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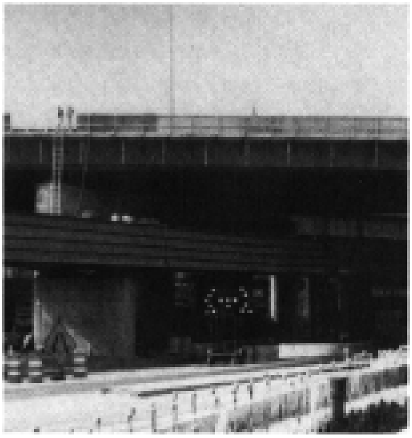
Effects of Road Salt on Motor Vehicles and Infrastructure



Road salt's impacts on motor vehicles and infrastructure are examined in this chapter. The focus is on three major areas: motor vehicles, bridges, and parking garages. Impacts on other infrastructure components, such as pavements, underground utilities, and roadside objects, are also discussed, although in less detail.

MOTOR VEHICLES

Motor vehicles have suffered from more severe corrosion since the widespread introduction of road salt following World War II. Among the various side effects of salting, vehicle corrosion is by far the best known and the most extensively studied, and it is typically the single largest component in estimates of overall cost.

Corrosion damage to motor vehicles can be separated into three categories: functional, structural, and cosmetic. Functional and structural damage occur when corrosion causes a loss of operating performance or structural integrity. Examples include perforation of body panels (Figure 3-1), corrosion of brake linings, and deterioration of the frame and bumper support systems. Cosmetic corrosion affects only the appearance of the vehicle. Examples include rust staining of painted body panels and discoloration and pitting of trim metals (Baboian 1990, 1–2).

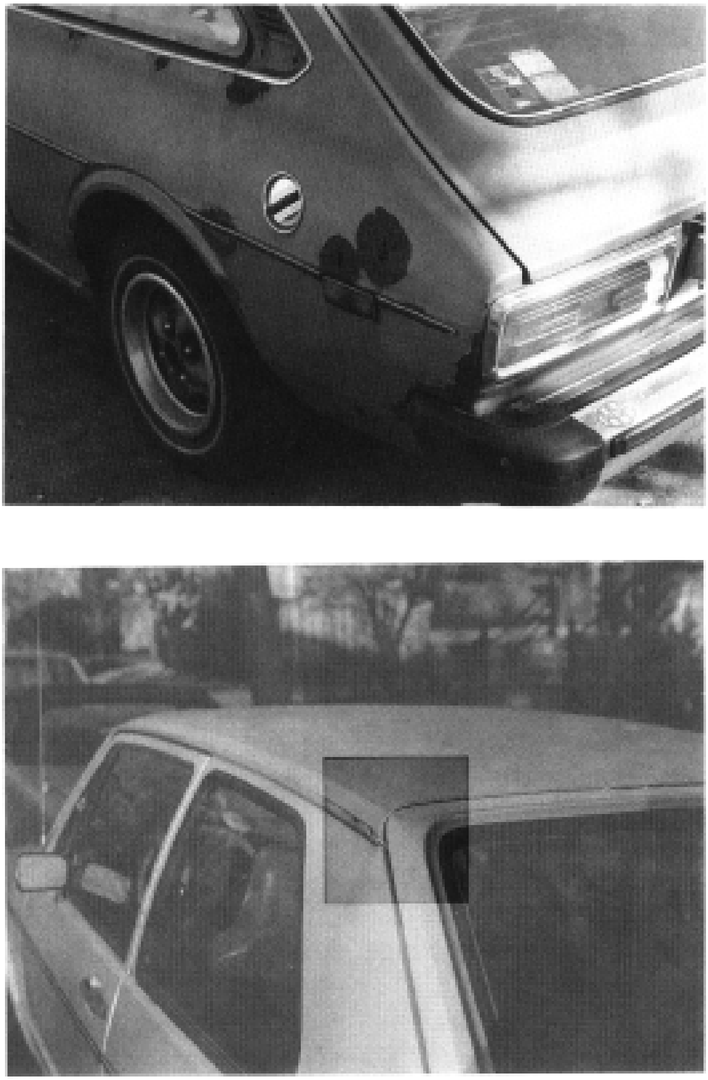


FIGURE 3-1 *Top:* Structural corrosion (perforations). *Bottom:* Cosmetic corrosion.

