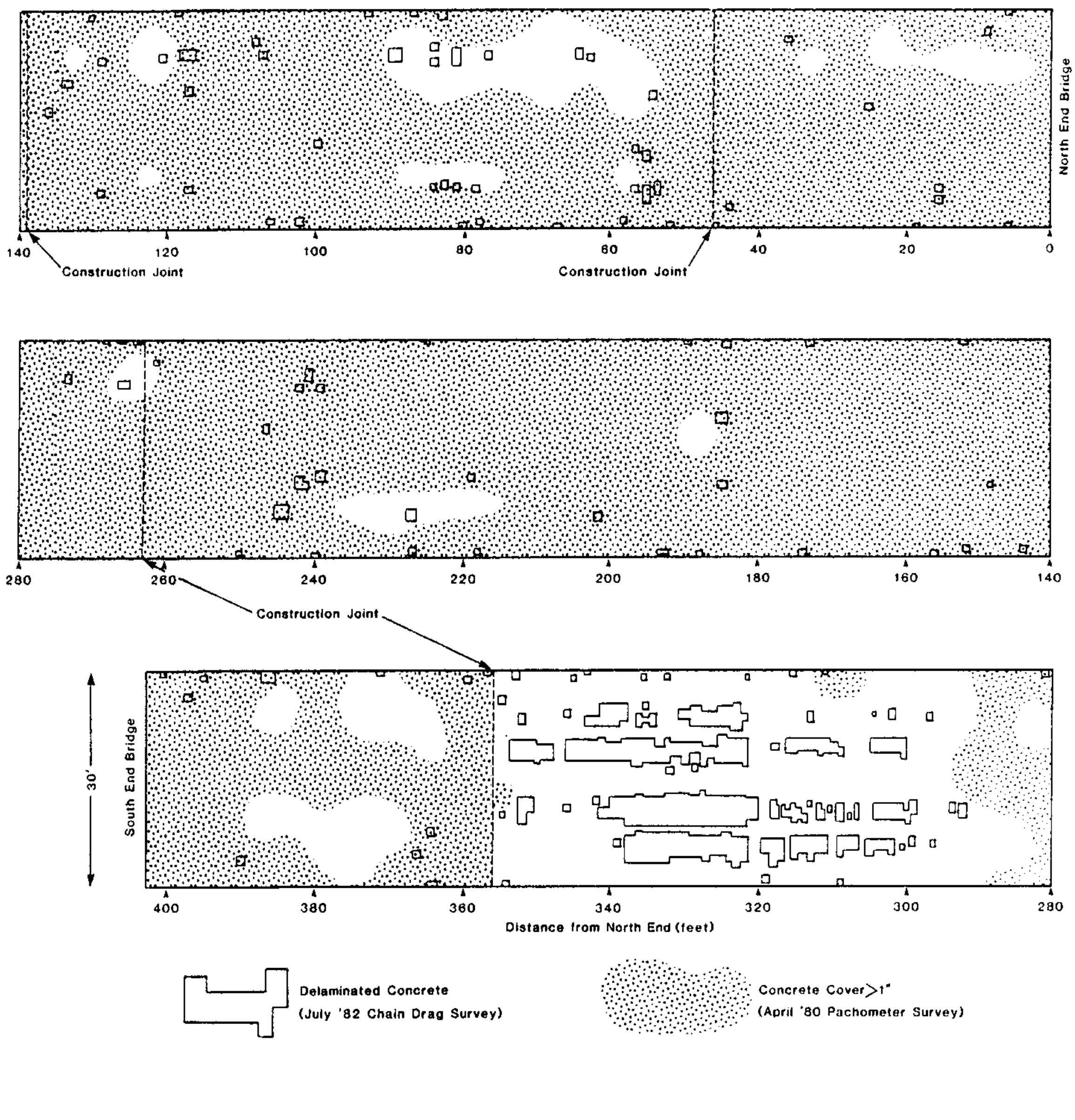


Figure 4-3: Concrete Cover Depth and Delaminations, Wendell Street Bridge



The cathodic protection system installed on the Wendell Street Bridge used anode wires grouted into slots spaced two feet apart along the length of the bridge. It was planned to saw the slots in the original concrete, and cover them with a single concrete overlay. Due to insufficient cover in some areas (3/4 of an inch was needed) this could not be done without locating anodes too close to the rebar. An initial overlay was therefore needed in which to cut the anode slots. This resulted in significantly higher costs for the project. Cathodic protection system costs on Wendell Street would have been more than 40% lower if there had been as much concrete cover as was shown in the original bridge plans.

The amount of current passing through the Wendell Street cathodic protection system is automatically controlled to maintain a "safe" potential with respect to reference electrodes embedded in the deck. The amount of current required for protection is highly variable with respect to temperature, as shown in Figure 4-4. The data shown in the figure were recorded during the first 18 months operation of the system.

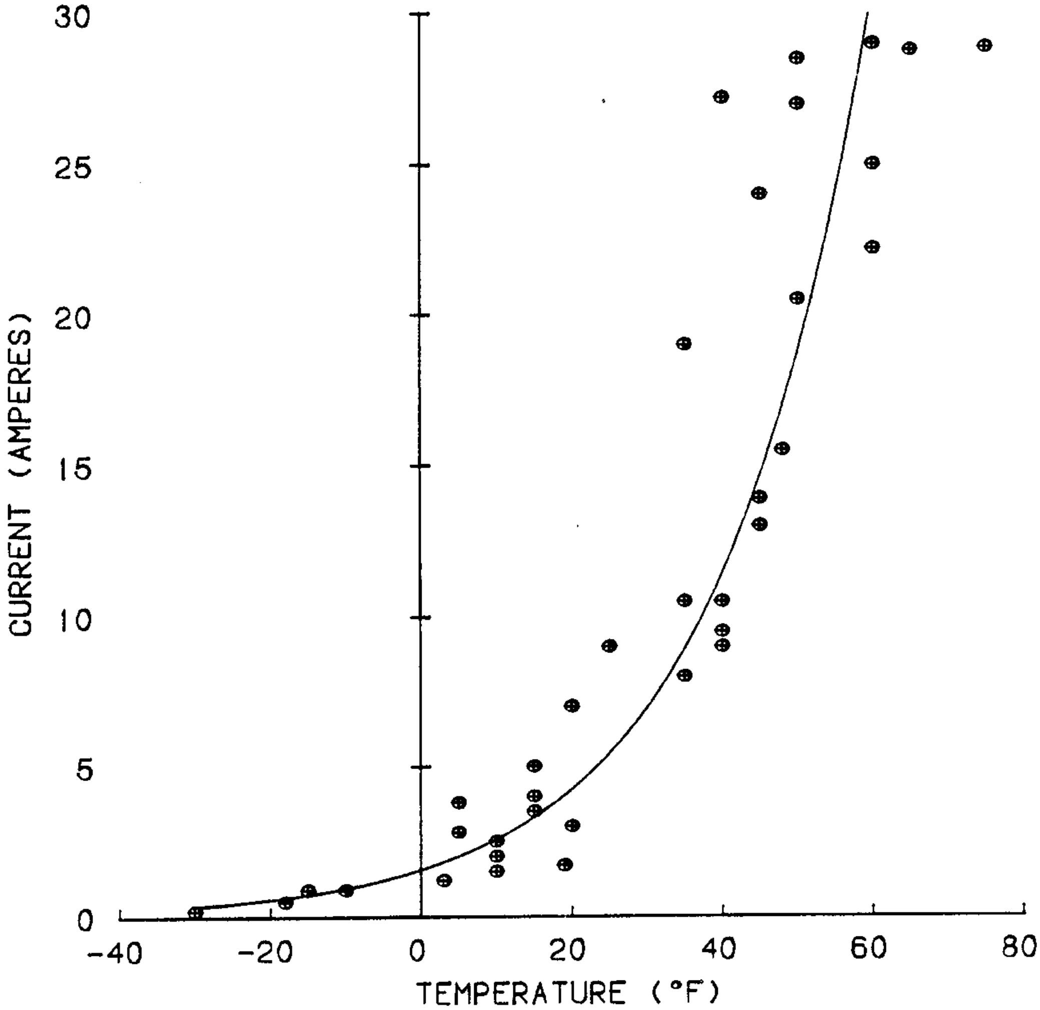
The curve shown is a "least squares" best fit (r^2 = .905) exponential function of the form

$$i = 1.5669\ell^{0.0496T}$$

where i = current in amperes
and T = temperature in °F

The precision of this relationship can be questioned, since air temperatures (not concrete temperatures) were recorded, and the controls are set to limit the current to 30A maximum. The general trend, however, is quite clear. The amount of corrosion which would occur without the cathodic protection would probably demonstrate a somewhat similar variation with temperature.

