NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
SYNTHESIS OF HIGHWAY PRACTICE **67**

BRIDGE DRAINAGE SYSTEMS

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

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BRIDGE DRAINAGE SYSTEMS

RESEARCH SPONSORED BY THE AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS IN COOPERATION WITH THE FEDERAL HIGHWAY ADMINISTRATION

AREAS OF INTEREST:

STRUCTURES DESIGN AND PERFORMANCE
MAINTENANCE
(HIGHWAY TRANSPORTATION)

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
WASHINGTON, D.C. DECEMBER 1979

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as: it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to its parent organization, the National Academy of Sciences, a private, nonprofit institution, is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the Academy and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are responsibilities of the Academy and its Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

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PREFACE

There exists a vast storehouse of information relating to nearly every subject of concern to highway administrators and engineers. Much of it resulted from research and much from successful application of the engineering ideas of men faced with problems in their day-to-day work. Because there has been a lack of systematic means for bringing such useful information together and making it available to the entire highway fraternity, the American Association of State Highway and Transportation Officials has, through the mechanism of the National Cooperative Highway Research Program, authorized the Transportation Research Board to undertake a continuing project to search out and synthesize the useful knowledge from all possible sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series attempts to report on the various practices, making specific recommendations where appropriate but without the detailed directions usually found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems. The extent to which they are utilized in this fashion will quite logically be tempered by the breadth of the user's knowledge in the particular problem area.

FOREWORD

By Staff
Transportation
Research Board

This synthesis will be of special interest and usefulness to bridge engineers and others seeking information on design procedures and maintenance practices for bridge drainage systems.

Administrators, engineers, and researchers are faced continually with many highway problems on which much information already exists either in documented form or in terms of undocumented experience and practice. Unfortunately, this information often is fragmented, scattered, and unevaluated. As a consequence, full information on what has been learned about a problem frequently is not assembled in seeking a solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem. In an effort to correct this situation, a continuing NCHRP project, carried out by the Transportation Research Board as the research agency, has the objective of synthesizing and reporting on common highway problems. Syntheses from this endeavor constitute an NCHRP report series that collects and assembles the various forms of information into single concise documents pertaining to specific highway problems or sets of closely related problems.

For a variety of reasons, bridge drainage systems frequently do not function properly. This report of the Transportation Research Board includes an evaluation of design principles and procedures and maintenance practices for bridge drainage systems. Recommendations are included for improvements on current practice.

To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, the Board analyzed available information assembled from numerous sources, including a large number of state highway and transportation departments. A topic panel of experts in the subject area was established to guide the researchers in organizing and evaluating the collected data, and to review the final synthesis report.

This synthesis is an immediately useful document that records practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As the processes of advancement continue, new knowledge can be expected to be added to that now at hand.

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Special appreciation is expressed to Arthur L. Elliott, Sacramento, California, who was responsible for the collection of data and the preparation of the report.

Valuable assistance in the preparation of this synthesis was provided by the Topic Panel, consisting of David V. Halvorson, Hydraulic Engineer, Minnesota Department of Transportation; Frank Johnson, Chief, Hydraulics Branch, Office of Engineering, Federal Highway Administration; Jimmy D. Lee, Head of Bridge Maintenance, North Carolina Department of Transportation; John B. Poppe, Applied Research Engineer (Bridges), California Department of Transportation; Dah Cheng Woo, Hydraulic Research Engineer, Office of Research, Federal Highway Administration.

Adrian G. Clary, Engineer of Maintenance, Transportation Research Board, and Lawrence F. Spaine, Engineer of Design, Transportation Research Board, assisted the Special Projects Staff and the Topic Panel.

Information on current practice was provided by many highway and transportation agencies. Their cooperation and assistance were most helpful.

BRIDGE DRAINAGE SYSTEMS

SUMMARY

Many bridge engineers regard bridge drainage as an inescapable nuisance rather than as a primary problem because only rarely is bad drainage directly responsible for a structural failure. But poor drainage can cause such problems as ponding on the roadway, erosion of abutments or paving, and deterioration of structural members. Most of the problems can be prevented through good design provisions for collecting the runoff, getting it into the drains, and transporting it away from the bridge.

Bridges should have adequate cross-slope and grade to allow the water to run quickly to the drains. Where grades permit, some states do not use drains on short bridges but carry all the water to catch basins at the ends. Bridge drains are sometimes open holes through the deck that can have short pipes to carry the water clear of the beams. More often, however, an inlet box is used to collect the runoff. The spacing and location of drains depend on the amount of rainfall expected, the design of the bridge, the grades, and what is beneath the bridge. Some states have detailed procedures for determining drain spacing.

Debris can be controlled by keeping it out of the inlet boxes, accepting and storing it so it cannot go through the system, or transporting it through. Because all debris cannot be kept out, many drainage systems are designed to trap larger debris and to let the smaller debris pass. The grates used to screen out larger debris should be hydraulically efficient, strong enough to support traffic, and bicycle safe. If pipes have adequate size, slope, and curvature for debris control, hydraulic considerations seldom limit the flow.

Maintenance at regular intervals is the key to success of a drainage system. Because this periodic attention is necessary, the design should make it as easy as possible. Numerous cleanouts should be provided in locations where they are easily and safely accessible. Cleaning equipment ranges from shovels to high-pressure water. Recent innovations include a system for backflushing with high-pressure air and a truck-mounted high-pressure water system.

Disposal of runoff water can be a simple straight drop onto the land or water beneath the bridge or a pipe system to carry the water to a local sewer system. Provisions for controlling or containing spills of hazardous materials are costly and warranted only where the risks are high.

The consensus of current practices indicates that deck cross-slope and grade should be no less than 2 percent and 0.5 percent, respectively; that bridge drains may be holes through the deck, fabricated inlet boxes, or catch basins at the ends of the bridge; that inlet areas should be as large as possible; that pipes should have a minimum diameter of 6 in. (150 mm), a minimum radius of 18 in. (450 mm), and a minimum slope of 2 percent (preferably 8 percent); that cleanout plugs and elbows should be easily accessible; that there should be improved communication between designers and maintenance personnel; and, most importantly, that bridge drainage systems should be regularly and carefully inspected and serviced.

CHAPTER ONE

INTRODUCTION

Tennyson has written of "the useful trouble of the rain" which, although a life-giving bounty, can be very troublesome.

For the bridge engineer, precipitation is a many-faceted problem. It may collect in ponds or run in sheets. It may freeze or fall as ice or snow, making roadways slick and plugging drains. Rain is not the only drainage problem. Corrosive, flammable, and sticky liquids spilled on highways must eventually be carried away by drainage systems.

Drainage is regarded by many as an inescapable nuisance, not a problem. Only rarely does bad drainage lead directly to a structural failure. Therefore, engineers seem to view drainage difficulties as something to be prevented if possible but nothing to get very excited about. Every state surveyed, however, admitted bridge drainage to be a continuing concern.

The drainage problem cannot be solved and forgotten, but it is controllable. Proper designs and procedures can ensure that drains are working and bridge decks are free of standing water. It is the purpose of this synthesis to pinpoint the many areas of difficulty and then present solutions that various states are using to control bridge drainage.

TERMINOLOGY

There is often misunderstanding in discussions of things for which people have different names. To be consistent and to make sure the reader grasps what the writer had in mind, a list of terms is given below.

Catch basin (drop inlet): A drain that is used away from a bridge and is usually of a larger size than an inlet box and is set in earth in the subgrade or shoulder of a highway.

Cleanout plug: A removable plug in the piping system that gives access to a run of piping for cleaning.

Drain: A receptacle that receives water.

Drainage system: The entire arrangement of grates, drains, inlet boxes, pipes, gutters, ditches, and outfalls necessary to collect water and get it to a disposal point.

Grate: The ribbed or perforated cover of an inlet box or catch basin that supports traffic and live loads.

Inlet box: A drain that is used on a bridge and is usually inset into the bridge deck but that is sometimes only an open hole through the deck.

Outlet pipe: The pipe that leads the water away from an inlet box, catch basin, or drop inlet.

Runoff, drainage, water: Any liquid that may run off the roadway surface and that is usually water but is sometimes another liquid. Although the term "water" is often used for runoff, it always includes any other liquids that may make their way into the drainage system.

Scupper: A horizontal opening in the curb or barrier through which water can flow.

Sewer: An underground piping system that may connect to a municipal sanitary sewer or storm drain system or may be a separate disposal system for highway and bridge drainage.

RESULTS OF POOR DRAINAGE

The first evidence of a poor drainage system usually is ponding on the roadway. Ponds have a variety of causes and can have many detrimental effects, both on traffic and on the structure itself.

Uncontrolled water can cause serious erosion, settlement of pavement slabs, and sometimes structural failure. The rain that falls on a structure may cause stains and discoloration on exposed faces if it is not collected and disposed of properly. Rain may also pick up corrosive contaminants, which, if allowed to come into contact with structural members, may cause deterioration.

Cold weather brings its own problems. The damage caused by the freezing of infiltrated water can be considerable. Much of this trouble will be avoided if the water is carried away from the structure as soon as possible.

These detrimental effects of runoff emphasize the importance of getting all liquids off the bridge deck as soon as possible. This in turn points up the need for an efficient drainage system in good working order at all times.

REQUIREMENTS OF AN ADEQUATE DRAINAGE SYSTEM

Number of Drains

From the standpoint of draining the deck adequately, there probably cannot be too many drains. Numerous drains ensure that water will be taken away without having to run too far. Should one drain become plugged, the next one can carry the load. Many drains reduce the water and debris per drain and diminish the probability of stoppage. The designer must strike a balance between the luxury of many drains and the cost of installing them. In open country, where a drain can be just an open hole through the deck, more drains can be used than in an urban situation, where each drain must be accompanied by piping. Most states arrive at the best spacing by anticipating the conditions they expect to encounter. Often all the runoff can be carried off the bridge to catch basins, thus eliminating the need for drains on the bridge.

Hydraulic Capacity

As a general rule, the hydraulic capacity of a system is not a problem after the water leaves the inlet box. Most pipes are designed large enough and with sufficient grade to prevent clogging and are thus much larger than purely hydraulic considerations would require. Moreover, the restriction of the grates, the debris, and the quantity of water that can be collected at one point from a plane surface all work to limit the amount of water that gets into the outlet pipe.

Self-Flushing Drains

Most automatic or manual drain-flushing systems that have been tried merely spray water into inlet boxes but have no heavy jets to break up the debris. However, if too much debris has accumulated, water alone will not wash it away. The flushing systems are quite expensive because the feed pipes are as large as 3 in. (75 mm) and usually run a long way from the nearest water supply. Flushing must be done frequently before the debris is packed in too tightly. A maintenance person must inspect each drain to see that the water has washed it clean; if not, the cleaning must be done manually.

Traffic Safety

If possible, it is desirable *not* to have traffic run over grates and drop inlet boxes. There is always a greater concentration of water around the inlet boxes, so traffic running over them is bound to cause splashing. Also, unless the grates are securely fastened, traffic will whip them up and out of the box. Traffic running over a grate will break up the collected debris and jam it down through the grate openings. In addition, when traffic uses the outside lane, the maintenance crew has no place to work on the drain unless a lane is closed.

In recent years, bicycle traffic on highways has increased rapidly. Most modern bicycles have narrow tires that can drop into a slot only 1.5 in. (40 mm) wide, and many existing grates have slots wider than 1 in. (25 mm) parallel to traffic. Small transverse bars welded across the tops of the grates will prevent bicycle tires from dropping in and being caught. Care must be taken to see that new designs are bicycle safe yet hydraulically efficient (Fig. 1). An FHWA study of this subject may be of help (*1, 2, 3*).

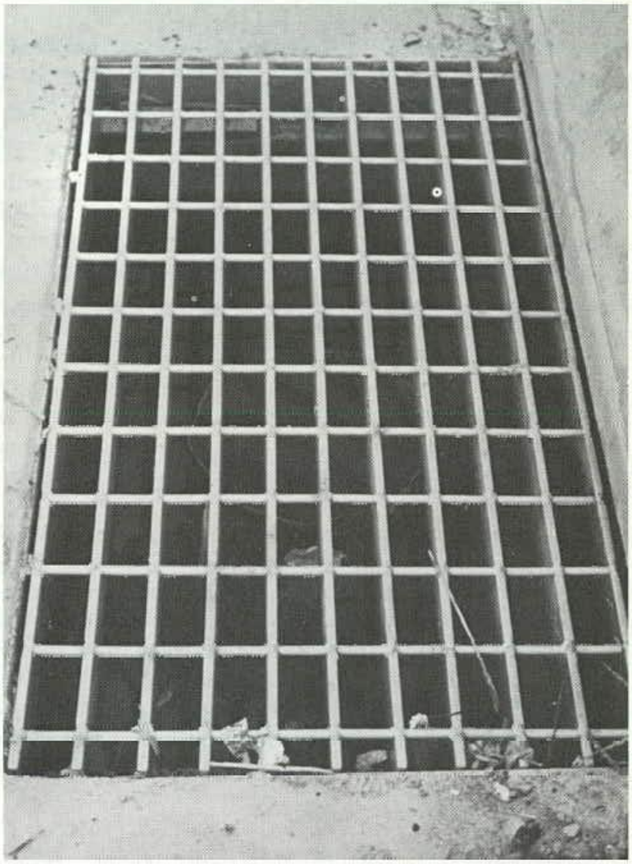


Figure 1. A lightweight, bicycle-safe, welded-bar grate.