The corrosive effect of road salt on motor vehicles became apparent as early as the mid-1950s, when it was discovered that certain kinds of steel used for exterior trim were no longer resistant to localized pitting corrosion (Baboian 1981, 4–6). Although vehicle manufacturers were able to develop alternative trim metals to control this type of rusting, by the mid-1960s galvanic corrosion was occurring in body metals adjacent to trim (galvanic corrosion occurs where dissimilar metals contact). Later, during the 1970s, rust perforations became more common in the fenders, deck lids, hoods, quarter panels, and doors of many vehicles in the Northeast and Midwest (Baboian 1981, 4-6). At about this time, unprecedented corrosion was occurring in less visible sections of the vehicle, such as frames, floor panels, exhaust systems, and fuel and brake pipes.

The proliferation of rusted-out vehicles in many northern states identified road salt as a major cause of automotive corrosion. Other contributors, however, include sea spray in coastal areas, dust-control chemicals (e.g., calcium chloride) in rural areas, and atmospheric pollutants from the burning of organic fuels. These pollutants—nitrogen oxide (NO_x) and sulfur dioxide (SOJ-convert into acids (nitric and sulfuric acid) that cause acid rain, acid dew, and acid snow (i.e., acid deposition). Acid deposition increases the acidity (i.e., lowers the pH) of the environment, which hampers the formation of natural protective films on metal surfaces. When low-pH conditions are combined with chloride ions from road salt and sea spray, the corrosivity of the highway environment is significantly increased (Haynes and Baboian 1986).

Figure 3-2 shows that the highway environments in some regions of the country are far more corrosive than in others. The most corrosive environments are in the northeastern United States and in southern Canada, where the interactive effects of acid deposition,

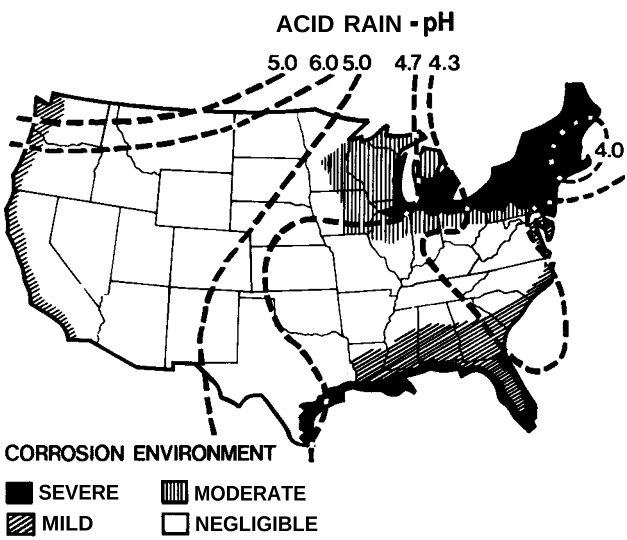


FIGURE 3-2 Corrosivity of the environment by region (Turcotte and Baboian 1985).

sea spray, calcium chloride, and road salt are greatest. Other corrosive environments are in the southern coastal areas of Florida and the Gulf Coast, where salt from sea spray, high humidities, and warm temperatures are especially conducive to corrosion.

Protection of Motor Vehicles from Corrosion

Figure 3-3 shows the benchmark years in motor vehicle corrosion superimposed on trends in salt usage and emissions of NO_x and SO_2 since World War II. The data indicate that the corrosivity of the highway environment reached its peak during the mid-1970s.

During this period, the combination of harsher operating environments and demands by motorists for vehicles that last longer forced automobile manufacturers to set up special engineering groups and testing facilities aimed at reducing the severity and frequency of corrosion. These efforts led to changes in vehicle designs, manufacturing processes, and material selection, including the use of

- More resistant and durable body metals, materials, and substrates—such as stainless steels, aluminum alloys, and plastics—and coated metals, such as clad steel, zinc alloys, and galvanized steel;
- New primer and coatings technology, such as cathodic electrodeposition primer, antichip coatings, and clearcoat paints;