Figure 4-4: Protective Current versus Temperature, Wendell Street Bridge



Costs of the repairs to the Fairbanks bridge decks are summarized in Table 4-3. Changes in the original contract which were made to reduce closure time led to higher traffic control costs on the Cushman Street Bridge (three to four times that of the other bridges). A cathodic protection system for Cushman Street was also deleted in order to reduce closure time. The contractor was paid over $20,000 nonetheless for equipment already purchased and work already done on this system; these costs are not shown in the table.

TABLE 4-1: GLENN HIGHWAY BRIDGE DECK RECONSTRUCTION COSTS (1973)

CATEGORY OF WORK	KINGS RIVER #544		EAGLE RIVER #535		KNIK RIVER #1121		CUMULATIVE TOTAL	
Deck area repaired	879 sq. yds.		751 sq. yds.		5,084 sq. yds.		6,714 sq. yds.	
	Dollar costs	$ per sq yd	Dollar costs	$ per sq yd	Dollar costs	$ per sq yd	Dollar costs	$ per sq yd
Deck preparation items	11,632	13.23	15,270	20.33	62,732	12.34	89,634	13.35
Deck overlay items	18,464	21.01	17,443	23.23	119,428	23.49	155,335	23.14
Traffic control items	19,512	22.20	43,093	57.38	138,905	27.32	201,510	30.01
Mobilization	3,584	4.08	3,584	4.77	10,753	2.12	17,921	2.67
TOTAL COSTS	53,192	60.51	79,390	105.71	331,818	65.27	464,400	69.17

Source: Alaska Department of Highways final estimate, project F-042-1(42), 1(44), and 2(12). Costs do not include Department of Highways design and project engineering costs.

TABLE 4-2: KETCHIKAN DECK RECONSTRUCTION COSTS (1974-75)

CATEGORY OF WORK	AVERAGE OF THREE LOW BIDDERS $ cost	AVERAGE OF THREE LOW BIDDERS $/sq yd	FINAL COSTS $ cost	FINAL COSTS $/sq yd
Concrete Overlay Preparation	242,323	23.67[1]	297,859	29.00[2]
Concrete Overlay	202,825	19.81[1]	119,861	11.67[2]
Traffic Control Items	162,000[4]	15.82[1]	104,837	10.20[2]
Mobilization	87,500[5]	8.55[1]	103,954	10.12[2]
Miscellaneous	38,067	1.77[3]	34,449	1.60[3]
SUBTOTAL	732,715	69.62	660,960	62.59
Asphalt Concrete Overlay Items	117,043	5.44[3]	112,290	5.22[3]
TOTAL	849,758	75.06	773,250	67.81

NOTES:
1. Based on 10,239 square yards plan concrete overlay area.
2. Based on 10,271 square yards actual concrete overlay area.
3. Based on 21,500 square yards asphalt overlay area (estimate).
4. Assumes that 90% of traffic control was for deck repair work.
5. Assumes that 50% of mobilization was for deck repair work.

TABLE 4-3: FAIRBANKS BRIDGE DECK REPAIR COSTS (1982-83)

CATEGORY OF WORK	MINNIE STREET #295		ILLINOIS STREET #283		CUSHMAN STREET #390		WENDELL STREET #532	
Deck Area Repaired	450 sq. yd.		450 sq. yd.		1,295 sq. yd.		1,342 sq. yd.	
	Dollar cost	$ per sq yd	Dollar cost	$ per sq yd	Dollar cost	$ per sq yd	Dollar cost	$ per sq yd
Deck preparation and overlay items	50,190	111.53	38,040	84.53	139,915	108.04	112,453	83.80
Cathodic protection (note 4)	NA	NA	NA	NA	NA	NA	87,837	65.45
Traffic control items	2,511	5.58	3,149	7.00	28,161	21.75	6,976	5.20
Other items (note 2)	6,656	14.79	6,656	14.79	18,167	14.03	18,167	13.54
TOTAL COSTS (note 3)	59,357	131.90	47,845	106.32	186,243	143.82	225,433	167.98

NOTES:

1. Source is final estimate, Alaska DOT&PF project X20143.
2. Includes mobilization, surveying, and furnishing of field office.
3. Does not include costs of wingwall and sidewalk modifications or settlement for deletion of cathodic protection system from Cushman Street Bridge.
4. Includes $36,278 for added overlay required to provide sufficient cover to saw anode slots.

CHAPTER 5: RESULTS OF DECK CONDITION INSPECTIONS

Anchorage

The decks of the Hillcrest Overcrossing, International Airport Ramps, Spenard Overhead, and Ship Creek bridges in Anchorage were tested in October 1982 as part of the Bridge Deck Corrosion Study. The tests performed included visual inspections, delamination (chain drag) and pachometer surveys, half-cell electrical potential measurements, and chemical analysis of concrete samples for chloride ion concentration.

Similar inspections were made on five bridges in the Juneau area, five in Ketchikan, four in Fairbanks (all of which have since been repaired), two in Valdez, and one (Robertson River) on the Alaska Highway between Delta Junction and Tok. Of all these bridges, those in Anchorage demonstrate the worst overall deck corrosion problems. The Spenard Overhead Bridge exhibits the most severe deterioration of any bridge tested as judged by any of the tests made.

The other Anchorage decks have levels of concrete damage (judged by spalling and delaminations) comparable to those of the Fairbanks bridges, and worse than those elsewhere. While the amount of damage on the Anchorage decks is roughly equal to that in Fairbanks, it has occurred more rapidly. The Fairbanks decks tested were all built between 1951 and 1960, while those in Anchorage, built between 1967 and 1973, are less than half as old. Half-cell potential and chloride ion measurements, which are more indicative of the current rate of deterioration than delaminations, are significantly higher in Anchorage than in Fairbanks or elsewhere.

A summary of the test results for Anchorage bridge decks is shown in Table 5-1. The International Airport Ramps show the least deterioration. It is possible that the half-cell potentials measured were affected by the cathodic protection system operating on the deck between these ramps; nonetheless the other indicators are also low. Chloride ion contents near the surface on these ramps were quite high, however, indicating that significant corrosion may begin in the future. These ramps, therefore, are good candidates for preventive maintenance before corrosion problems start. The Ship Creek and Hillcrest Overcrossing bridges are in conditions comparable to the worst of the Fairbanks bridges when the latter were repaired and thus the same type of repair (removal of damaged concrete, patching, and overlay) may be warranted. Cathodic protection might also be cost effective on these bridges. The Spenard Overhead bridge is so severely deteriorated that repairs (beyond patching) may not be cost effective. Instead, an entire deck replacement, an effective cathodic protection system, or possibly deep polymer impregnation will eventually be required.