CHAPTER TWO

COLLECTING THE RUNOFF

DECK SLOPE

Adequate slope and grade must be provided so that the water will run quickly toward the drain. Because the ultimate object is to remove the water as soon as possible, the steeper the slope the better. However, there are limits to the grade and slope desirable in a deck. Most states use from 1 to 2 percent cross-slope as a minimum (also noted as ⅛ in. per ft to ¼ in. per ft). Some advocate that the shoulders be given a steeper slope (4 percent minimum). This gives the bridge cross-section a broken-back profile and makes finishing the bridge deck difficult. Too much cross-slope may trouble slow-moving vehicles when the deck becomes icy.

The cross-slope guides the water to the gutter in which it must then run to the nearest drain. Although some states specify no minimum grade for the bridge itself, most states do specify a grade of at least 0.5 or 1 percent. Should the grade be less than 0.5 percent, the designer must specify a gutter grade that will run the water to the inlet boxes from high points midway between the boxes. Failure to provide adequate gutter grade will result in ponding in the gutters.

PONDING

Ponds on a bridge deck have a dangerous effect on traffic because of sudden slowing or blinding. Ponding is the most common result of a poorly maintained drainage system but can be caused by improper design or construction. The camber may not have been computed or provided for properly, or the deck finishing may have been faulty. Prestressing complicates the camber prediction process. Rather than sag because of plastic flow, the prestressed girder, which is under compression, will rise. In some cases, it may be necessary to provide extra drains in areas of the deck that will be temporarily low until the plastic movement takes place.

BERMS AND CHANNELS ON FILLS

Some states do not provide drains on short bridges but allow the water to be carried across the bridge and disposed of on the approaches. In this case, a channel is needed to carry the runoff to its ultimate disposal point. The water must be transported across the paving notch (the joint between pavement and bridge), and the abutment or wingwalls must be minimized. A paved channel should carry the water along the approach gutter to a catch basin. From the catch basin there must be either a pipe or a paved channel or trough to carry the water down the face of the embankment. Figure 2 shows the arrangement used by one state.

WATER RUNNING ONTO THE BRIDGE

If a bridge is on a grade or in a sag where it may collect highway drainage, a catch basin should be provided just off the upstream end of the bridge in each gutter to intercept the drainage before it gets to the structure. Most bridge drainage systems are marginal, and additional water from the approach roadways should not be imposed on them. Water should be prevented from running down a crack at the paving notch and undermining an abutment or wingwall. A similar nuisance is created when water runs down a median strip between parallel roadways and between parallel bridges and washes out the slope paving underneath.

EXPANSION JOINTS

By carefully applying the newer materials and the new compression seal designs, one can successfully exclude water from expansion joints. When the joint cannot be sealed, provision should be made to collect the water that runs down through the joint and to conduct it away.

A variety of arrangements have been tried to catch water passing through expansion joints. These range from neoprene sheets to sheet metal gutters installed under joints to catch what comes through them and carry it to the side of the bridge (Fig. 3). Adequate cross-slope for these gutters is essential—preferably not less than 8 percent or 1 in./ft. These collection arrangements are necessary to prevent leakage, unsightly stains made by water running over exposed faces, corrosion of joint parts and structural elements, and the nuisance of having water drip on pedestrians or traffic below.

PAVING NOTCHES

Although a bridge is comparatively stationary, roadway paving is subject to much temperature movement. This makes the joint between the two very difficult, if not impossible, to seal. One solution is to make the joint as tight as possible so that most of the water will cross it and then to use underdrains in the fill below the joint to carry the leakage away.

WEEPHOLES

Water collecting behind walls can undermine the supporting soil and develop hydraulic pressure that may topple the wall. Weepholes and carefully laid pervious layers and/or perforated pipes should be provided to prevent this pressure buildup. Often specifications will require that the first 2 ft (0.6 m) of fill behind an abutment be a pervious material so water can percolate through to the weepholes

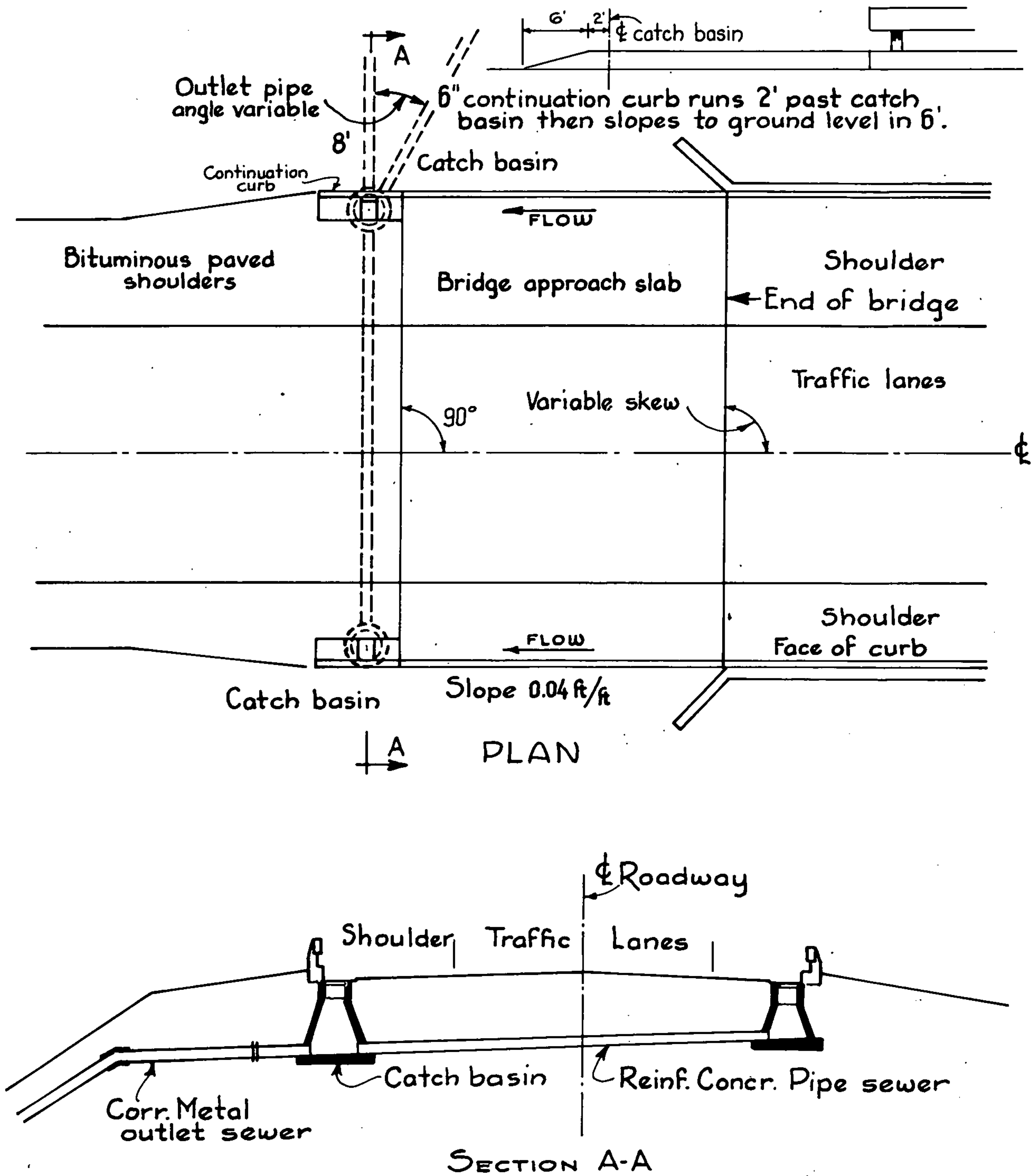


Figure 2. Bridge-end catch basin system (Minnesota).

(Fig. 4). It is common practice to place 2 ft³ (0.06 m³) of coarse gravel behind every weephole.

As a minimum, at the bottom behind every wall there should be a pervious layer of gravel 1 ft (0.3 m) thick to collect the seeping water. This layer of coarse gravel must be placed with care so that no dirt or fines become mixed with it while it is actually being placed.

It is inevitable that water running to the gravel channel will carry some silt with it, which may in time partially clog the drain. However, if the pervious layer has been made thick enough, there will be room for considerable accumulation before it plugs up.

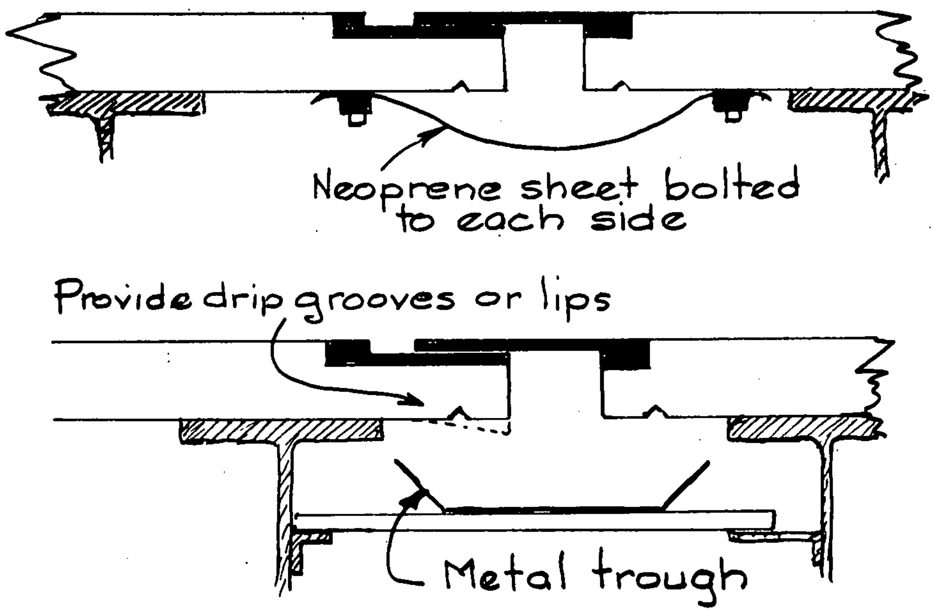


Figure 3. Methods of catching leakage under expansion joints. Slope so that water runs to one side of the bridge and either runs into a drain or falls free.

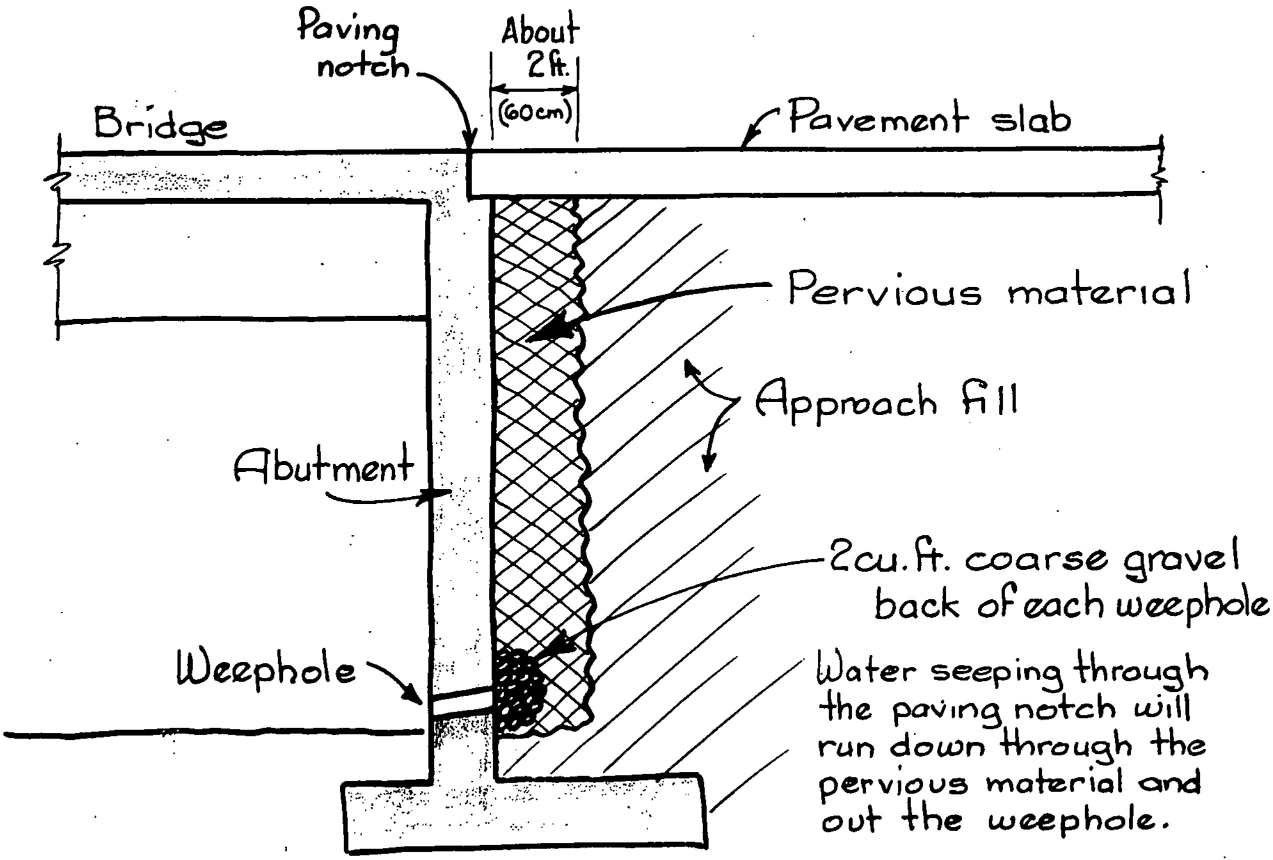


Figure 4. Pervious material placed behind an abutment or wingwall.