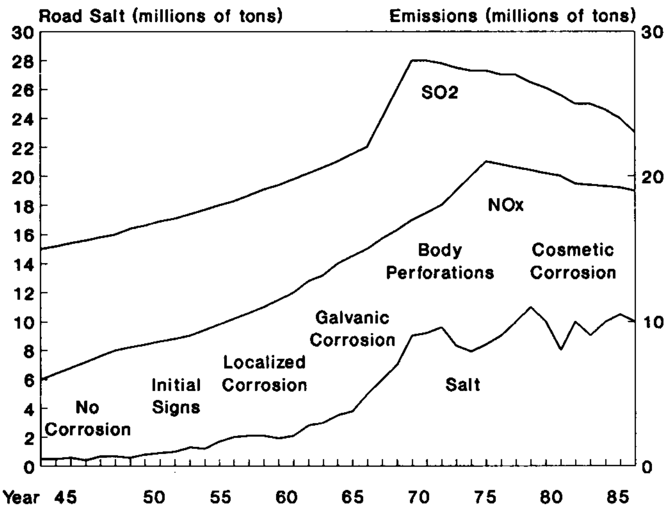


FIGURE 3-3 Road salt use and emissions of SO_2 and NO_x, 1945–1985 (Baboian 1991).

- Resin sealers for insulating body joints and crevices;
- Design configurations that reduce entrapment areas and improve the ease with which protective coatings can be applied; and
- New manufacturing technologies, such as more reliable robotics and adhesively bonded panels.

These advances and others are now used widely by most manufacturers of cars and trucks sold in the United States and Canada. Table 3-1 gives a rough approximation of the time of introduction

TABLE 3-1 APPROXIMATE TIMING OF CORROSION PROTECTION IMPROVEMENTS (Piepho et al. 1991)

Approximate Timing	Improvement
1963–1965	Two-side galvanized steel rocker panels and wheelhouses
1968	Two-side galvanized steel tailgates and use of bimetal trim
1975–1980	Immersion cathodic electrodeposition (ELPO) primer to improve perforation corrosion resistance; process implemented in most vehicle manufacturers' assembly plants by 1985
1975–1985	More one-side precoated steel products (e.g., one-side galvanized steel) on fenders, hoods, doors, and deck lids
1976	Incorporation of antichip lower body coatings
1977	One-side galvanized quarter panels
1980	Expanded use of two-side precoated steels for structural members (i.e., engine compartment rails, etc.) on new front-wheel-drive vehicles
1980	Industry provision of a 3-year/36,000-mi rust-through corrosion warranty
1982	Small crystal-size phosphate incorporated into exterior coating to improve corrosion resistance
1985	Spray phosphate systems improved and implementation of immersion phosphate systems started to improve coverage in body cavity areas for perforation resistance
1985	More two-side precoated steel products incorporated on hood, door, and deck lid inners; also, two-side precoated steel products phased into floor panels
1985–1989	Two-side galvanized steel on all major body inner and outer panels (except roof)
1987	Domestic manufacturers warranty coverage against rust-through corrosion increased to 6 to 7 years or 100,000 mi
1990	Two-side precoated products incorporated to resist rust-through corrosion

of many of these improvements. Today the stated goal of the industry is to eliminate all exterior surface rust on new vehicles for at least 5 years and perforations for at least 10 years (Piepho et al. 1991).

Perhaps the best evidence of the success of these efforts is that most manufacturers now offer long-term warranties that include rust-through coverage. Table 3-2 summarizes the corrosion warranties of various 1990 model vehicles. Of 41 major automobile makes and models, 39 include perforation coverage in their extended 1990 warranties. Coverage for most domestic cars and trucks is between 6 and 7 years or 100,000 mi. By comparison, as recently as 1980, few manufacturers were offering 3-year corrosion warranties (Piepho et al. 1991).

Cost of Corrosion Protection

Motor vehicle manufacturers have improved corrosion protection during the past 20 years for many reasons. Certainly the principal reason was the rapid increase in the use of salt and other chloride deicers (e.g., calcium chloride) during the 1960s and 1970s. Other reasons include the corrosivity of coastal environments, the aggravating effect of acid deposition, and, to a lesser degree, the summertime use of calcium chloride on dirt and gravel roads for dust control (Piepho et al. 1991).

In the late 1970s, the National Institute of Standards and Technology (formerly the National Bureau of Standards) estimated that the rust-resistant metals, special paints, and protective coatings used to control corrosion added approximately $100 to the price of a new car purchased in 1975, or about 2 percent of the total purchase price (Bennet et al. 1978; Passaglia and Haines 1981, 13–24). As indicated in Table 3-1, improvements have been made in corrosion protection since that time. Many improvements, such as the expanded use of galvanized steel, are solely the result of efforts to improve vehicle corrosion resistance; however, several others, such as the use of plastics to improve fuel efficiency and reduce denting, are by-products of concerns other than corrosion protection.