Both the severity and the variability of the deck corrosion problems found on the four bridges tested indicate that a comprehensive testing program should be carried out in Anchorage. Table 5-2 lists those bridges in the Anchorage-Palmer metropolitan area which are believed to have concrete decks without protective systems such as waterproof membranes or epoxy coated rebars. Priority for these inspections should be given to those bridges whose decks are part of the main structural support as indicated in the table (these include bulb-tees, slabs, and concrete box girders).

Southeast Alaska

Several bridges in both Juneau and Ketchikan were tested and inspected for this study. Corrosion problems in both cities might be expected, given the aggressive environments where they are located. Most of the area bridges are very close to salt water, and the use of deicing salts in winter is common by Alaskan standards. Test results, however, did not show serious problems in either city.

The work in Juneau was performed in late November 1982. Half-cell potential surveys could not be made due to sub-freezing temperatures. Chain-dragging, pachometer surveys, and a few concrete chloride analyses were made, however, for five bridges: the (old) Mendenhall River (#217), Eagle River (#735), Kowee Creek (#870), Herbert River (#736), and Fish Creek (#353).

Chain-dragging revealed no delaminations on any of these bridges. It is possible that some existed, but were bonded to sound concrete by ice, thus escaping detection. No visible spalling of concrete was noted on any of the five bridges.

Chloride levels at rebar level (as determined with the pachometer) were high enough to indicate significant corrosion only on the Mendenhall River Bridge. This is one of the oldest bridges in the state (built in 1946), and a replacement is planned, probably in 1984. There is therefore little need for concern about the structure.

The next highest chloride levels were found on the Fish Creek Bridge, built in 1959. Chloride contents of about 270 ppm were found at rebar level, slightly above what is considered the threshold value of 250 ppm (1 pound per cubic yard), where some corrosion may begin. Significant corrosion activity, however, is not considered likely at levels below 500 ppm, so there is no evidence that a serious condition exists. Chloride levels in the remaining three bridges were less than half the values at Fish Creek.

Bridges tested in the Ketchikan area included Herring Bay (#253), Whitman Creek (#1078), Ketchikan Creek at Park Avenue (#1133), and part of Water Street Viaduct (#797). Tests were also made on Front Street between Dock and Mission Streets; this roadway is a concrete slab on fill, not a bridge. A summary of the tests results is presented in Table 5-3.

The oldest of the bridges, at Herring Bay, was built in 1952. It is built over tidewater on South Tongass Highway about 8 miles outside Ketchikan city limits. Despite its age and proximity to salt water, deck corrosion does not appear to be a problem. This may be partly due to the depth of concrete cover over the rebars, which the pachometer survey found was, in most locations, greater than the 1 1/2 inch design minimum. Half-cell potentials were quite low, indicating little or no corrosion. Only two concrete samples were taken to check chloride levels. These showed chlorides at rebar level of 320 and 330 ppm, although in the top 3/4 of an inch they were as high as 1290 ppm.

One very small (3" x 8") spall was noted; a slightly larger delaminated area adjoined it. Only one other minor (6" diameter) delaminated area was found.

The principal problem with this deck appeared to be not corrosion damage but wear under traffic. In one location concrete cover over the rebars was thin enough to show rust stains and small parts of two of the bars were exposed. Judging from the pachometer survey, the concrete cover here was probably less than design depth when built. There was no spalling or delamination in this area.

Traffic wear, although slight, was also evident on the deck of the Whitman Creek Bridge. It is also on South Tongass Highway, 1/2 mile further from town than Herring Bay, and is newer (built in 1962) and farther from saltwater both horizontally and vertically. There was no evidence of any delamination or spalling on the deck. Chloride contents at rebar level were high enough to sustain corrosion activity (from 300 to over 900 ppm), but half-cell potentials were very small (almost entirely between 0 and -0.10 volts). These contradictory results lead to the suspicion that one of the two sets of tests was faulty. Given the complete absence of problems evident from visual inspection and chain-dragging, it seems more likely that the chloride analyses are in error. The samples at rebar level may have been contaminated with saltier concrete from nearer the deck surface.

Support for this hypothesis comes from the fact that chloride levels at rebar level were generally lower (335 to 500 ppm) on the part of Water Street Viaduct which was tested. The viaduct is built over saltwater in downtown Ketchikan, where it receives much heavier traffic and more frequent applications of deicing salts than the Whitman Creek Bridge. It is also 7 years older (built in 1955). Half-cell potentials showed significant areas where corrosion was likely to be occurring on the viaduct.

The entire length of the Water Street - Tongass Avenue Viaducts (two-thirds of a mile) was chain-dragged in 1982 prior to the placement of a new asphalt cement wearing course. Numerous delaminated areas were detected. These were located almost exclusively over fixed joints, however, and it is thought that the failure to properly form these joints during an overlay in 1974 (see Chapter 4), coupled with negative moments at these joints, are the principal cause of the delamination.

Deterioration of the Water Street Viaduct due to corrosion is of moderate severity. There are more severe problems with the structure, however. Traffic wear on the deck exposed large areas of rebar in the driving lanes, requiring the overlay in 1974. The repair has held up fairly well due to the maintenance of asphaltic wearing courses (the current one is the third since the repair was made). The delaminations mentioned above, however, have appeared in the overlay. The condition of the supporting superstructure is of even more concern. It shows severe deterioration in some areas (much of it apparently due to rebar corrosion). Replacement of the Water Street and Tongass Avenue Viaducts is tentatively planned for the late 1980's (reference 12). Major efforts to limit or repair corrosion damage to these decks are thus probably unwarranted at this time.

Fairbanks

Four bridge decks in Fairbanks were tested in 1980. These decks were all repaired in 1982 or 1983; the results are thus not applicable to their present condition. A summary of the data is presented in Table 5-4, however, for comparative purposes. The condition of these decks prior to repairs is discussed in more detail in Chapter 4.

Valdez

Two bridges in the Valdez area were tested, the Lower Lowe River Crossing (#557) and Valdez Glacier Stream No. 3 Bridge (#556). The tests were made in April of 1984. The results indicated that some salt contamination of the decks has occurred, but has not yet reached levels high enough to support significant corrosion.

The Lower Lowe River Crossing has severe scaling and pitting problems over most of its surface; the probable cause was judged to be freeze-thaw cycling. Chain dragging revealed some areas of incipient surficial scaling, but no delaminations at rebar level. The half-cell survey revealed probable active corrosion at only one point out of over 700 tested. Concrete cover was significantly less at this point than on most of the deck. Chloride content tests were made for three locations. These showed high chloride levels near the surface (1630 to 2690 ppm), but much lower levels (200 to 465 ppm) at rebar level.

A waterproof overlay system was recommended for the Lower Lowe River Crossing with the expectation that this would both reduce future freeze-thaw problems and prevent salt contamination from increasing to damaging levels.

The testing on Valdez Glacier Stream No. 3 Bridge was brief due to time limitations. The results were similar to those for the Lower Lowe River Crossing with regards to corrosion, and a waterproof overlay would thus benefit this bridge too. Unlike the Lower Lowe River Crossing, this bridge had very little visible freeze-thaw scaling or pitting.

Robertson River Bridge

The deck of the Robertson River Bridge was tested as part of a detailed inspection of the entire structure done during the summer of 1982. This is one of the oldest bridges in Alaska (built in 1944) as well as one of the longest. It is located far from urban areas on the Alaska Highway.

No spalling or delamination was found on the deck (although minor cracks and scaling were noted). Chloride ion contents of the concrete were, in most cases, well below that needed to support corrosion. Chloride content was also remarkably constant with depth. This indicates that salt contamination is proceeding slowly if at all; corrosion problems on this deck are thus unlikely in the near future.