FREEZING

When the temperature falls below freezing, draining a bridge deck becomes very difficult. For perhaps between 5 and 10 degrees below freezing in light snow storms, salt can be used to melt the snow and ice and the drainage system can carry the water away. As the storm worsens or the temperature drops or both, salt is required in too great amounts and ceases to be effective, and the whole system freezes. Traction is usually maintained by sanding the roadway. When the thaw comes, the sand usually goes into the drainage system and clogs the drains (Fig. 5). Some maintenance crews have steam outfits to hasten the thawing of drain pipes. Some states do not permit their maintenance crews to use sand near bridges.

After the deck becomes covered with ice and snow, finding the drains is a problem, should one want to service them. Painting a white stripe vertically up the curb and rail behind a drain makes it a lot easier to locate (Fig. 6).

In winter, traffic action and sunshine melt the snow in the traffic lanes. However, as it goes through an inlet, the water may refreeze into huge icicles (Fig. 7). Therefore, in regions that experience freezing temperatures, inlet boxes without pipes should not be used over or near pedestrian walks or roadways.

Special care should be taken to see that drainage systems are open and working before they freeze. If they are both plugged and full of water when they freeze, the pipes may burst. In some cases, water freezing in pipes has blown out the cleanout plugs.

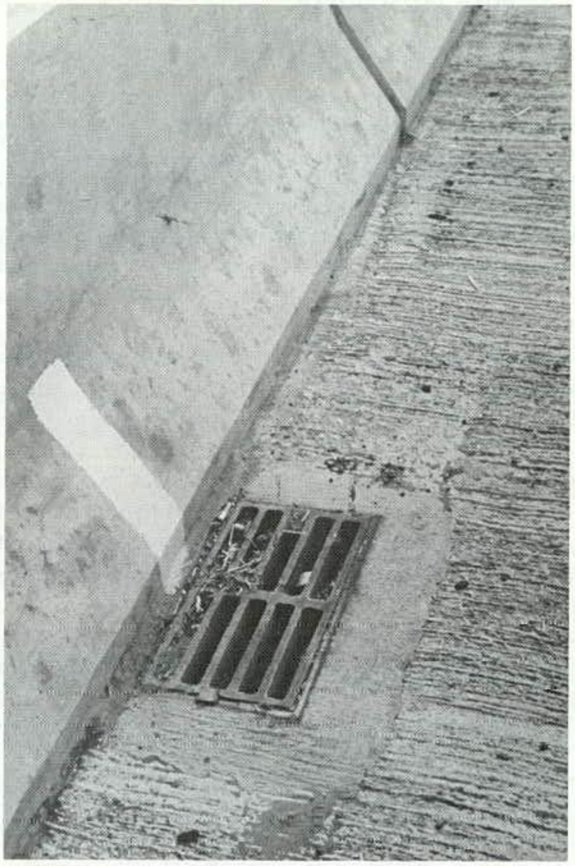


Figure 6. White stripe painted on the barrier to locate the drain when the roadway is covered with ice and snow.

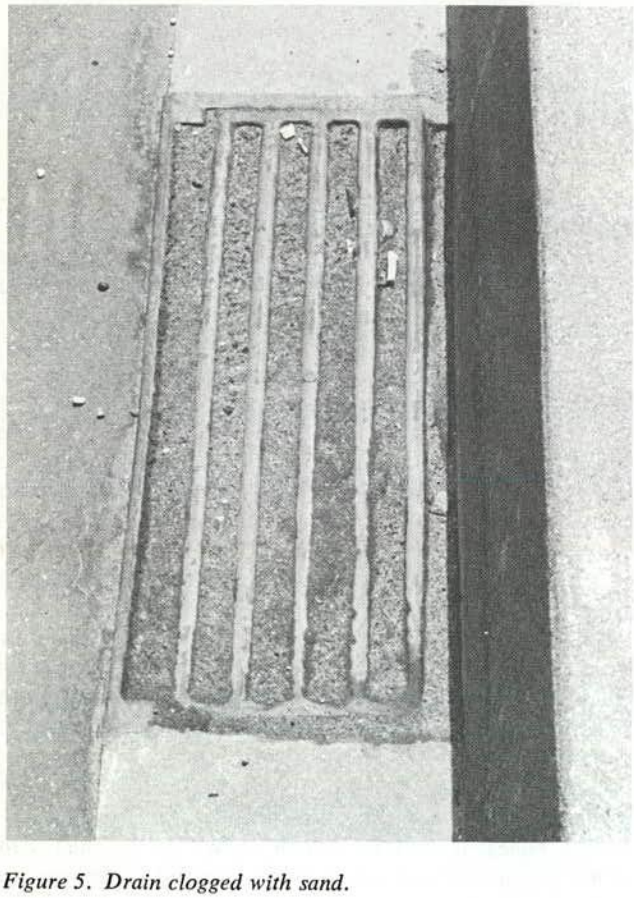


Figure 5. Drain clogged with sand.

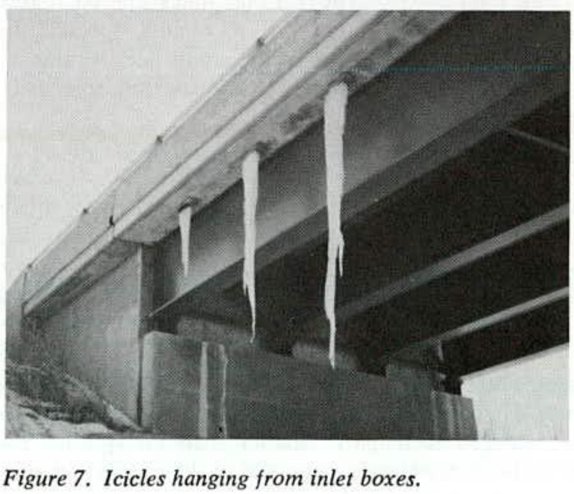


Figure 7. Icicles hanging from inlet boxes.

LIQUIDS OTHER THAN WATER

The variety of liquids transported over the highways runs from milk to gasoline, from honey to liquid fertilizer. Any accident involving a tank truck may entail a spill. All spills are hazardous, some more than others. A heavy layer of syrup or honey, although slick and a nuisance to clean up, is not lethal. A spilled load of volatile fluid can catch fire and send rivers of flame into gutters and storm sewers, endangering the area within blocks or even miles. The situation is not much better when the outfall is into a natural drainage channel.

The hazard can sometimes be reduced by having the bridge drainage system empty into a ponding area whose outlet structure is designed to trap floating objects. This area may in turn empty into a sewer or a natural channel, but in an emergency one can block its outlet and confine the noxious fluids to the holding area until they have been neutralized. In theory this provides a good safeguard, but in practice it may prove infeasible. A further question is whether any great expenditure is warranted for such a costly standby system when the probability of such a disaster's actually occurring at any given bridge is usually very small.

DRY-COUNTRY PROBLEMS

Blowing sand is a perpetual hazard in many parts of the country, not just deserts. It drifts against curbs and fills drains. Bridges in the desert are often built with only scupper openings through the curbs, yet sand drifts still clog the scuppers. Some designers provide bridges with open rails without curbs or scuppers. The wind has a free sweep across the deck and usually carries the sand away. Drainage runs off the edge of the deck where drip grooves keep it from running back underneath.

On separation structures and bridges closer to inhabited areas, casual disposal of drainage usually is not possible. Although the quantity of blowing sand around these structures may be somewhat smaller, it is still a problem. Sand and dirt are always present, usually as more than 50 percent of the volume of debris that collects in a drainage system. Continual maintenance with backflushing arrangements to break up the plugs is the only answer.

At the other extreme are the desert regions with their frequent cloudbursts. There, after dry debris has clogged the drains, the drainage system must handle extraordinary amounts of water. Adequately providing for these extremes creates drainage details that may seem incongruous in dry weather.

CHAPTER THREE

GETTING THE RUNOFF INTO THE DRAIN

INLET BOXES

Location

Assuming that the deck is adequately sloped and that the rain falling on it quickly runs into a gutter, there must be a drain to collect the water and carry it into an outlet pipe. First to be considered, therefore, are the location and spacing of the inlet boxes. The various states approach this problem with solutions running from casual to specific. In Appendix A, the procedures for locating deck drains in Idaho and California are shown to reduce the problem to a rather precise computation.

Whether the designer goes through this much computation or not, the thinking must follow these lines. The designer must know the likely rainfall intensity and how much water it will generate. From this, the number and spacing of the drains can be determined. Some states choose rather arbitrary spacings based on experience. If small, open holes, e.g., 4 in. (100 mm) round, are used, the spacing is usually from 6 to 10 ft (1.8 to 3.0 m). If inlet boxes are used, some states set them at a maximum spacing of 20 ft (6.1 m), whereas those with less rainfall may space them several hundred feet apart. Rather than set specific distances, some states merely require that their designers provide a drainage system that will handle the maximum rainfall expected in a 10-year period.

The location and spacing of drains are dictated by the local rainfall conditions, the design of the bridge, the grade and position of the structure, and what is under it. A long, rural bridge over a river in California was built with 2.5-in. (64-mm) diameter holes through the deck at 6-ft (1.8-m) centers. The holes are without grates or inlet boxes and are located in the gutter line just in front of the curb. The bridge is high, and there is nothing underneath but river and pasture. Because the drainage is dispersed by the wind and scattered like rain on the ground below, there is no erosion. Another bridge in North Carolina, about 300 ft (90 m) long and over a river, was built with 4-in. (100-mm) round, open drain holes at 6-ft (1.8-m) centers in each gutter line. However, these open-country or over-water bridges are in the minority. Most bridges are over other roadways, installations, or embankments, where a free drop is not possible and the water must be conveyed for some distance.

To avoid the problems of bridge deck drains on short bridges, some states carry the runoff to the end of the bridge, collect it there in a catch basin (Fig. 8), and then either run it over the side in a steep, paved gutter or pipe drain or collect it in a pipe and carry it away. This solves many problems. However, when a bridge is more than a few hundred feet long or on a flat grade, water can pond on the deck during a downpour if no drains are provided. Where it is practical, however, taking all of the drainage to catch basins at the end of a bridge and then carrying the runoff away in a pipe (Fig. 2) will eliminate many of the problems associated with inlet boxes and outlet piping.

On a new concrete bridge, when the grade is relatively flat, ponding may occur in some spots because of the initial camber. Drains should be provided for this temporary condition even though it may be known that plastic flow eventually will alter the drainage pattern and will leave some drains unused at high spots. When these temporary drains are simply holes through the deck, they may be filled and smoothed over later if their presence is objectionable.

Drains also should be located where the deck superelevation rolls from one side to the other, to catch the water before it flows across the roadway. A drain is needed where a center curb separating two roadways terminates, if the water following along this curb would flow out across the deck from the curb end. Drains should also be provided to catch water before it crosses an expansion joint.

The location of the inlet box in the cross-section of the roadway can be important. Some bridges are provided with a broken cross-slope so that a gutter or channel can be put there to carry the water 4 or 5 ft (1.2 or 1.5 m) in front of the curb. The inlet box is placed in the trough of this channel. Other cross-sections may be arranged so that the water is collected in the middle of the deck, even in a traffic lane. There should be compelling reasons for such locations because they cause great difficulties in maintenance and sometimes in operation.

The inlet box should be placed where it can be serviced by the maintenance crew with ease and safety. If it cannot be reached, the drain will be neglected and inevitably will become plugged and useless. Inlet boxes placed where traffic can run over them are also more apt to plug, because debris is crushed down into the box. Whenever drains are placed in the traffic lanes or when the water is run across a traffic lane there is a great deal of hazardous splashing.

A bridge in the mountains of Washington is on a grade and a curve so it has 8 percent of superelevation. Because there will be piles of snow along the low side of the bridge for several months of the year, the drains are placed out about 4 ft (1.2 m) in front of the curb to avoid being covered by the snow. There are a few long thin inlet boxes carried out near the centerline of the bridge just to make sure any water running along the roadway between the berms of snow will be intercepted. The drains are open, galvanized steel boxes about 12 x 20 in. (300 x 500 mm) that drop the water onto the creek and forest below. The grate has five ⅜- x 2-in. (10- x 50-mm) bars running across the width of the box, with two ½-in. (13-mm) round bars notched in flush and welded in the longer direction.