Because many improvements were implemented for more than one reason, it is difficult to isolate costs specifically associated with corrosion protection. Manufacturers rarely maintain cost data in such an exclusive manner; even when they do, they are seldom willing to make the information public, for competitive reasons. Manufacturers contacted for this study, therefore, were asked instead to identify in general terms the major elements of corrosion protection that have

TABLE 3-2 CORROSION WARRANTY COVERAGE BY MAJOR AUTOMOBILE MAKERS, 1990 MODELS (*Automotive News*, 1989)

Make or Model	Corrosion Coverage (years or miles)	Deductible ($)
Domestic		
Ford truck	6/100,000	100
Mercury	6/100,000	100
Lincoln, Merkur	6/100,000	100
Buick	6/100,000	100
Chevrolet truck	6/100,000	100
Oldsmobile	6/100,000	100
Pontiac	6/100,000	100
Cadillac	6/100,000	100
Cadillac Allante	7/100,000	25
Chrysler (all)	7/100,000	100
Japan		
Acura	3/Unlimited	None
Daihatsu	3/Unlimited	None
Honda	5/Unlimited	None
Infiniti	7/Unlimited	None
Isuzu	3/Unlimited	None
Lexus	3/Unlimited	None
Mazda	6/Unlimited	None
Mitsubishi	3/Unlimited	None
Nissan	5/Unlimited	None
Subaru	6/60,000	None
Suzuki	3/Unlimited	None
Toyota	5/Unlimited	None
Korea		
Hyundai	3/Unlimited	None
France		
Peugeot	3/36,000	None
Germany		
Audi	6/Unlimited	None
BMW	6/Unlimited	None
Mercedes-Benz	4/50,000	None
Porsche	10/Unlimited	None
Volkswagen	6/Unlimited	None
Great Britain		
Aston Martin	No	None
Jaguar	6/60,000	None
Lotus	8/Unlimited	None
Range Rover	6/Unlimited	None
Rolls Royce	3/Unlimited	None
Sterling	6/Unlimited	None
Italy		
Alfa Romeo	6/60,000	None
Ferrari	No	None
Maserati	2/24,000	None
Sweden		
Saab	6/Unlimited	None
Volvo	8/Unlimited	None
Yugoslavia		
Yugo	3/Unlimited	25

increased the cost of manufacturing vehicles. In response, the cost items listed were primarily special paints, coatings, and materials. Although not exhaustive, the list includes

- Precoated steels and plastics in the body;
- Electrodeposition primers;
- Underbody splash shields;
- More extensive use of adhesives, deadeners, and sealers, including sealed electrical systems (e.g., connectors, switches, and circuits);
- Special metals and coatings (such as stainless steel and aluminum) for engine and power train items, ignition components (e.g., starters and alternators), and fuel systems; and
- Special bumper support systems and trim metals.

No specific cost estimates were given for individual items; instead, a range of costs was developed for the entire group. It was generally agreed that most of these systems are now used on all major vehicle makes and models sold in the United States, including imported and domestic vehicles and economy and luxury lines. Cost estimates ranged from $250 to $800 per vehicle for typical late-model vehicles, or about $500 per vehicle on the average.

The $500 figure can be multiplied by the number of new vehicles sold each year in the United States to estimate a total national cost of corrosion protection. In 1989 approximately 14.5 million new passenger vehicles were sold nationwide, including 9.9 million cars and 4.6 million vans and light trucks (mostly pickups) (MVMA 1990). These figures do not include larger trucks, trailers, buses, and recreational vehicles. Altogether, 900,000 of these vehicles-330,000 large trucks and buses, 170,000 truck trailers, and 400,000 recreational vehicles-were sold in 1989 (MVMA 1990). If $500 is also spent on protecting these larger vehicles, the total cost of corrosion protection is about $7.7 billion per year ($500 x 15.4 million).