Half-cell potential readings taken on this deck were very inconsistent and fluctuated rapidly with time. It was later determined that the readings were taken during a period of strong auroral activity (although no aurora was visible since the test was made during daylight hours). Such activity can induce significant telluric currents in both the bridge steel and the electrical leads of the test equipment, especially on a long bridge such as this one (reference 13). The half-cell data that was collected is consequently useless in the assessment of corrosion conditions on the deck.

Table 5-5 is a list of bridges in Alaska which are believed to meet the following criteria:

- they have unprotected concrete decks.
- they are either in urban areas or close to salt water, and are thus prone to salt exposure.
- there are no definite plans for their replacement.

Bridges on the list which have visible deck problems of varying severity (as noted in inspection reports) are noted. Additional bridges in Alaska which have visible deck problems include Chatanika River (#836), Seward Highway bridges between Canyon Creek and Ingram Creek (#612-620), Wasilla Creek (#1156), and Cooper Creek (#674). In many cases these visible problems may be a result of frost and/or traffic wear, not corrosion.

An attempt was made to be as accurate as possible in compiling this list; it may, however, contain errors (i.e. protective systems do exist), and there may be omissions from it.

TABLE 5-1: ANCHORAGE DECK TESTING SUMMARY

Bridge	FHWA Deterioration Category	Deck Area Spalled or Delaminated (Approx)	lb/yd^3 Chloride Ions at Rebar Depth Range (Mean)	Half-cell Potentials < -0.35V (Approx)
Ship Creek	moderate	2.5%	6.8-9.2 (7.9)	30%
Hillcrest Overcrossing	moderate	5%	0.6-12.8 (8.2)	30%
Spenard Overhead	extensive	35%	2.6-12.8 (7.3)	30%
International Airport Ramps	light	0.5%	0.5-4.8 (1.5)	0.5%

TABLE 5-2: ANCHORAGE "METRO AREA" UNPROTECTED CONCRETE BRIDGE DECKS

Date Built	Bridge Number	Name	Deck part of main structural support?
1950	540	Matanuska River (Old Glenn Highway)	No
1952	537	Eklutna River	No
1958	541	Moose Ck (Glenn Hwy - 6 mi. N. of Palmer)	No
1959	391	Campbell Ck., W. Dimond Blvd.	No
1959	535	Eagle R. Northbound (Glenn Hwy)	Yes
1960	645	Campbell Ck, Old Seward Highway	No
1965	1121	Knik River Bridges	No
1965	1122	Knik River Bridges	No
1965	1123	Knik River Bridges	No
1965	1124	Matanuska River	No
1966	969	Campbell Ck, Lake Otis Road	Yes
1970	700	ARR Overhead, Int'l Airport Road	Yes
1978	1508	Campbell Ck., Dimond Drive	Yes
1979	970	Campbell Ck., Arctic Blvd.	Yes
1967	976	Hillcrest Overcrossing (Tested October 1982)	No
1968	1278	Int'l Airport Ramps (Tested October 1982)	No
1970	699	Spenard Overhead (Tested October 1982)	No
1973	534	Ship Creek (Tested October 1982)	No

TABLE 5-3: KETCHIKAN DECK TESTING SUMMARY

Bridge	FHWA Deterioration Category	Deck Area Spalled or Delaminated	lb/yd^3 Chloride Ions at Rebar Depth Range (Mean)	Half-cell Potentials < -0.35V
Herring Bay	light	< 0.1%	1.3	0
Whitman Creek	light	0	2.5[1]	0
Ketchikan Creek at Parks Hwy	light	0	N/A	0
Water Street Viaduct	moderate	1.2%[2]	1.6[3]	approx 11%[3]
Front Street[4]		N/A[5]	0.7	approx 14%

NOTES:

1. Chloride data for this bridge may be inaccurate.
2. Based on entire viaduct surface, chain dragged in 1982.
3. Based on 50' x 108' section tested in 1983.
4. Not a bridge, but a patchwork of concrete slab areas on fill at different times. As a result, the average chloride content has little meaning, as variance is great.
5. Chain dragging inconclusive due to areas of asphalt overlay.

TABLE 5-4: FAIRBANKS DECK TESTING SUMMARY

Bridge	FHWA Deterioration Category	Deck Area Spalled or Delaminated (Approx)	lb/yd^3 Chloride Ions at Rebar Depth Range (Mean)	Half-cell Potentials < -0.35V (Approx)
Minnie Street	moderate (5)	20%	1.6-4.2 (2.5)	1%
Illinois Street	moderate (6)	9%	0.1-1.2 (0.8)	10%
Wendell Street	moderate (6)	2%	0.3-2.4 (0.9)	1%
Cushman Street	moderate (5)	4%	1.2-4.2 (2.4)	2%

NOTES:

- Tests were performed in May 1980; all four decks have since been repaired.

- With the exception of Illinois Street, the half-cell potential data seem low compared to other evidence of deck condition. Dry concrete at rebar depth or other problems may have produced faulty data.

TABLE 5-5: CORROSION PRONE BRIDGE DECKS

Bridge Name	Bridge Number	Year Built	Length	Visible Deck Problems[1]	Deck Type[2]	Location and Comments
Gold Creek at Willoughby	315	1934	46' 9"	Yes	RCA	Juneau, rebuilt 1958
Calhoun Ave. Viaduct	1068	1934	294' 10"	No	RC	Juneau
Gold Creek at Ninth Street	314	1934	46' 11"	No	RCA	Juneau
Cascade Creek	867	1937	53' 6"	Yes	RCA	Halibut Pt. Rd. near Sitka; rebuilt 1972
Jordan Creek	789	1948	39' 1"	No	RCA	near Juneau Airport
Cannery Creek	746	1950	75' 6"	Yes	RCA	N. Tongass Hwy near Ketchikan; a.k.a. Walsh Creek
Matanuska River	540	1950	353' 8"	Yes	RC	Old Glenn Highway near Palmer
Gold Creek at 12th and Calhoun	1069	1950	64' 2"	No	RCA	Juneau
Eklutna River	537	1952	257'	Yes	RC	Eklutna
Herring Bay	253	1952	115' 10"	Yes	RC	S. Tongass Hwy; over tidewater
Indian River	865	1952	144' 6"	Yes	RCA	Sitka
Jarvis Creek	595	1952	183' 6"	No	RC	Richardson Hwy. near Delta Junction
Eyak River	381	1954	255'	No	PCSA	Copper River Hwy near Cordova
Tongass Avenue Tunnel	1130	1954	275'	No	RCA	Ketchikan
Water Street Viaduct	797	1955	1953'	Yes	RCA	Ketchikan
Tongass Avenue Viaduct	997	1956	1576'	Yes	RCA	Ketchikan
Montana Creek	264	1957	99' 4"	No	CSA	Mendenhall Loop Road near Juneau
Hoadley Creek	725	1957	45'	No	RCA	Ketchikan
Moose Creek	541	1958	183' 2"	Yes	RCA	Glenn Hwy near Palmer
Ketchikan Creek at S. Tongass	724	1958	124'	No	RCA	Ketchikan; rebuilt 1978
Campbell Ck, W. Diamond Blvd.	391	1959	22' 7"	No	RCA	Anchorage
Noyes Slough at Aurora	209	1959	103' 2"	Yes	RC	Fairbanks
Granite Creek	328	1960	85' 6"	No	RCA	Halibut Pt. near Sitka
Station 355 Creek	327	1960	91'	No	RCA	near Sitka Ferry Terminal
Moose River	672	1961	159'	No	RC	Sterling