Ideally, a bridge should have full shoulders and the inlet boxes should be placed at the outside edge of the shoulder. In this position, the maintenance crew can park on the shoulder and work on the side away from the traffic in reasonable safety. These drains have a good chance of being regularly maintained. When lanes must be blocked to service the drains or when the maintenance crew must work on the edge of the stream of traffic, accidents often happen. After a few bad experiences, the maintenance crew may decide that an inlet box in a difficult location does not need regular maintenance. (Note the case history of the Chicago Expressways, Appendix B.)

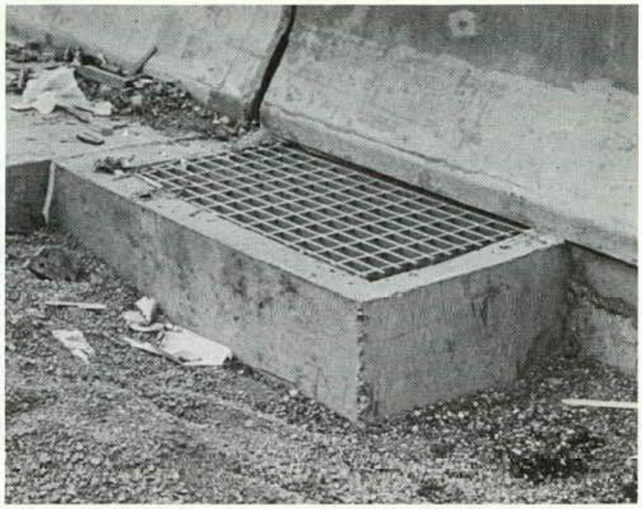


Figure 8. A catch basin at the end of a bridge under construction.

Drains should always be provided where there is a sag vertical curve. Unfortunately, debris of all sorts seems to collect in the sags and eventually gets into the inlet box to plug the drains. Drains cannot be avoided in these locations for obvious reasons. However, it should be realized that they are more likely to become plugged, and special precautions should be taken to provide adequate capacity, debris traps, and accessibility for easy maintenance. Even better, sliding the sag vertical curve ahead (or back) on line will get the sag completely off the bridge and save trouble.

Drain outlets should not be placed over roadway shoulders, sidewalks, or railroad tracks, nor should they be placed where they discharge onto unpaved bridge-end fill slopes (Fig. 9). If drains must discharge over riprap slopes, the riprap under the drains should be grouted to prevent erosion. An even better plan would be to provide a paved splash area and a paved flume section to take the runoff away from the fill.

Design of Inlet Boxes

The design of the inlet box is important because the box provides the first opportunity for collected debris to clog the drainage system. In general, the inlet box should be as deep as possible. Depth is not easy to come by in thin concrete bridge decks, and designers do not like to have boxes hanging down below the deck soffit.

The long dimension of the box should run parallel to the flow of the water to give it the greatest opportunity to enter. Long, narrow openings that water will normally flow into can be jumped by a heavy flow. The box should be large

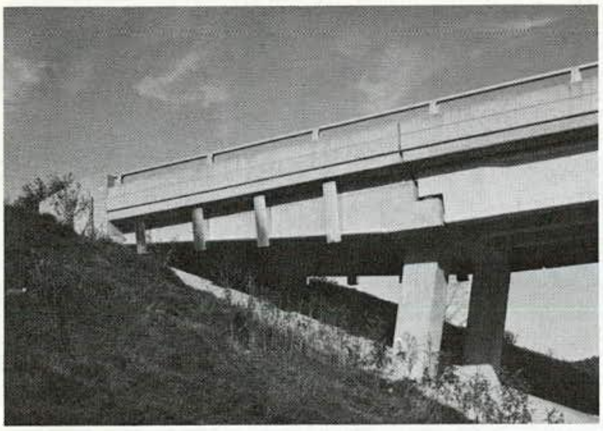


Figure 9. Extensions put on deck drains to direct the water back onto the slope paving. It had been falling outside the paving slab and eroding the embankment.

enough to be easily cleanable: i.e., a shovel can be used to scoop out the debris after the grate has been removed. If the outlet pipe is raised above the floor of the box, there should be shovel room between the pipe and the sidewalls of the box (the more room to work, the easier the job). The virtue of uniformly sized inlet boxes is that special equipment may be devised to make the cleaning job easier. There are also construction advantages when all the boxes are similar.

The simplest drain is a hole in the deck. If such a hole is used, it can be tapered larger at the bottom than at the top. This makes it difficult for debris to lodge in the tube. The rim of the hole on the under side should be ringed with a drip groove to force the water to fall rather than run along on the soffit faces of the bridge. Some states cast a short piece of polyvinylchloride (PVC) tubing in the deck and allow it to extend a few inches below the soffit. The smooth inside surface of the tube seldom snags debris, and the extended length below the soffit avoids the necessity for a drip groove. If a drain is close to a girder, a longer pipe should be used to carry the water at least 1 in. (25 mm) below the bottom of the adjacent beam. This is to make sure the water falls clear and does not get onto the nearby beams (Fig. 10).

Inlet boxes used by several states are shown in Figures 11 to 19.

Different states use different materials to make inlet boxes. Some specify all cast-iron boxes. Others specify the box size and shape and allow it to be either cast or made of fabricated steel. Many states require all their metal drainage hardware to be galvanized. Although galvanizing is the most popular finish, it is expensive. Not only is painting and asphalt dipping of boxes considerably cheaper than galvanizing them, experience has shown that boxes treated in either way will perform as well as galvanized boxes in most locations. Especially corrosive conditions may require special treatment, such as especially heavy galvanizing or an epoxy coating.

One subject that receives little attention is the draining of accumulated water inside box girder bridges. At least a 4-in. (100-mm) hole should be provided at the low point in the box to ensure drainage (Fig. 20). Smaller holes, such as 2 in. (50 mm), are not adequate; they are readily plugged up with small debris. Where nesting birds might create a problem, these drain holes should also be screened to prevent them from entering. The nests invariably plug the drain holes.

DEBRIS

Character of the Debris

Those studying debris control can be greatly helped by a tour given by a maintenance employee, just to see the volume and kind of debris with which the drainage system has to contend. In Chicago, because 12 drains located in the traffic lanes were dangerous to service, the outlet pipes were opened just below the deck and the water and debris allowed to fall directly onto the ground. In just two years, 140 tons (128 Mg) of debris from those 12 drains piled up on the ground.

The character of debris represents practically everything: wood, rags, cigarette butts and packages, beer and soft drink cans, leaves, cups, plates, soda straws, gum wrappers, tissues, newspapers, cardboard boxes, wire, nails, nuts and bolts, straw, seed and grain (which sprout in the inlet box), bottles, broken glass, broken parts of vehicles, dead animals (and some live ones that have taken up residence in the debris in the inlet box), and, of course, dirt and sand, which form the major part of the debris. In the fall, leaves

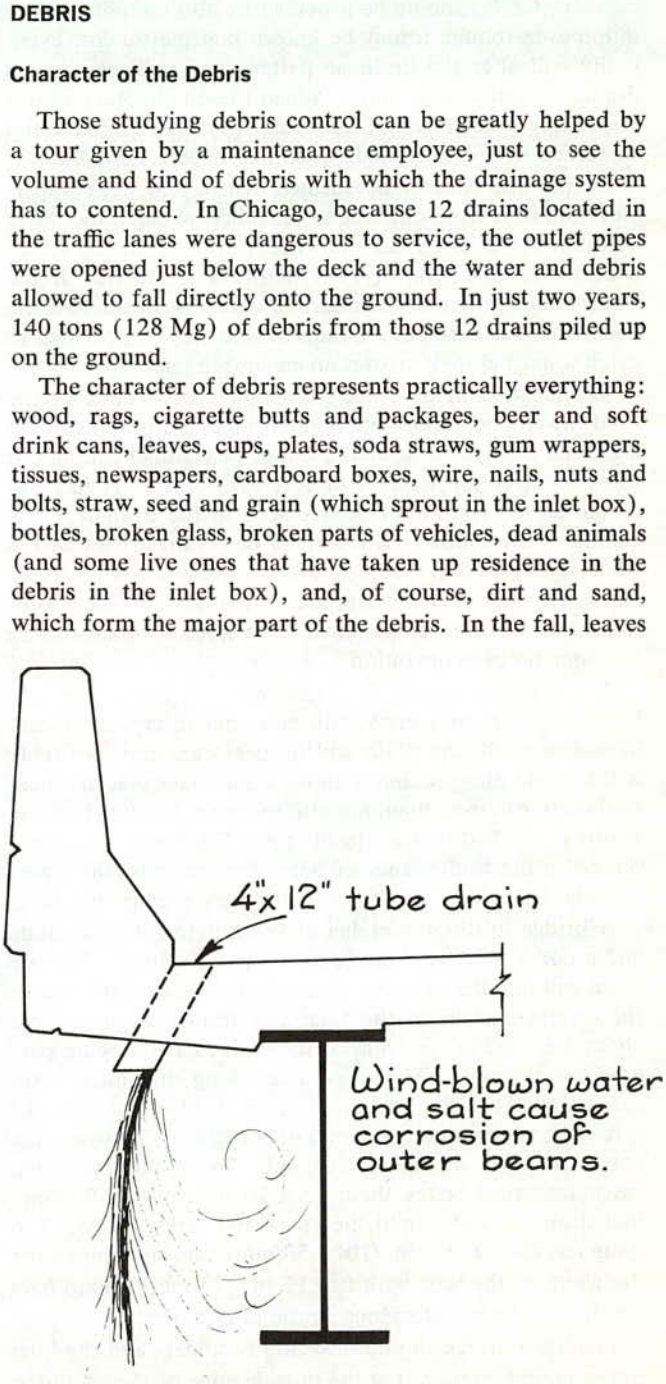


Figure 10. Short pipes next to a girder may allow salt-laden water to be blown onto beams and cause corrosion. The outlet should be carried below the bottom of the beam as shown in Figure 9.

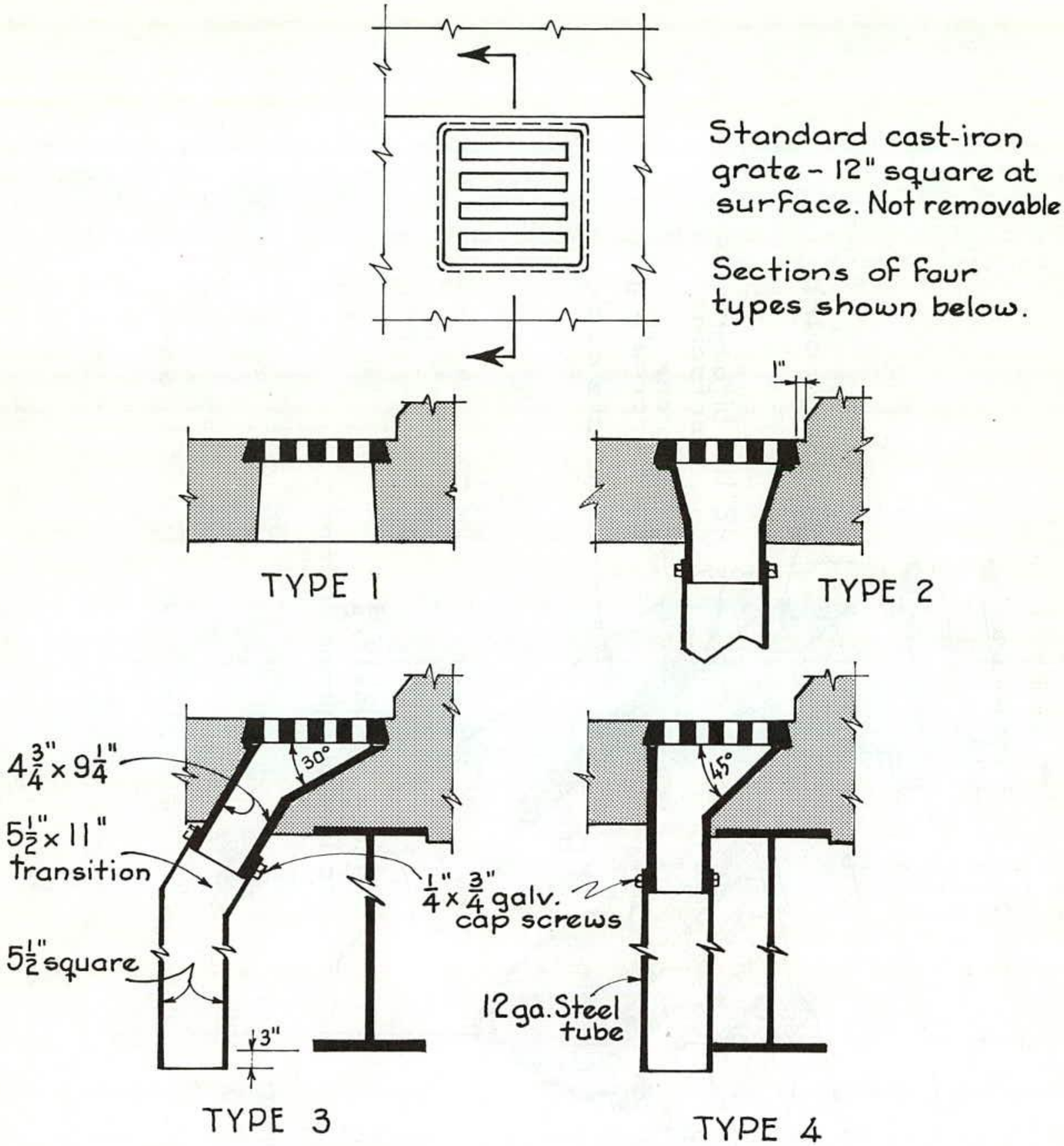


Figure 11. Cast-iron grates and drains (Michigan).

and dead branches are the main difficulty. They pile on top of the grate and prevent water from entering the box. Regular street cleaning becomes a necessity if the drainage system is to be kept in operation.