The attribution of a precise share of this cost to road salt is complicated because of the various reasons for corrosion protection besides salt. Though the expanded use of road salt has historically been the driving force behind corrosion protection, it is not clear that significant reductions in salt use today would result in substantial savings in the cost of corrosion protection. New vehicles are shipped worldwide, frequently to markets such as Europe, where the other sources of corrosion-sea spray, acid deposition, and calcium chloride-are especially severe. Also, because automotive technologies have improved and vehicle prices have increased, motorists now operate vehicles longer and demand long-term protection from all types of corrosion and premature wear.

Estimates of savings in the cost of corrosion protection that would result from reductions in salt use vary depending on the importance ascribed to these other considerations. Estimates from motor vehicle manufacturers contacted for this study suggest that, as a practical matter, only limited reductions in the cost of corrosion protection would result, even if salt and calcium chloride were no longer used for highway deicing. The estimated savings ranged from $125 to $250 per vehicle, with the largest savings resulting from the reduced application of galvanized steel. To determine the savings on a national basis, a rough estimate can be developed by multiplying the $125 to $250 savings by the 15.4 million new cars and trucks sold each year in the United States. The estimate suggests a total cost of salt-related corrosion protection ranging from $1.9 billion to $3.9 billion per year.

Undoubtedly some additional corrosion-protection costs are incurred by motorists who rustproof their vehicles after purchase. Such aftermarket rustproofing is usually performed by the dealership or companies specializing in rustproofing applications. There is considerable controversy about whether aftermarket rustproofing is desirable and in fact deters corrosion (Piepho et al. 1991; Peterkin 1990). In this study no attempts were made to estimate these additional rustproofing costs, although the committee believes that they are fast declining in significance as manufacturer (i.e., assembly-line) rust protection improves.

Persistent Motor Vehicle Corrosion

Results from several studies indicate that assembly-line corrosion protection has been successful in reducing the severe structural corrosion that plagued cars during the 1960s and 1970s. For example, since 1985, the Automotive Corrosion and Prevention Committee of the Society of Automotive Engineers (SAE) has conducted biennial surveys of vehicles in the Detroit metropolitan area, identifying corrosion as surface rust (paint has been removed and the steel surface is rusted), blisters (bubbling of paint), or perforations (Bryant et al. 1989). To date, three surveys have been conducted, for model years 1980 through 1985 (1980, 1982, and 1984 models were surveyed at age 6; 1981, 1983, and 1985 models were surveyed at age 5).

Table 3-3 gives the share of vehicles in each survey with at least one rust defect. The table indicates that all types of body corrosion were reduced during the 1980s. For instance, the share of vehicles

TABLE 3-3 PERCENTAGE OF SURVEYED VEHICLES WITH RUST DEFECTS (Bryant et al. 1989)

	Survey 1 (1980 and 1981 Models)	Survey 2 (1982 and 1983 Models)	Survey 3 (1984 and 1985 Models)
Blisters	61	56	34
Surface rust	78	67	46
Perforations	20	8	3
Total with defects	86	80	59

with one or more perforations decreased by 85 percent, and the share of vehicles with one or more blistered panels decreased by almost one-half. Altogether, the share of 5- and 6-year-old vehicles with one or more rust defects declined from 86 percent in the first survey to 59 percent in the most recent survey.

The most important of these trends is the near elimination of perforations for at least 5 to 6 years. The SAE surveys indicate not only that the share of vehicles with perforations declined sharply but also that the number of body panels affected declined. In 1980 and 1981 models, perforations were found in 23 panels, ranging from the fenders to the roof. In 1984 and 1985 models, perforations were found in only seven panels (Bryant et al. 1989).

Reductions in cosmetic corrosion were less dramatic than declines in perforations—34 percent of vehicles surveyed had blisters and 46 percent had surface rust in 1984 and 1985 models. As mentioned previously, cosmetic corrosion often involves the trim metals. Rust "bleeding" or pitting where the trim and body metals meet (due to galvanic corrosion) is an example of cosmetic corrosion. Localized mechanical damage to the paint work and trim caused by minor accidents or stones striking the vehicle sometimes results in surface rust and paint blisters.

Without data for later-model vehicles, it is difficult to estimate the degree to which cosmetic corrosion continues to affect new cars and trucks. However, in the analysis of its survey results, SAE noted that the percentage of panels containing precoated steel on the outer surface was still small for 1984 and 1985 vehicles (the last model years in the most recent SAE survey). It anticipated that the expanded use of this material in more recent models, combined with continued improvements in phosphates, coatings, and antichip materials, will be reflected in even lower corrosion rates in future surveys (Bryant et al. 1989).