Bridge Name	Bridge Number	Year Built	Length	Visible Deck Problems[1]	Deck Type[2]	Location and Comments
Chena River at University Avenue	263	1962	267'	No	RC	Fairbanks
Sawmill Creek	432	1962	164' 11"	Yes	RC	near Sitka
Whitman Creek	1078	1962	146'	No	RC	S. Tongass Hwy.
Deep Creek	668	1965	135' 3"	No	RC	Sterling Hwy. near Ninilchik
Goldstream Creek	357	1965	102' 6"	No	RC	Sheep Creek Road near Fairbanks
Kenai River at Cooper Landing	675	1965	401' 10"	No	RC	Sterling Highway
Knik River #2	1122	1965	521' 2"	Yes	RCA	Glenn Highway
Knik River #3	1123	1965	925' 2"	Yes	RCA	Glenn Highway
Matanuska River	1124	1965	353' 8"	Yes	RCA	Glenn Highway
Ninilchik River	669	1965	159' 2"	No	RC	Sterling Highway
Valdez Glacier Stream No.3	556	1965	241' 10"	No	RC	Valdez
Swanson River	214	1966	211' 2"	No	RC	Kenai Spur Road
Scott Glacier Nos. 1-5	348-352	1966	61' 10" to 211' 10"	No	RC	near Cordova
Scott Glacier Nos. 6-11	406-411	1966	51' 10" to 401' 10"	No	RC	near Cordova
Kasilof River	670	1966	284' 2"	Yes	RC	Sterling Hwy in Kasilof
Kenai River at Soldotna	671	1966	394' 2"	Yes	RCA	Sterling Highway
Campbell Creek at at Otis Road	969	1966	62' 6"	Yes	CSC	Anchorage
Cripple Creek	1008	1967	58' 6"	No	RC	Chena Pump Road near Fairbanks
Falls Creek	868	1967	122'	Yes	RC	Mitkof Highway near Petersburg
Girdwood ARR Overcrossing	1001	1967	120' 6"	Yes	RC	Alyeska Rd, Girdwood
Glacier Creek	639	1967	162' 6"	Yes	RC	Seward Hwy, Girdwood
Glacier Creek	999	1967	222' 6"	Yes	RC	Alyeska Road
Ketchikan Creek at Fair	1131	1967	90'	No	RC	Ketchikan
Ketchikan Creek at Park	1132	1967	90'	No	RC	Ketchikan
Ketchikan Creek at Park	1133	1967	64' 6"	No	RC	Ketchikan
Nome River	320	1967	283' 2"	No	RC	Nome-Council Road near Nome
Peterson Creek	636	1967	122' 6"	No	RC	Seward Hwy near Portage
Placer R., Main Crossing	629	1967	486' 6"	No	RC	Seward Hwy near Portage
Placer R., Overflow	627	1967	324' 6"	No	RC	Seward Hwy near Portage
Resurrection River Nos. 1-3	596-598	1967	151' 10" to 201' 10"	No	RC	Seward
Tanana River at Nenana	202	1967	1307'	Yes	RC	Parks Highway
Tidewater Slough	640	1967	122' 6"	Yes	RC	Seward Hwy near Girdwood
Twentymile River	634	1967	567' 7"	No	RC	Seward Hwy near Portage
Virgin Creek	638	1967	122' 6"	Yes	RC	Seward Hwy near Girdwood
Front Street Viaduct	1080	1969	650'	No	RCA	Ketchikan
Resurrection Creek	1025	1969	243'	No	RC	Hope

Bridge Name	Bridge Number	Year Built	Length	Visible Deck Problems[1]	Deck Type[2]	Location and Comments
ARR Overhead	700	1970	150'	Yes	PCBGA	Anchorage, Int'l Airport Road
Sitka Harbor	245	1971	1255'	Yes	RC	Sitka, over salt water
Cowee Creek	1220	1971	192' 2"	No	RC	Douglas
Chatanika River	836	1971	249'	Yes	RC	Elliot Highway
Goldstream Creek	478	1972	112' 7"	No	RC	Goldstream Road near Fairbanks
Salmon Creek	853	1972	110' 3"	Yes	PCCG	Nash Road near Seward Airport
Small Creek	855	1972	36' 9"	Yes	PCCG	Nash Road near Seward Airport
Lemon Creek	1197	1973	181' 2"	No	RCA	near Juneau
Salmon Creek Powerhouse	1218	1973	22' 6"	No	RFCA	near Juneau
Small Creek	854	1973	36' 9"	Yes	PCCG	Nash Road near Seward Airport
Skagway River	308	1974	481' 10"	No	RC	Skagway
Unnamed Creek	1389	1977	112' 5"	No	RC	Seward
Safety Sound Estuary	1127	1978	807' 6"	No	PCBT	Nome-Council Road; over salt water
Ward Creek	1051	1978	125'	No	PCBT	near Ketchikan
Blind River	429	1979	200'	Yes	RC	near Petersburg; a.k.a. Blind Slough
Campbell Creek at Arctic Blvd.	970	1979	52'	No	PCBGA	Anchorage
Chilkoot River	387	1979	200'	No	RC	near Haines
Dunton Street Viaduct	453	1979	540'	No	PCS	Ketchikan
Quinn Street Viaduct	454	1979	255'	No	PCS	Ketchikan
Water Street Trestle No.2	446	1979	1050'	No	PCS	Ketchikan
Gunnuk Creek	1152	1981	130'	No	PCBT	Kake

NOTES:

1. As noted in biannual bridge inspections. Noted problems are not necessarily due to corrosion.

2. Deck Type Coding:

RC	Reinforced Concrete	PCCG	Prestressed Concrete Channel Girder
PCS	Prestressed Concrete Slab	RFC	Rigid Frame Concrete
CS	Concrete Slab	PCBT	Prestressed Concrete Bulb Tee
PCBG	Prestressed Concrete Box Girder		

The suffix "A" indicates the presence of an asphalt wearing course.

APPENDIX A
INSPECTION AND TESTING METHODS

The basic types of testing generally performed in deck condition evaluations are visual inspections, delamination detection tests, half-cell potential surveys, rebar depth surveys, and chloride content analysis. The Federal Highway Administration demonstrated these techniques to state highway departments during the mid-1970s; their final report on this project (reference 2) contains good descriptions of the needed equipment and its use. The nuts-and-bolts of testing will not be repeated here. Instead, this section will discuss the nature of the information the tests provide, along with some comments on their limitations and potential problems.

Corrosion of reinforcing steel in concrete is a complex and progressive combination of physical, chemical, and electrical processes. The tests, too, are alternately physical, chemical, and electrical in nature. Each gives only a limited amount of information about the deck under investigation; it is important to recognize these limitations.

Comparison of data from different tests is not always consistent and can, at times, be confusing. Attempts to statistically relate data from different tests, both in this and other studies, have failed. One such study reached the following, seemingly contradictory, conclusions (among others):

> 7) Half cell potential readings are much more consistent and easier to obtain than chloride content data which have an exceptionally high coefficient of variation . . . .
>
> 24) Chloride contents in the vicinity of the top rebars seem to give a better indication of expected deck surface distress than half-cell readings.
>
> (reference 14, pp. 92 & 95)

Combining the results of each of the deck tests usually leads to a reasonably complete understanding of deck condition. To be successful, however, the investigator has to rely on good judgement and experience as well as raw data.

A crew of four seems to work well for bridge deck testing (with additional people to flag traffic, if necessary). One or two people begin attaching electrical leads to the deck for half-cell testing while the others begin laying out a testing grid. As soon as the leads are in place, the half-cell survey can be started (two people are needed for this). When grid layout is done, the others can start the pachometer survey and the chain dragging. As soon as someone finishes a survey, the first sites for chloride sampling can be chosen and the free person can begin on that (which one is finished first will depend on the condition of the deck).