Debris Control

Controlling debris can take one of three possible forms: screening it out so it cannot reach the box, accepting and storing it so it cannot go through the system, or transporting it through the system.

Generally, it is not possible to screen all debris out of the system. The grate will screen out the larger debris that might clog the system but will let the smaller debris through.

Just how much of the debris is to be permitted to enter the system depends largely on the nature of the drainage and disposal system. A great deal more debris can be admitted when the inlet box opens through the deck and drops free than when water is to be conducted through an extensive piping system to a sewer or storm drain.

With a free-drop or easy-disposal system, an arrangement may be used where the exposed portion of the inlet box is covered with a grate but some of the box is recessed under the curb and the top left open to accept larger debris that would ordinarily be screened out by the grate (Fig. 21).

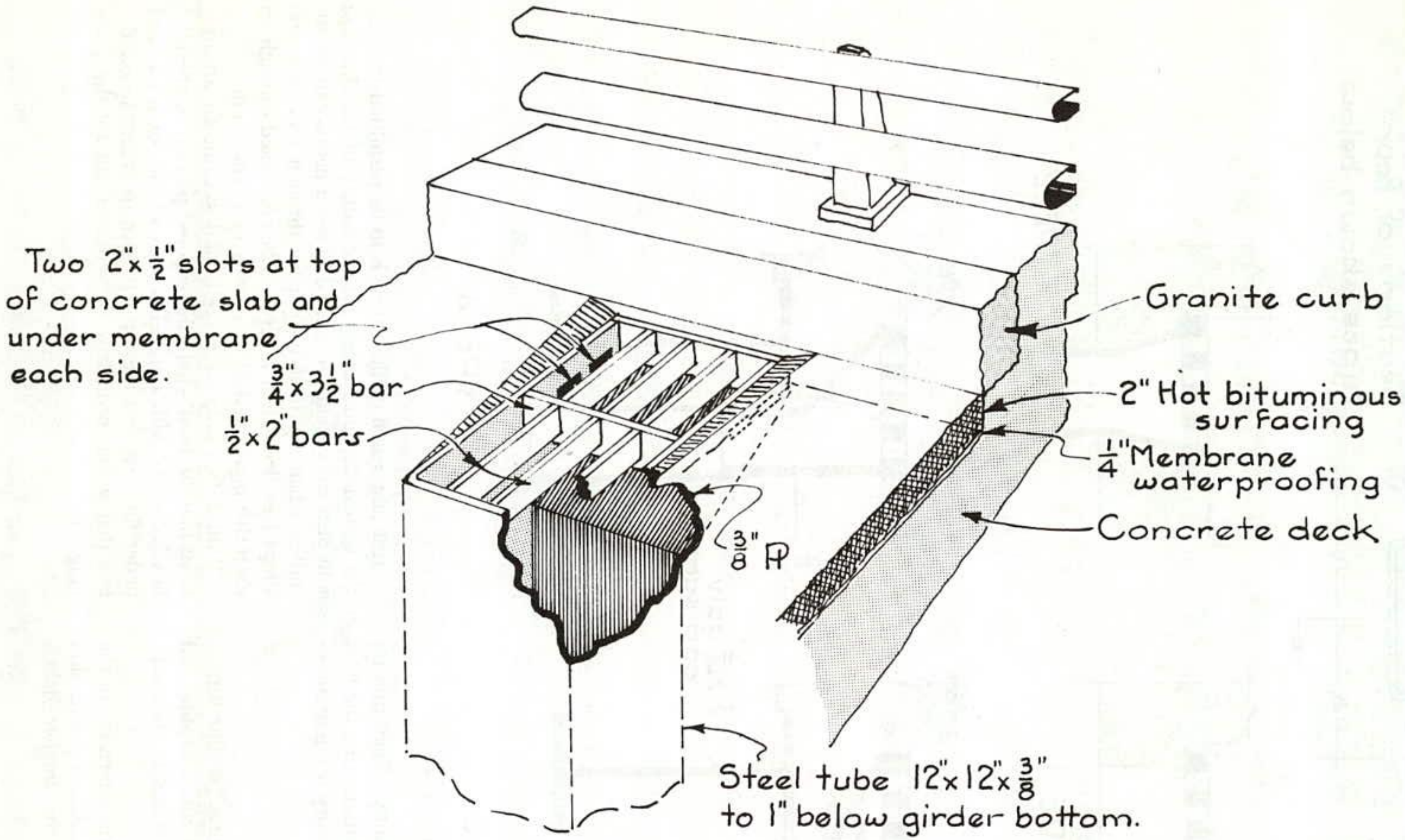


Figure 12. A snow-country inlet box (New Hampshire).

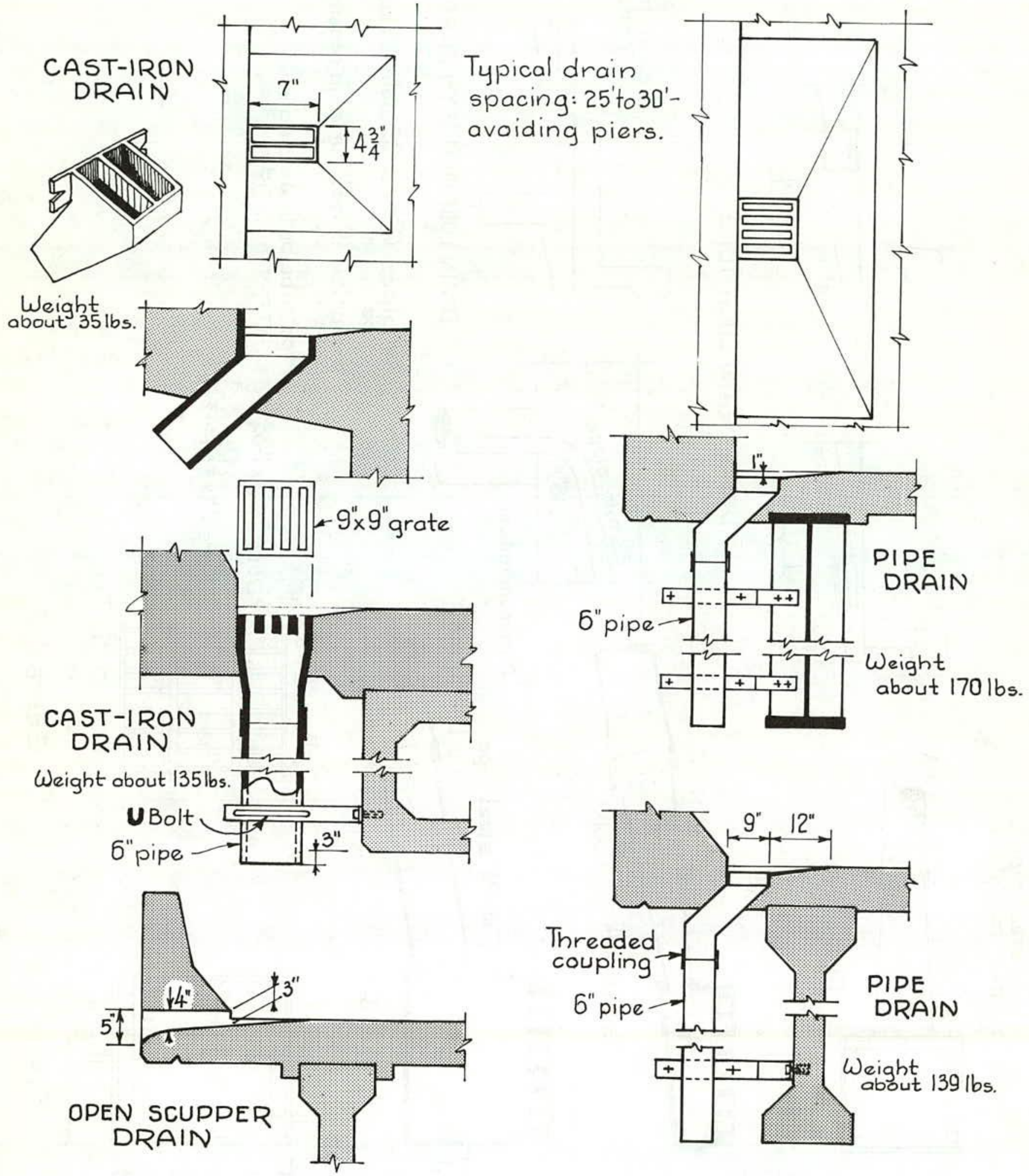


Figure 13. Bridge drains (Kentucky).

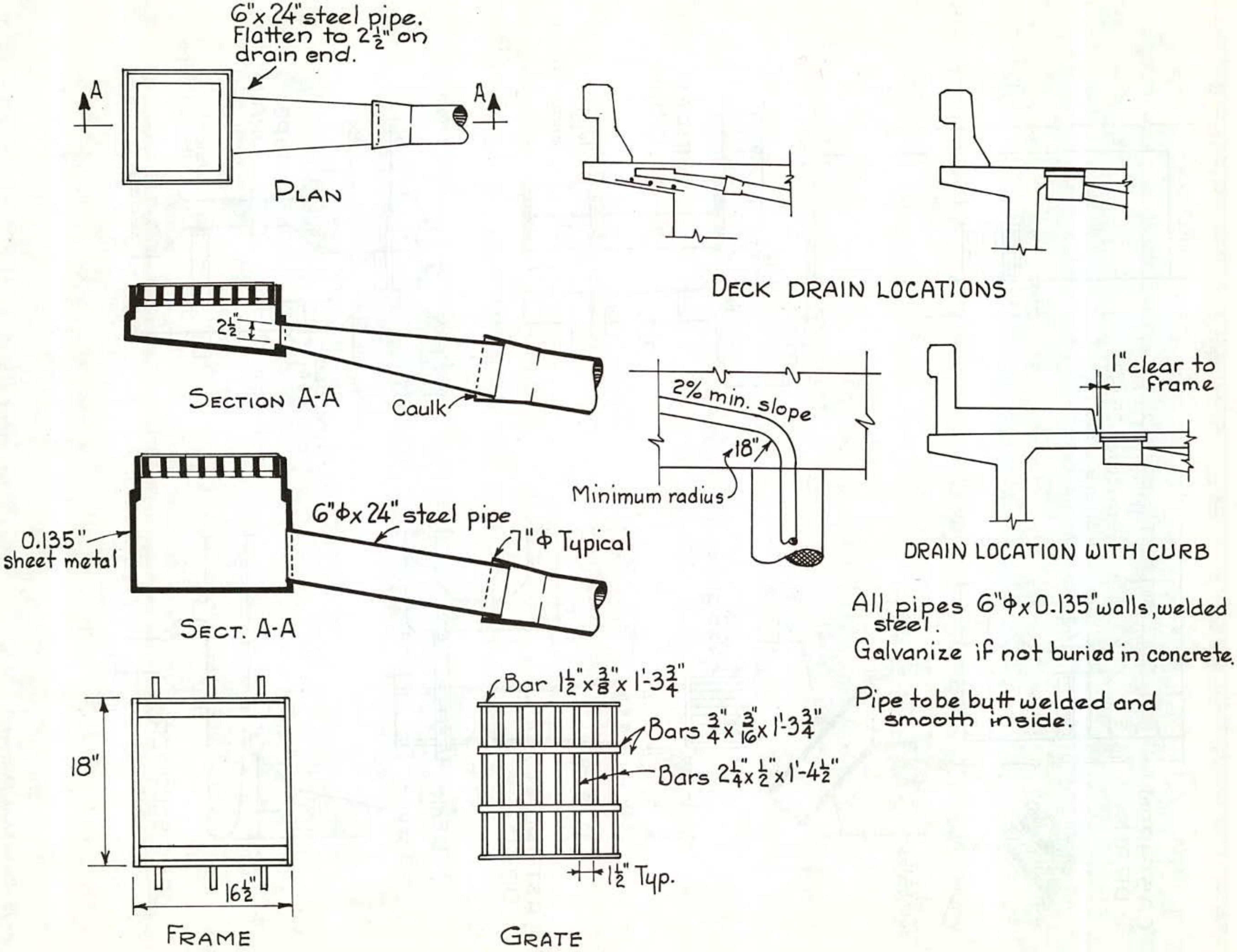


Figure 14. Welded-steel inlet boxes (California).