Cost of Persistent Corrosion

Murray and Ernst, in their 1976 economic analysis of the environmental impact of road salt conducted for the Environmental Protection Agency, estimated that the cost of salt-related vehicle corrosion, including corrosion protection, was about $2 billion per year (in 1975 dollars) (Murray and Ernst 1976). Vehicle depreciation due to corrosion, which accounted for $1.4 billion, represented the largest share of this cost. It was estimated that salt-related corrosion reduced the value of motor vehicles by as much as 1 to 2 percent per year in heavy salt-using states like New York and Massachusetts.

A simple update of Murray and Ernst's $1.4 billion cost estimate to reflect inflation and changes in the number of vehicles would probably lead to an inaccurate depiction of current corrosion costs. Because of the progress that has been made in corrosion prevention by manufacturers, today's vehicles are less vulnerable to corrosion than vehicles built 10 to 20 years ago. Whereas cosmetic corrosion remains a significant cost for many vehicle owners, perhaps the single largest cost of corrosion is paid when purchasing new vehicles, which are equipped with more expensive corrosion-resistant materials and coatings.

Few data are available to quantify the cost of cosmetic corrosion,[1] although it remains a concern in some areas of the Northeast and Midwest, where motorists still spend money and time to prevent it and consequent losses in vehicle value. Preventive efforts include more frequent car washing and other exterior maintenance (e.g., waxing) and touching up of paint damage caused by minor accidents and stone chips. Although no reliable data are available to estimate these costs, they are likely to be significant because of the large number of vehicles in salt-using states.

A rough estimate of the magnitude of these costs can be developed on the basis of the amount that motorists in salt-using regions might be willing to spend to completely eliminate persistent cosmetic corrosion for the life of a vehicle.[2] As estimated in the previous section, motorists now spend between $125 and $250 per new vehicle for protections added by the manufacturer. This has reduced both the incidence and the severity of the structural and functional corrosion that plagued automobiles during the 1970s. If motorists in the salt-using regions of the Northeast and Midwest—where approximately 9 million new vehicles (60 percent of the total) are purchased each year (MVMA 1990)—were willing to spend an additional $125 to $250 per new vehicle to completely eliminate the minor forms of cosmetic corrosion that persist, this cost alone would be roughly

$1 billion to $2 billion per year (9 million vehicles × $125 to $250 per vehicle = $1.1 billion to $2.2 billion).

BRIDGE DECKS

During the past 20 years, the condition of the nation's highways has received increasing attention from the public and legislators. Much of the attention has focused on premature deterioration of concrete bridge decks, caused in large part by chloride deicing salt. Whereas bridge age, traffic levels, and construction quality have also played an important role, the use of road salt has been the single most important factor in deck repair and maintenance problems.

The effect of salt on bridge decks is well understood. During the 1950s and 1960s, thousands of decks were constructed, many of them on newly constructed Interstates, using cast-in-place concrete heavily reinforced with steel bars. The upper steel bars were designed to be positioned approximately 2 in. below the concrete surface in most of the decks (TRB 1984, 107). Soon after construction, however, many decks developed pores or fine cracks from the deck surface to the reinforcement bars (rebars). Under low- or no-salt conditions, rebars are normally protected from corrosion by the highly alkaline environment of the concrete, which forms a natural protective film of ferrous oxide on the steel surface. However, when chloride ions from road salt penetrate through the pores and cracks, the protective film is disrupted and corrosion can begin.

Corrosion of steel in concrete can occur in several forms. The most damaging form is termed macrocell corrosion, in which large areas of the steel (often the top rebar mat) become corroding anodes, and other areas (usually the bottom rebar mat) become noncorroding cathodes. The rebars act as an electrical pathway, conducting electrons from the anodic to the cathodic areas. The chloride ions and water molecules act as an electrolyte, completing the electrical circuit. As the steel corrodes, the rust product expands, exerting pressure on the surrounding concrete and causing it to crack and disbond. Eventually this process leads to spalling, or potholing, of the deck surface (Figure 3-4). In turn, the potholes provide access to additional salt and moisture, which aggravates the destructive processes already caused by freeze-thaw, vibrations, and impact loadings from traffic (TRB 1984, 109).