In this way, the work proceeds rapidly with little idle time and without people getting in each other's way. Approximately 150 square yards of deck can typically be field tested per hour with such a crew, including setup of traffic signs and cones (but excluding travel time). On exceptionally easy bridges (good deck condition and little traffic) over 200 yd^2 per hour may be achieved; on exceptionally difficult bridges as little as 100 yd^2 per hour may be all that is possible. This assumes a five-foot grid for the half-cell and pachometer surveys, which is usually adequate. In areas where the readings change rapidly from one point to another, readings at intermediate points may be desirable.

Visual Inspections

Visual inspections of decks are currently made on all state owned bridges as part of DOT&PF Bridge Design Section's biannual condition surveys. These inspections have several advantages. They are simple, take little time, and rarely require any disruption of traffic. The training required of the inspector is minimal, and no equipment is necessary.

The principal disadvantage of these inspections is that they reveal little about the corrosion conditions of the deck. Corrosion damage is visible only in its later stages (i.e. spalled areas and/or cracks which have reached the surface). Once this sort of damage has begun, it will usually continue, often at an accelerating rate.

If spalling has not occurred, there is little that can be deduced from a visual inspection about the likelihood of future damage, or even of the current condition of the deck. Heavy traffic wear (rutting) may indicate a greater likelihood of corrosion damage, since this leaves less concrete cover over the rebars, making it easier for salts to penetrate to their level. Corrosion in rutted decks is not certain, however.

Visual inspections are even less useful if the deck has an asphalt wearing course, which may hide spalled areas. Patched asphalt areas may indicate spalling of the underlying concrete, or may indicate only a failure of the asphalt itself. To find out which is correct requires drilling, digging, or driving a hole through the patch (or use of exotic methods such as ground-penetrating radar).

Chain Dragging

Chain dragging is used to locate areas of delaminated concrete. It is very effective at this on bare decks. If the deck has an asphalt wearing course, it is not very useful, although it may reveal some large delaminated areas (see, for example, reference 15). The chain drag device is very simple and can be built from materials found in any hardware store at a negligible cost. The testing itself is also simple; the procedure can be easily learned in a few minutes.

Disadvantages of chain dragging include the need for lane closures and the length of time needed to perform the test. Reference 2 states that about 200 square yards of deck can be tested in an hour, with more time required on more severely damaged decks. This is consistent with the results of testing performed for this study. Another disadvantage of chain dragging is that it can be difficult to do on busy routes where traffic noise is high.

Chain dragging will not reveal early stages of corrosion problems; this is a major drawback to the test. Cathodic protection systems, for instance, are economically most effective on decks where chloride contents have reached a high level and corrosion has begun, but delamination and spalling have not yet occurred. These conditions cannot be determined by chain dragging.

There are several other methods for locating delaminated concrete which have been tried. These include the "Delamtect" machine, infrared thermography, ground-penetrating radar, resistivity, micro-seismic refraction, and ultrasonic transmission (references 15, 16, 17, 18). So far as could be determined in this study, only the first two have been used on more than an experimental basis.

The "Delamtect" is described in reference 2, which lists its price in 1978 as about $9,000. It is essentially an automated chain drag. It has hammers which tap the deck, sensors to pick up the sounds generated, and circuitry to digest the information. The output is printed on a paper tape. When properly calibrated, the machine produces results very similar to those found with the chain drag. Its main advantage seems to be the reduced amount of labor required, especially in the field. Because of its high initial cost, it does not seem practical unless a large number of decks are to be surveyed.

Infrared thermography relies on the fact that thin concrete (i.e. in delaminated areas) heats up faster in bright sunlight than thick concrete (i.e. intact deck areas). Thermographs of decks filmed in the middle of a sunny day will reveal delaminated areas as "hot spots." The equipment is expensive and requires considerable training to use. It has been found more effective than chain dragging on asphalt overlaid decks (reference 15). The filming can be done from a slow-moving vehicle with proper equipment, minimizing traffic disruption (reference 17). The dependence on weather is a major drawback, since a negative result doesn't really prove the deck is solid; such results may prove only that weather conditions weren't right at the time of filming.

While thermographic techniques are potentially useful, the expense of purchasing equipment and training operators is not justifiable for bridge deck evaluations in Alaska. The equipment and operators are available in Alaska (for other purposes), and it may be worthwhile to contract these services under some circumstances.

Half-cell Potential Surveys

Half-cell surveys are very useful because they can indicate where corrosion is occurring (or is likely to occur) before physical damage to the concrete has taken place. The standardized test (ASTM C876) basically measures the effectiveness of the concrete as an electrolyte.

The equipment is relatively simple and inexpensive, and the test procedure is straightforward. In tests performed for this study, it was found that two people could do a half-cell survey on a five foot grid in about the same amount of time it took a third person to chain-drag a deck. This relationship will vary somewhat since chain dragging takes more time on more severely damaged decks, while half-cell surveying time is independent of deck condition.

The simplicity of half-cell surveys is somewhat deceiving, because it is easy to get inaccurate readings. Consistently small readings may not indicate the absence of corrosion problems. Such readings may indicate instead that the concrete around the rebars is too dry at the time of the survey (despite the fact that the deck surface is moistened prior to testing). A poor choice of electrical ground location can also result in bad data. If the ground location does not have good electrical continuity with the deck rebar, inaccurately small readings may result. Connections made to galvanized metal embedded in the concrete (e.g. guardrail supports) can also result in bad data. In this case, copper-zinc potentials may be recorded, when copper-iron potentials are desired. Since copper-zinc galvanic cells have a higher potential than copper-iron cells, excessively large readings may be obtained. This can lead to the conclusion that corrosion is occurring in places where, in fact, it is not.

Another possible problem is the presence of telluric currents induced by auroral activity. The severity of the problem increases with the length of the deck and of the wires connecting the half-cell to its ground. It also increases with the intensity of the auroral activity (which isn't apparent during daylight hours). Half-cell readings affected by this disturbance should fluctuate fairly rapidly, so it should be apparent that some problem exists, even if its cause isn't known. "Stray current" leaking from DC sources (such as arc welders and telephone lines) can also result in bad half-cell data.

All of these possible sources of error in half-cell survey data illustrate the need for some knowledge and experience on the part of the inspection personnel. Comparison of the half-cell survey results with other test data from the same deck, coupled with an awareness of potential problems, will usually reveal any errors that occur. Without this, test results may lead to confusion and/or an incorrect assessment of a deck's condition (which occurred during early testing for this study).

Pachometer Surveys/Chloride Analysis

The pachometer is used to determine the depth of concrete cover over deck rebars, which often differs from that shown on the bridge plans. The pachometer is simple to use and easy to calibrate. Other things being equal, rebars under a thin cover are more likely to corrode than those under thicker cover, since salts can penetrate to rebar level more readily. Pachometer readings thus have some usefulness by themselves.

A more important use of the readings from the pachometer survey is to determine the depth at which concrete samples should be obtained for chloride analysis. Rebar location is also determined, so that sample holes can be drilled where they won't hit the rebars.

Chemical analysis of chloride content of deck concrete at the level of the rebar provides the best indicator of corrosion activity. If samples were taken at each of the grid points, there would be no need for half-cell potential surveys. Obtaining this many samples is impractical because of the amount of time it would take and expense of the chemical analyses. It would also leave numerous holes in the deck which, even when grouted, would provide pathways for salt penetration into the deck.