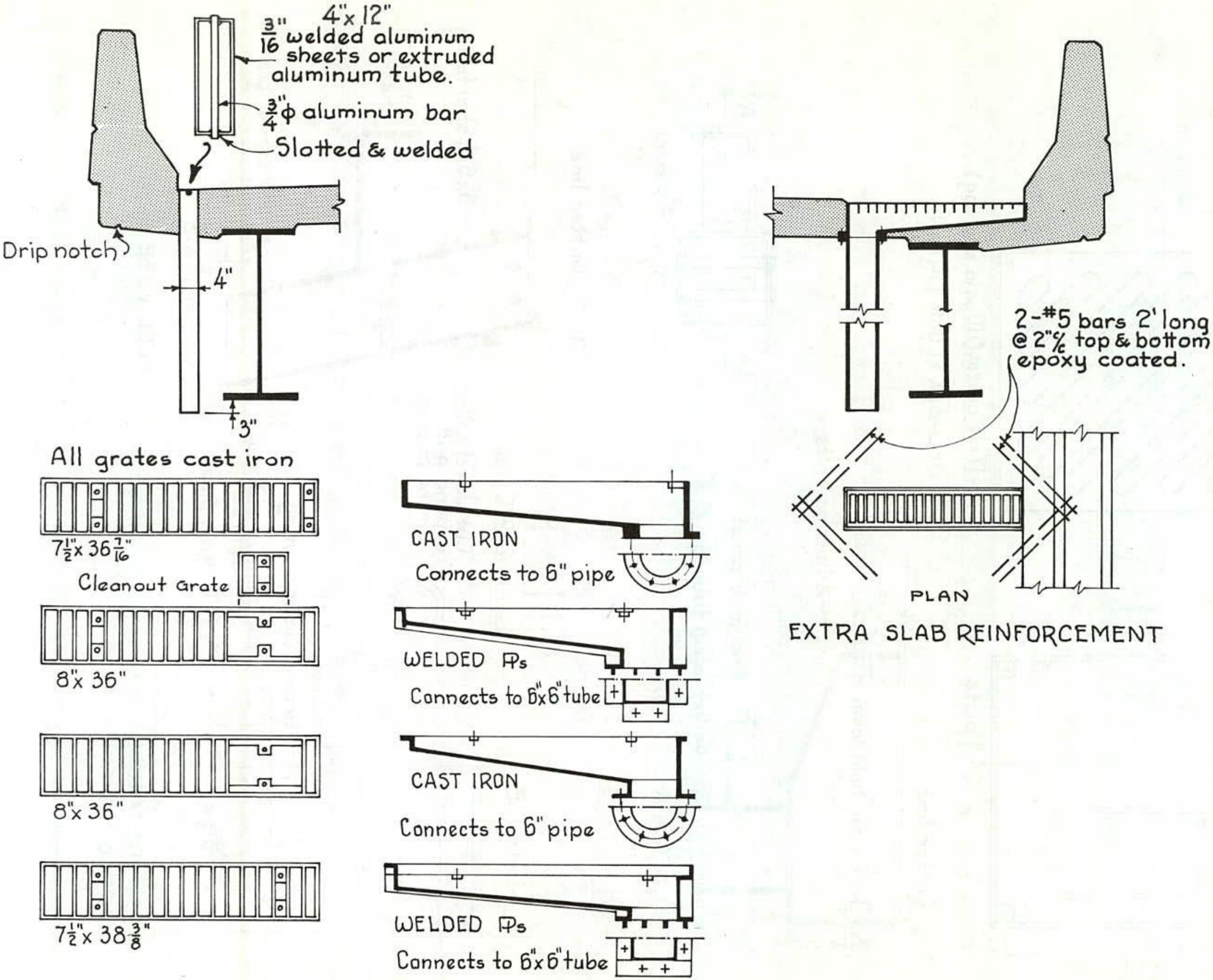


Figure 15. Drainage collection devices (Illinois).

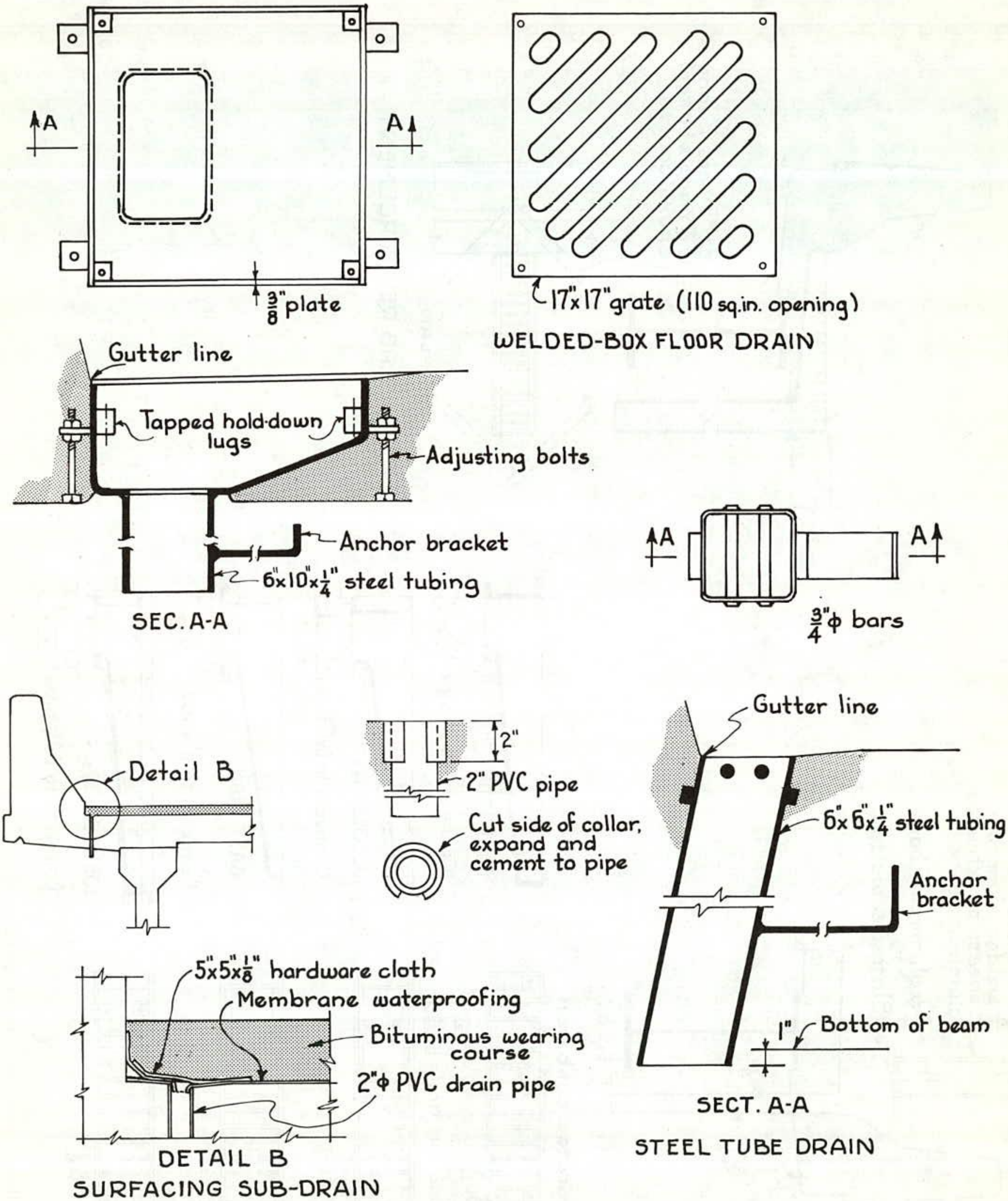


Figure 16. Drain details (Minnesota).

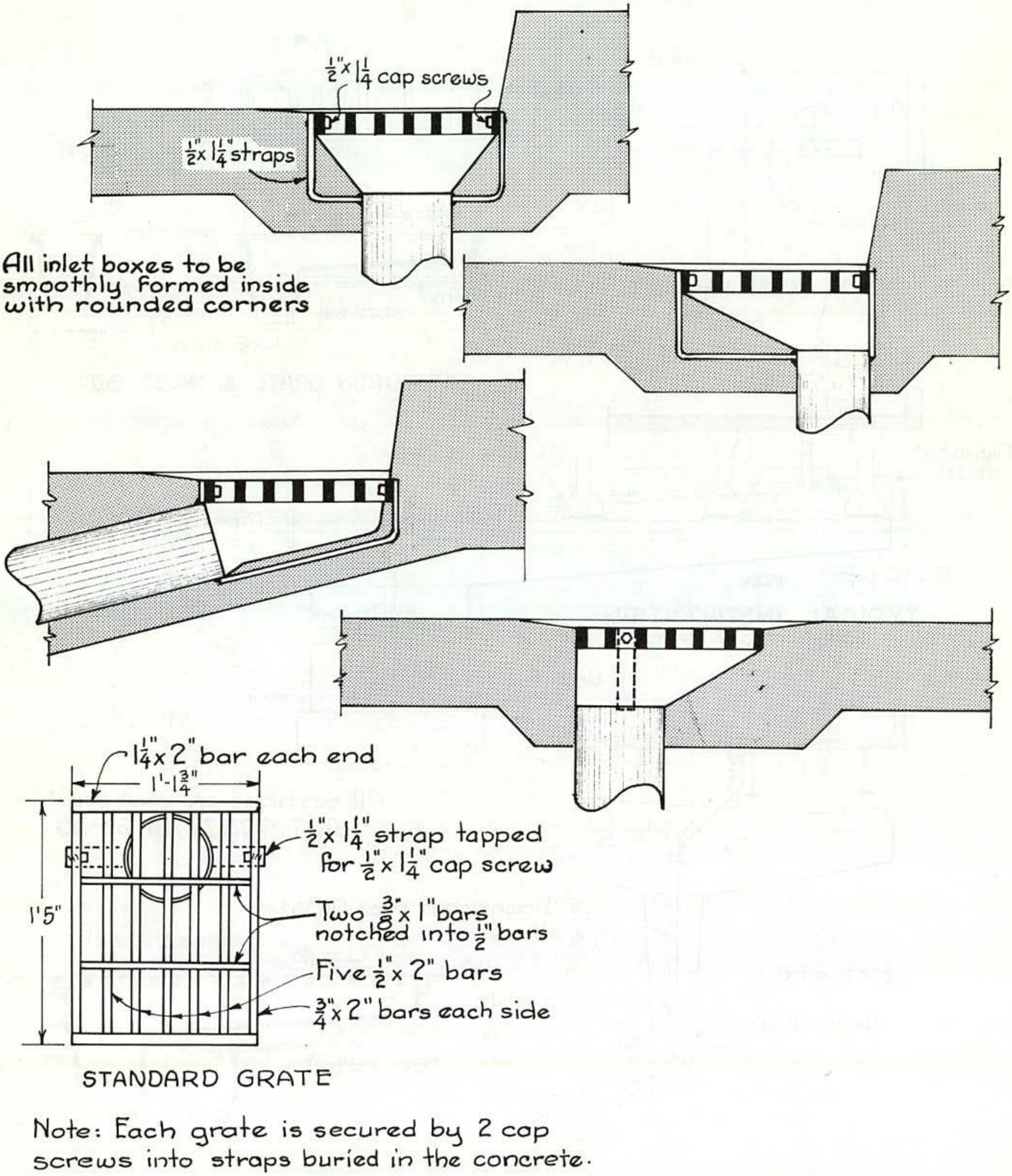


Figure 17. Standard drop inlets (Oregon).