Rusting of rebars is usually considered detrimental because it degrades the ride quality of the deck. Safety is also a concern. Because bridge decks often have limited maneuvering room and sometimes

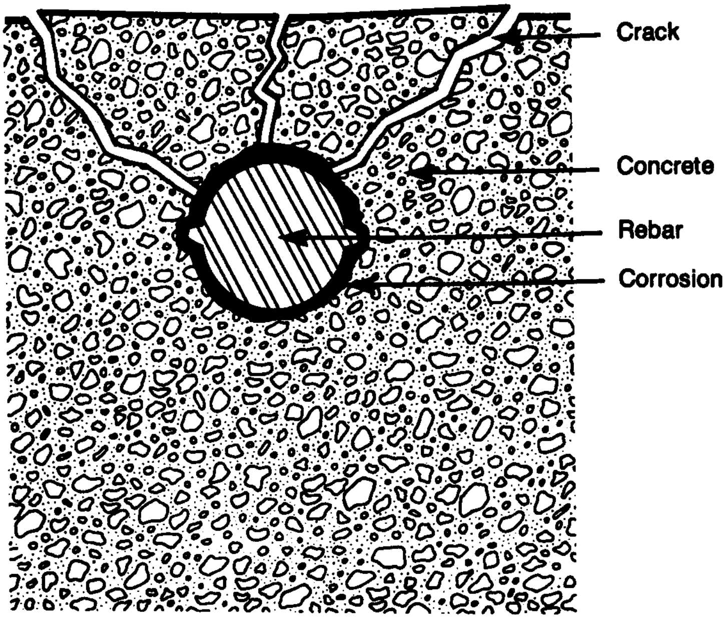


FIGURE 3-4 Damage caused by rebar corrosion.

lack full shoulders, even minor irregularities and potholes can result in hazards that require prompt repair.

Bridge Deck Repair and Rehabilitation

Conventional methods of deck repair range from patching of individual potholes during early stages of deterioration to complete deck replacement if potholes and patches cover a large portion of the deck. Because of its low cost, patching is the most common repair, although its effectiveness is usually only temporary (Figure 3-5). To provide longer-lasting repair, the damaged concrete must be replaced with new concrete and special waterproof membranes or sealers that prevent further intrusion of salt and moisture. Such partial restoration, however, is seldom completely successful in halting the corrosion process, because unrestored sections often begin to corrode after the deck has been repaired.

A disadvantage of partial deck restoration is that signs of corrosion, such as potholes, may not become evident until well after a large portion of the deck has become critically contaminated with chlorides. Once this critical, or threshold, contamination level has been