Chloride sampling is therefore generally reserved for those areas of the deck where the half-cell survey did not conclusively indicate whether or not corrosion was occurring (i.e. where potentials between -0.20 and -0.35V were obtained). The number of sample locations will vary depending on the size of these inconclusive areas and may be constrained by budget limitations. Washington State DOT requires one sample per 750 ft^2 of deck area, with a minimum of 10 samples per deck. In addition to analysis for chlorides at rebar level, they require chloride content profiles from the deck surface to below rebar level at a minimum of two of the locations (reference 19, p. 23). This is a greater frequency of testing than most agencies use.

It is recommended that an initial hole be drilled to the level of the top of the rebar mat. After cleaning the hole, a second, smaller bit should be used to take the sample itself. This reduces the likelihood that concrete shaved from the sides of the hole near the surface will contaminate the sample. This is very important, given the small sample size. It is similarly important to use clean equipment to gather the sample, and not to handle the sample with bare hands.

APPENDIX B
UNIT COSTS

Cost Inflation

Historical costs in this report have been multiplied by the values listed in Table B-1 in order to account for inflation. These values are based on the Building Cost and Construction Cost Indices published by the Engineering News-Record. The ratios of the indices for 1982 to those for the year in question were averaged. All costs in this chapter are thus presented in 1982 dollars.

TABLE B-1: Cost Adjustments for Inflation

Year of Cost	Multiplier to convert to 1982 dollars
1982	1.000
1981	1.071
1980	1.163
1979	1.248
1978	1.353
1977	1.462
1976	1.577
1975	1.716
1974	1.871
1973	1.987

New Decks

The costs of class A-A concrete, reinforcing steel, and guardrail are included here. The average in-place cost of these items per cubic yard, pound, and linear foot, respectively, were calculated from DOT&PF Bridge Design Section's summaries of all bridge contracts since 1975. The costs were adjusted for inflation and converted to equivalent costs per square yard of deck surface. This was done by estimating the average deck thickness, pounds of rebar per square yard of deck, etc., based on plans for eight to ten bridges. This is summarized below:

Class A-A concrete: ($839/c.y.) (0.21 c.y./s.y.)	= $176/s.y.
Reinforcing steel: ($1.04/lb) (50 lb/s.y.)	= $52/s.y.
Guardrail: ($72.06/l.f.) (0.5 l.f./s.y.)	= $36/s.y.
TOTAL	= $264/s.y.

Removal of (Old) Decks

There isn't much historical cost data on which to base cost estimates for deck removal in Alaska. Costs are likely to be quite variable, depending on such things as the location of both the bridge and the disposal site, ease of access, and type of deck. Cost data from three projects, adjusted for inflation, are listed in Table B-2.

TABLE B-2: Deck Removal Costs

		Cost (1982 dollars per square yard)			
Bridge	Deck Area (sq. yds.)	Lowest Bidder	Second Lowest Bidder	Third Lowest Bidder	Average
#788 Lawson Creek (removed 1975)	743.1	55.24	57.73	120.08	77.68
#654 Slana River (removed 1981)	441.5	24.26	72.77	145.55	80.86
#1188 Salmon Creek (removed 1982)	316.9	N/A	N/A	N/A	45.23

Waterproof Membrane and Asphalt Concrete Overlay

The costs of membranes and overlays on 21 DOT&PF projects were examined. These projects involved over two dozen bridges built between 1976 and 1982. Unit prices appear to decrease significantly with increase in deck size, as Table B-3 shows. The highest cost for a single project was $49.85; the lowest $10.51.

TABLE B-3: Membrane and Overlay Costs

Deck Size (Square Yards)	Number of Projects	Average Costs (1982 dollars per sq. yd.)
< 400	4	38.20
400 - 800	8	23.79
> 800	9	18.18
all decks	21	24.13

Epoxy-coated Reinforcing Steel

Epoxy-coated rebar hasn't been widely used on Alaskan bridges. It was used on Peters Creek Undercrossing, where it cost 47 cents a pound more than uncoated rebar in 1980 (equivalent to about 55 cents in 1982). On the Lemon Creek Bridge the premium for epoxy coating was 31 cents a pound in 1982.

Epoxy-coated rebar was used on Campbell Creek Bridge at Dowling Road, built in 1980. Deck protection cost $2867, or about $17 per square yard in 1982 dollars. This is equivalent to 68 cents per pound of rebar, assuming 25 pounds per square yard.

Costs per square yard of deck surface depends on whether all rebar is coated or only the top mat. About 50 pounds of rebar are used per square yard of deck; if only the top mat is coated (as per current DOT&PF specifications), the amount would be roughly half as much.

In the lower 48 states the cost of epoxy coating is lower, and use of it is more widespread. In Pennsylvania epoxy coating cost an average of 39 cents per pound in 1975 (reference 22). This is equivalent to about 67 cents in 1982. Prices were falling at that time, however, due to increased production volume and relaxed specifications; the national average by 1977 was about 15 cents a pound (reference 20). This is equivalent to about 22 cents a pound in 1982 dollars.

Reference 21 cites a cost of epoxy coating in the Minneapolis-St. Paul area of $300 to $350 per ton of rebar in 1980. In 1982 dollars, this is about 20 cents a pound. This represents deck protection material costs of only $5.00 per square yard of deck (assuming 25 pounds coated rebar per square yard).

Cathodic Protection Systems

The only full scale cathodic protection system on an Alaskan bridge deck is the one installed on Wendell Street in Fairbanks during 1982. The original contract also included a system for the Cushman Street Bridge; this was later deleted. The bids for furnishing and installing the systems were as follows:

Engineer's estimate:	$180,000 ($68/sq. yd.)
Lowest bidder:	$103,119 ($39/sq. yd.)
Second lowest bidder:	$129,600 ($49/sq. yd.)
Third lowest bidder:	$150,000 ($57/sq. yd.)

Extra work required because of insufficient concrete cover (see Chapter 4) resulted in costs of about $65/sq. yd. attributable to the system on Wendell Street. Deck surveys with a pachometer can determine the depth of concrete cover. The need for this type of extra work on future projects thus should be determined in the design stage and figured into cost estimates.

Table B-4 contains cost information for three other impressed current, anode-in-slot type systems installed in 1982. This type of system appears to have several advantages over others and is likely to be the type used in any future projects.

TABLE B-4: Cathodic Protection System Costs

Owner	Bridge Location	Deck Area (sq. yd.)	Cost & Remarks
Ohio DOT	I-670 in Columbus	1,518	$53,900 ($35/sq. yd.) including design, traffic control and mobilization
Pennsylvania DOT	TR 15, Union County	1,076	$43,900 ($41/sq. yd.) cathodic protection system $10,000 ($9/sq. yd.) traffic control and mobilization
City of Akron, Ohio	N. Arlington Street	714	$61,750 ($86/sq. yd.) includes all costs except design and inspection

Notes:

1) Source of information is reference 6 and City of Akron Construction Engineering (personal communication).

2) All systems were installed in 1982 and were of the impressed current, anode-in-slot type.

Deck Rehabilitation

Deck rehabilitation, as discussed here, includes a number of items of work likely to be performed together on a job. These include deck scarification, removal of delaminated concrete and concrete surrounding rusted rebar, replacing badly corroded rebar, cleaning the concrete and rebar surfaces, and overlaying the deck with fresh concrete. Reference 5 recommends that this work be divided into five contract items, although in past Alaskan projects they have been divided into only two or three (e.g.

"deck preparation" and "deck overlay"). This discussion will be based on the items recommended in reference 5. It relies heavily on communications with the authors of that report and on records from the Fairbanks Bridge Deck Repair project.