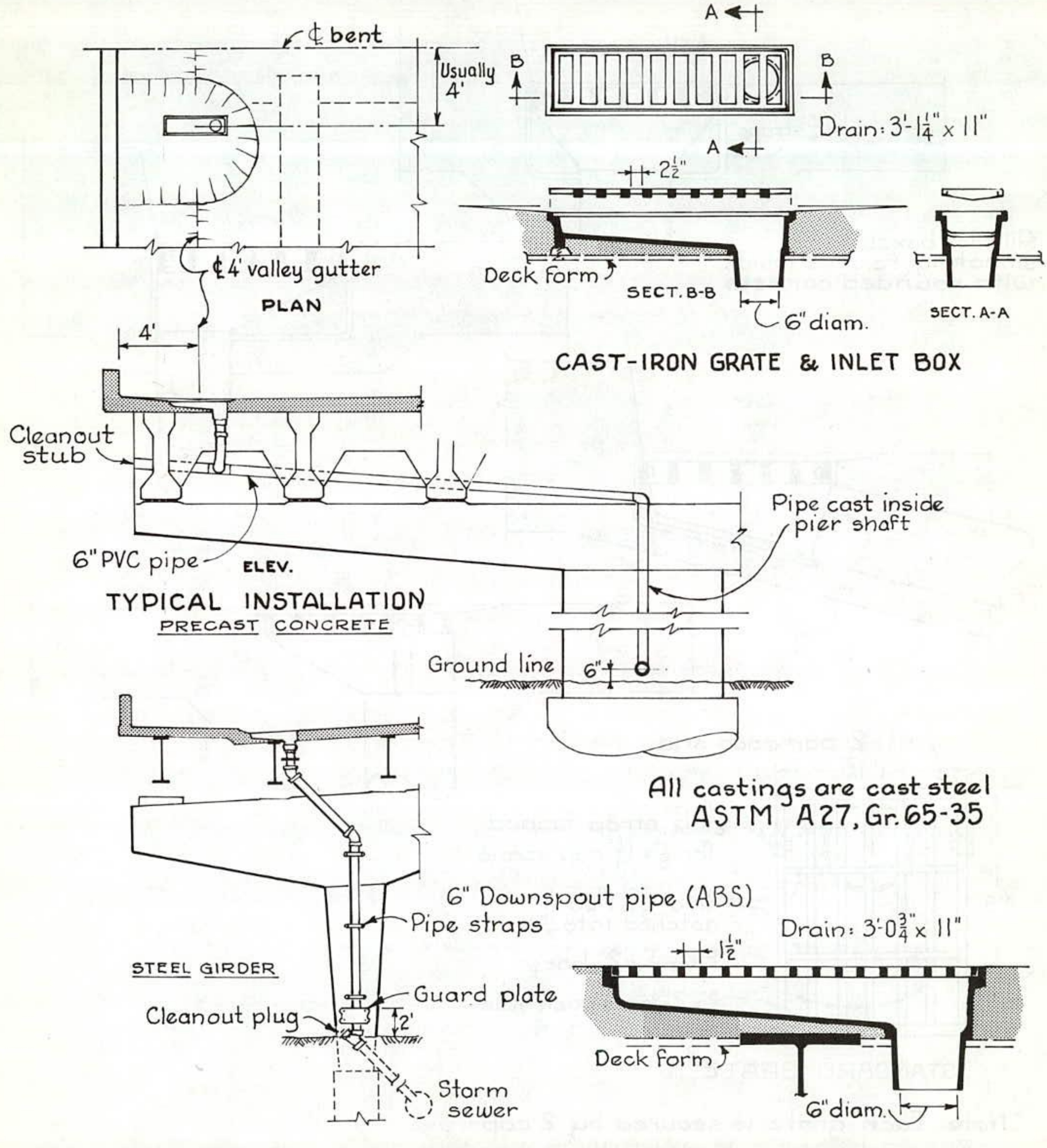


Figure 18. Cast-steel inlet box installations (Texas).

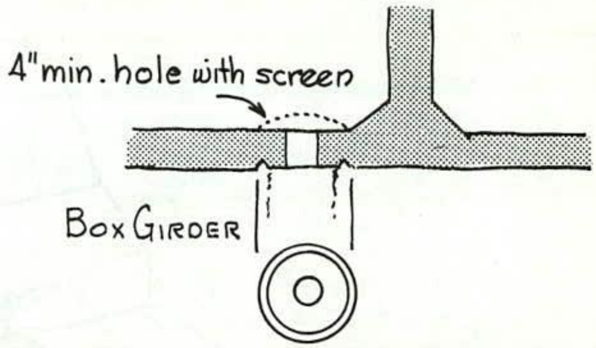


Figure 20. Drain inside a box girder.

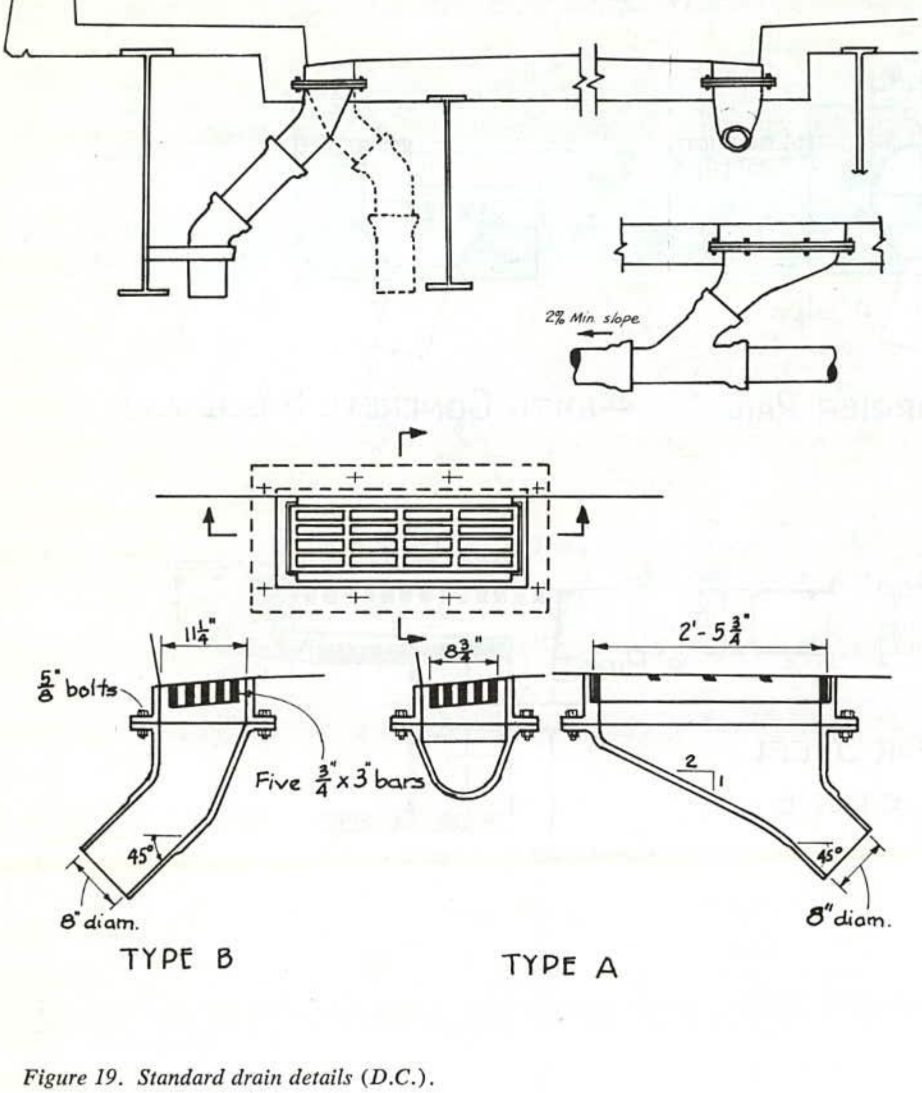


Figure 19. Standard drain details (D.C.).

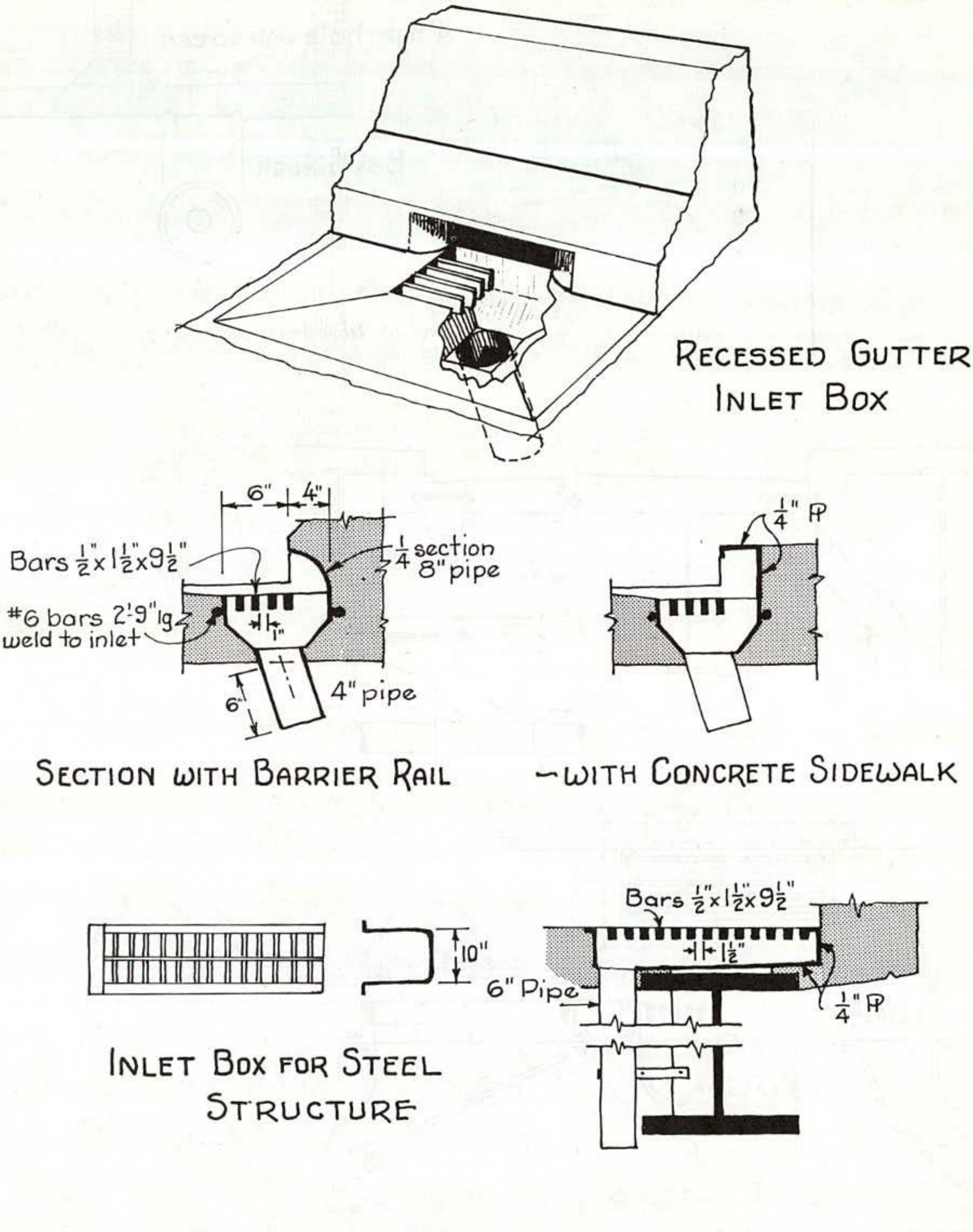


Figure 21. Standard bridge drain (Idaho).

Some systems accept the larger debris, hold it free of the water flow until it can be removed, and allow the smaller debris to pass on through the system. This entails the design of an inlet box that traps or holds the debris while water escapes to the outlet. Figure 22 shows a number of arrangements designed to accomplish this; not all of them are successful. Figure 22A shows a rather long box with the outlet located in the end. This design is often needed when the drain is in a thin, cantilevered overhang. Figure 22B shows an outlet in the bottom of the box, but in that position it is more susceptible to plugging. How well an outlet high in the wall of the end of the box performs as a debris trap depends on how the outlet is placed. The debris sinks to the bottom of the box, and the water runs

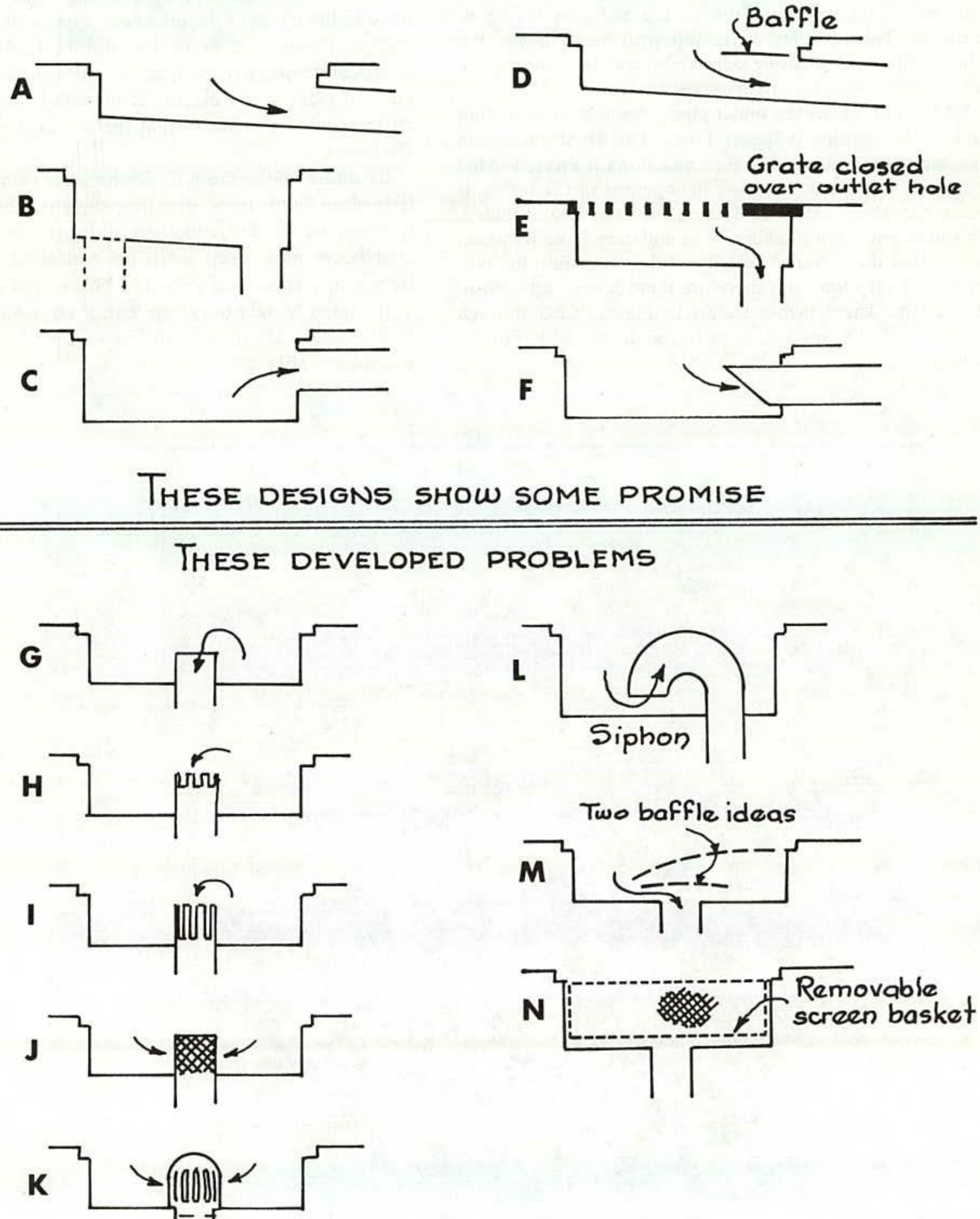


Figure 22. Inlet box debris traps. Designs A through F show promise; designs G through M have had less success; and design N has not been tried.