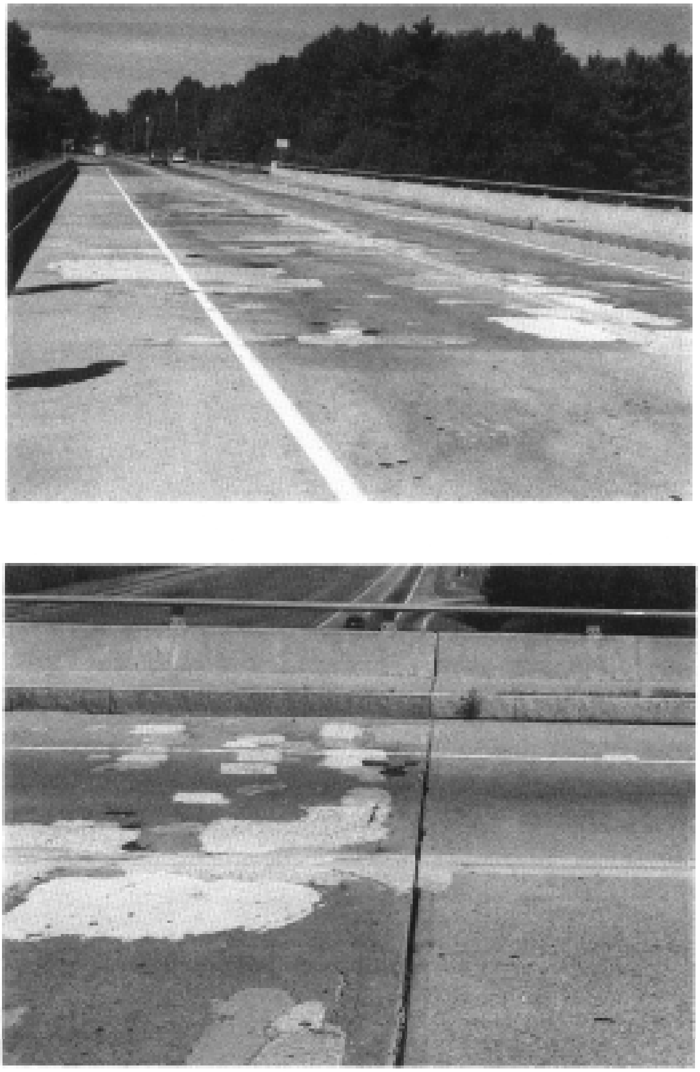


FIGURE 3-5 Patching of a severely contaminated concrete deck.

reached, deck deterioration usually continues, regardless of the subsequent use of salt or noncorrosive deicers. In many northern cities, where road salt is applied frequently and in large quantities, unprotected decks reach the threshold contamination level within 10 to 15 years after construction.

Unless they are rehabilitated (and protected), continued deterioration is probably inevitable for thousands of decks in northern states that are already severely damaged or critically contaminated with chloride.[3]

Repair and Rehabilitation Costs

According to the National Bridge Inventory, about 55 percent of concrete decks in the United States are in sound condition and not already critically contaminated with chlorides. Presumably, however, some of them will become contaminated and damaged by continued salting. Table 3-4 gives the percentage of undamaged decks by region. In particular, the heavy salt-using regions of the Northeast and Upper Midwest have a noticeably smaller share of undamaged decks than do other regions. For instance, among 11- to 20-year-old decks, only 75 percent are undamaged, compared with about 85 percent in low-salt regions. Moreover, among 21- to 30-year-old decks, only about 45 to 60 percent are undamaged, compared with about 65 to 75 percent elsewhere.

Regional variations in deck condition are useful reference points for estimating the effect of continued salting on future deck repair costs. For example, in salt-using states of the Northeast, Midwest, and Mountain regions, approximately 60,000 new decks (built during the past 20 years) are undamaged and vulnerable to chloride contamination from continued salting (Table 3-5). On the basis of historical rates of deck deterioration in these regions, one would expect approximately 15 percent, or 10,000, to become damaged during the next 10 years because of continued salting. If the lower rates of deck

TABLE 3-4 DETERIORATION RATES OF DECKS BY REGION

	Percentage of Bridge Decks in Sound Condition After		
Region	1–10 years	11–20 years	21–30 years
New England	93	77	47
Upper Middle Atlantic	94	74	47
Lower Middle Atlantic	91	72	58
Great Lakes	92	80	58
Upper Plains	90	70	64
Lower Plains	95	88	74
Mountain	91	83	64
South, Pacific, and West[a]	92	85	74

[a]Excluding Florida, Alaska, and Hawaii, which have exceptional environments.
SOURCE: Computer analysis of National Bridge Inventory file.

TABLE 3-5 ESTIMATED NUMBER OF DECKS THAT WILL BE DAMAGED BY CONTINUED SALTING DURING NEXT 10 YEARS

Region	Current No. of Undamaged Decks[a] (1)	No. of Undamaged Decks Damaged During Next 10 Years: Continued Road Salting (2)	No. of Undamaged Decks Damaged During Next 10 Years: Absence of Road Salt[b] (3)	Difference (4) = (2) − (3)	Average Deck Surface Area (ft^2) (5)	Total Deck Surface Area (ft^2) (6) = (4) × (5)
New England	2,100	500	200	300	7,600	2.3 million
Middle Atlantic (Upper and Lower)	22,000	4,200	1,000	3,200	7,300	23.3 million
Great Lakes	20,400	4,000	1,700	2,300	7,100	16.3 million
Plains (Upper only[c])	11,900	1,000	200	800	6,800	5.4 million
Mountain	6,200	800	500	300	6,600	2.0 million
Total	62,600	10,500	3,600	6,900	7,100	49.3 million

[a]Includes only the population of bridges that are less than 20 years old, because these bridges may not already be contaminated with chlorides.
[b]Calculated by applying historical deck deterioration rates in the South and West to the existing population of undamaged decks in salt-using regions.
[c]Lower Plains states have deterioration rates similar to those of the South and West and therefore were excluded from the analysis.
SOURCE: Computer analysis of National Bridge Inventory file.