Scarification

Scarification is most effectively done with large, self-propelled equipment (e.g. a Roto Mill). This equipment may be unavailable in remote locations. Scabblers or other hand operated equipment will be needed to work along gutterlines and joints, around drains, etc., even on decks where the larger equipment can be obtained. The recent Fairbanks work indicates that shallow (1/4 inch) scarification can be done for about $15 per square yard. If all the work must be done by hand the cost may be twice this amount.

Scarification was a bid item in 1973 on contracts for work on Glenn Highway bridges and Ketchikan decks. The average of the three low bids for the Glenn Highway work was about $11 per square yard (adjusted for inflation); those for work in Ketchikan were about $17 per square yard (adjusted). The 1973 Ketchikan bids were rejected as too high (although not because this item was high); the work was done under a contract bid the next year.

Hand Chipping

Alaskan deck repair projects have usually included two types of concrete removal (in addition to scarification). The first is the removal of delaminated concrete; this exposes some of the deck rebar. The second is to hand chip intact concrete from around rebars where half or more of their diameters has been exposed. It is difficult to know in advance how much labor this work will require. As a result, this is the largest potential source of error in estimating deck repair costs.

Based on the Fairbanks deck repair work, it appears that "hand chipping" (or "concrete removal") costs may range between $60 and $360 per square yard of delaminated concrete, with an average of $175-$200. The cost will tend to increase with greater thickness of the delaminated concrete and with greater concrete strength. The cost will tend to be lower the farther apart the rebars are and the larger the individual delaminated areas are.

"Removal of unsound concrete" was an item in the 1973 contracts mentioned above for Glenn Highway bridges and Ketchikan decks. The two lowest bids for the Ketchikan work averaged $174 per square yard, adjusted for inflation (the third lowest overall bid listed $5 per square yard for this item which is clearly unreasonable). The three low bids for the Glenn Highway work averaged only $36 per square yard (adjusted). A good deal of trouble was encountered during construction there, however, because the contractor claimed he understood "unsound concrete" to mean "delaminated concrete" exclusively. The low bid prices for this item, then, were the result of a misunderstanding and should not be considered representative for this work.

High pressure water jets capable of removing intact concrete were mentioned in Chapter 3 and are discussed in reference 8. The successful development of these systems could lead to large reductions in the cost of concrete removal and essentially eliminate the subsequent need for sandblasting and/or wire brushing.

Reinforcing Steel Repairs

Repair of badly damaged rebars is done by cutting out the bad section and splicing new rebar in its place, with a suitable overlap with the remaining parts of the old rebar. For the recent Fairbanks project, the cost of this was estimated at $2 per pound of steel; the three low bids were all within 15 cents of this.

Corrosion itself will rarely be serious enough to warrant rebar replacement. Replacement may be necessary, however, where rebar has been exposed to traffic due to severe wear of the concrete or spalling.

Deck Preparation

Cleaning concrete and rebar surfaces consists of sandblasting and/or wire brushing followed by removal of debris with pressurized water or air. Although this has never been a separate pay item on an Alaskan deck repair project, it has been estimated that the cost of the work is about $10 per square yard.

Overlays

The cost of concrete deck overlays depends on the type of concrete specified. Two types commonly used for deck repair work have been used in Alaska. The first of these is a Portland cement mix with a high cement content, a low water/cement ratio, and a low slump. The second is a latex-modified concrete.

The first of these types was used on the Glenn Highway work in 1973. The mix contained more cement and had a lower water/cement ratio than normal deck concrete, as shown in Table B-5. The specifications were not as extreme in this regard as "Iowa method" concrete, also shown in the table. The cost of the Glenn Highway concrete, including changes made after the contract award, was somewhere between $660 and $825 per cubic yard in 1982 dollars, assuming an average overlay thickness of 2 to 2 1/2 inches. This is somewhat lower than typical for full deck pours with Class 'A-A' concrete, but not extraordinarily so.

A similar concrete was specified in the contract the following year for the Ketchikan viaducts. Slightly more water was allowed than on the Glenn Highway work, but the slump was restricted to 2 inches maximum (see Table B-5). The low bid was relatively inexpensive: $250 per cubic yard, equivalent to about $470 in 1982 dollars. The engineer's estimate and the average of the three lowest bids (about $750 and $890 in 1982 dollars respectively) are typical of the prices for deck concrete on new bridges.

Compared to deck pours for new bridges, overlays require more finishing work per unit volume of concrete, but there is practically no form work needed. It appears that the latter more than compensates for the former judging from the two projects cited above.

TABLE B-5: Deck Concrete Specifications

	"Normal" deck concrete (Class 'A-A')[1]	Glenn Highway Deck Repair (1973)[2]	Ketchikan Viaduct Repair (1974)[2]	"Iowa Method" Concrete[3]
Minimum Cement Content, Sacks/cu. yd.	7.0	8.0	8.0	8.75
Maximum Water/Cement Ratio, Gallons/sack	5.0	4.5	5.0	3.7
Water/cement ratio	0.44	0.40	0.44	0.33
Slump range, inches	1-2.5	0-3	0-2	1/2-1
Entrained Air, %	5-9	6-10	5-8	5-7

Notes:

1 from Alaska DOT&PF 1981 Standard Specifications for Highway Construction

2 from project records

3 from Iowa Highway Commission Supplemental Specification 712 (March 28, 1972)

Latex-modified concrete has been much more expensive as an overlay material. The original contract for repairs to the Ketchikan viaducts (in 1973) specified this material. The low bid of $50 per square yard was exactly double the engineer's estimate. The average of the three lowest bids was $66 per square yard. It was principally because of the cost of this item that all bids were rejected as too high. The low bid, assuming a 2 1/2 - 3 inch average overlay depth, is equivalent to almost $1600 per cubic yard in 1982 dollars.

The cost of latex-modified concrete used on the Fairbanks deck repairs in 1982-83, while not as high, was considerably more than typical for deck concrete. While it was not a separate pay item, the cost of the concrete in place has been estimated at about $1200 per cubic yard. This was the first time that latex-modified concrete had been used on a deck in Alaska, and the contractor's equipment had to be modified to produce it. It is likely that given greater experience with the material, unit prices would decline to something closer to that of more conventional concrete.

Incidental Work

There are a number of incidental items of work which will add considerably to the cost of bridge deck repairs or replacement. The most important of these are mobilization and traffic control expenses. Other items may include providing a field office for state personnel, performing surveys, adjusting expansion joints, manhole covers, valve covers and the like. It is difficult to estimate these costs for a generalized case, as they are quite variable. They are almost certain to total at least 20%, and may be as much as 100%, of the cost of the major work items.

Mobilization costs for the four decks repaired in Fairbanks in 1982 and '83 totaled under $32,000. For the four Glenn Highway bridges mobilization costs were similar; about $36,000 in 1982 dollars. This item, however, cost nearly $200,000 (in 1982 dollars) for the viaduct repair work in Ketchikan. This high cost was due partly to the fact that more equipment was needed (asphalt paving was included in the repair work) and partly to the high costs of transporting equipment by sea to that location.

Traffic control costs on the Minnie Street and Illinois Street bridges were very low -- about $2500 per bridge for both traffic maintenance and construction signs items. It was possible to close these bridges entirely and detour traffic around them while repairs were being made. At the other extreme, the long Knik River Bridge on the Glenn Highway couldn't be closed for any extended period. The signal system and flagging needed for repairs to that bridge cost almost $140,000 in 1973 -- equivalent to about $275,000 in 1982.

If bridge decks are replaced entirely, there is liable to be a great deal of incidental work required. Mobilization costs will be much higher than for rehabilitation work due to the greater equipment and material requirements, and traffic control is likely to cost more. There may also be considerable costs for utilities work and modifications to abutments and piers.

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