out over the top and into the outlet (Fig. 22C). In cold country there may be disadvantages to water standing in the box and freezing. Figures 22D, 22E, and 22F show the outlet located so there is no open grate above it.

Another idea is to have the outlet in the bottom of the box but to extend the outlet pipe up into the box from 6 to 8 in. (150 to 200 mm) above the box floor (Figs. 22G through 22K). Again, this creates a place to store debris and yet lets the water run out on top and over the lip of the pipe. These outlets work well with heavy debris but plug rapidly with floating debris and are therefore, without constant attention, of questionable value.

Figure 22L shows the outlet pipe given a U-bend up and over so the opening is facing down. This creates a siphon that raises the water in the pipe and flows it away, leaving the debris in the box. Because the opening of the siphon is below the water level, the floating debris is also excluded. This idea works but it takes a wide and deep box. Its weakness is that the entrance velocity of the water into the outlet pipe is very low, and therefore there is very little flushing action. The schemes shown in Figures 22G through 22L can all be applied to existing drains with bottom outlets.

When the outlet is already in the bottom of the box and under the open grate, a baffle can be suspended under the grate like an umbrella over the outlet (Fig. 22M). This deflects the debris to the side and does not allow it to fall directly into the hole. Smaller pieces can float back under the baffle, of course, but the baffle is effective in keeping debris from falling directly over the hole and blocking it.

Figure 22N shows a proposed inlet with a wire basket fitted to the inside of the inlet box. For cleaning, one needs only to remove the grate, lift out the basket, dump the debris, and replace the basket. This dispenses with the difficulty of picking and digging at the debris in the box. The basket could be made so that the screen does not rest on the outlet.

Because some agencies do not have the resources to regularly clean debris traps, they have designed their inlet boxes to transport all debris that gets through the grate. These inlet boxes have steep sides, no horizontal surfaces, and large outlet areas (see Figs. 11, 13, 16, and 19).

It cannot be said too often that, if no one comes around to check and clean, the fanciest systems become clogged and useless (Fig. 23).

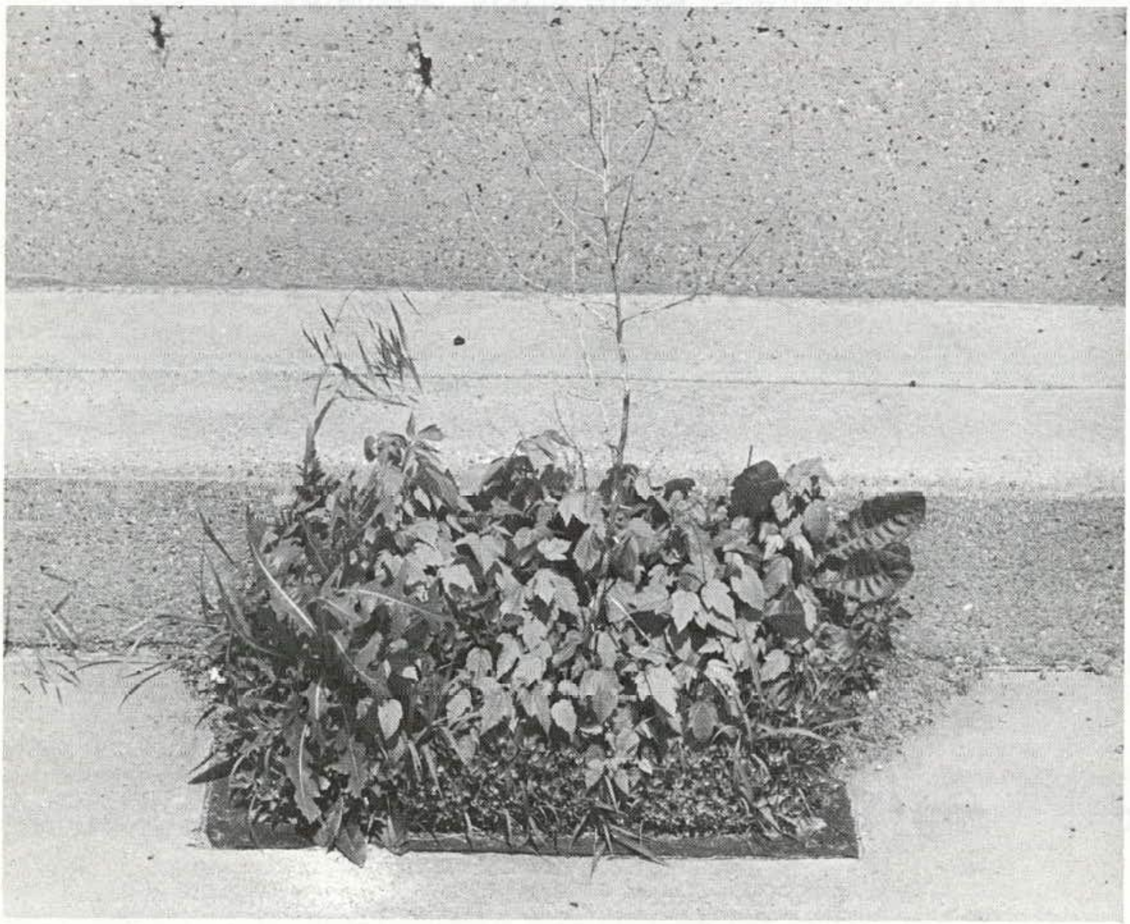


Figure 23. This system needs maintenance.

GRATES

The function of an inlet box is to intercept the water and direct it into an outlet pipe. An open hole would be very efficient, but it would be a hazard to traffic and would admit large debris that might clog the system. Therefore, it is customary to place a grate over most drainage openings.

The grate has several functions. It must admit the water coming to it; it must also screen out the larger debris but permit the smaller bits to pass through; and it must safely carry traffic loads across the opening. But it must not present a hazard to narrow bicycle tires, and it must be durable and resist corrosion.

An exhaustive study of the bicycle-safe grate problem as well as the hydraulic efficiency of grates is contained in three volumes published by FHWA (*1, 2, 3*).

Hydraulic Efficiency

If they are to admit water, grate openings must be designed in terms of the quantity of water, longitudinal slope and cross-slope of the deck, and geometry of the grate. An improperly designed grate may actually transmit a considerable portion of the water across the top of the drain. Bear in mind that flowing water follows a parabola as it leaves the square lip of a grate opening. If the velocity is fairly high, considerable distance must be allowed for the water to drop into the box; otherwise much of it may overshoot the opening. Generally, the steeper the slope, the longer the openings needed.

If the long dimension of the slots is perpendicular or at an angle to the flow of the water, much of the fast-flowing water will jump across the openings. It is better to place the long dimension of the slot parallel to the flow to give the water enough distance to fall into the slot regardless of its velocity. Hydraulic capacity will be impaired by the presence of any debris. Actual tests are the best evaluators of the efficiency of any grate. A grate designed for the greatest anticipated flow will certainly work well for all lesser flows. Considering the inevitable cluttering by debris, it is always better to err on the large side and provide plenty of room. Making the grate twice the calculated size is a good rule (Fig. 24).

Load-Carrying Capacity

A grate with a crisscross of welded bars becomes a highly indeterminate structure from a design standpoint. Most grates are probably several times as strong as they need be when they have not been analytically designed or full-scale tested. Several states have run load tests on their grates to determine their adequacy and have usually been able to reduce them to their structural necessity. An FHWA report (*4*) contains more information on structural design of grates.

Grates may be fabricated from welded bars or made of cast iron or steel. Some states prefer to use all cast drain assemblies—a cast-iron inlet box as well as a cast-iron grating. These assemblies have the advantage of long life and virtual indestructibility after being cast into the concrete deck. However, cast-iron grates can be very heavy. Lifting them out at as much as 500 lbs (227 kg) can present a

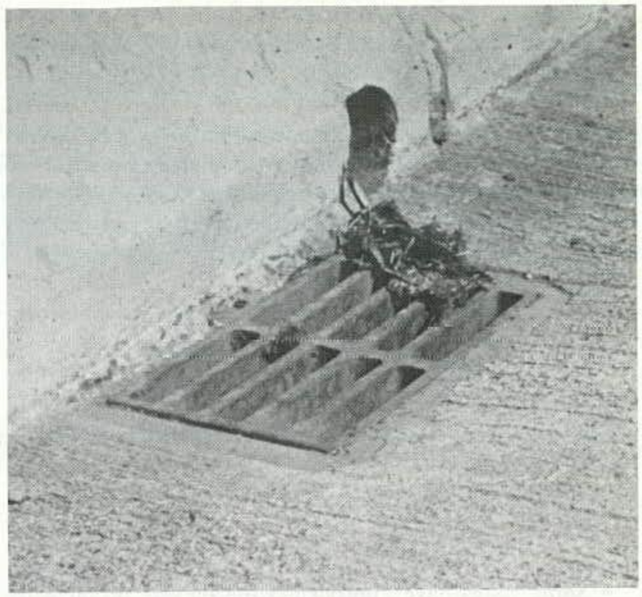


Figure 24. This could be the start of a plugged drain and is why the grate should have twice its design area: when it is half plugged, the water can still get in.

problem. Nodular cast iron and cast steel have commonly been used, but welded-steel grates are growing in popularity because they weigh and cost less.

It is important that grates be securely fastened. The ability of traffic to flip out even very heavy grates should not be underestimated, and positive hold-downs should always be provided.

Bicycle Safety

When welded-bar grates became popular, the bars were usually placed parallel to the water flow to provide the water easy access. This meant that the bars were also usually parallel to the traffic flow. As the number of bicyclists increased, these grates became the cause of many complaints. Cyclists, normally forced by traffic to ride in or near the gutter, suddenly found themselves airborne when their front wheels dropped into grates and stuck. Immediate steps were taken to weld small strips across the long slots of the existing grates and to design new grates.

A cyclist should be able to ride safely over the grate in any direction. There are several methods of making grates safe for bicycles.

- The slots may be made less than 1 in. (25 mm) wide. However, unless its area is very large, a grate with these narrow openings usually impedes the flow of water into the box and also catches the smaller debris, which hastens clogging.
- Crossbars may be placed in the grate perpendicular to the traffic direction and close enough together to prevent a bicycle tire from dropping in. This allows wider slots, which will restore some of the hydraulic efficiency lost by adding the crossbars.

• Diagonal bars may be used when the grate is so close to the curb that it would be impossible to get a bicycle wheel into the 45 degree slots.

• Wider slots—up to 2.4 in. (60 mm)—may be used if they are short enough to exclude a bicycle wheel. Sometimes the wheel is not allowed to drop deeper than 1 in. (25 mm) into a slot. For the smaller, 20-in. (500-mm) wheels, this would mean limiting the length of slot to about a 9-in. (230-mm) maximum, but this is safe only for wheels traveling in a straight line. The 1-in. depth of penetration would not be enough to trap the wheel, but it would prevent the rider from turning the wheel and could cause a fall. The FHWA study (*1, 2, 3*) indicated that a rider might feel some effect of the grate's deflecting the wheel or resisting turning it somewhat for any slot length greater than 4 in. (100 mm). Therefore, if the slot is as short as 4 in., the width would not be critical (as far as safety is concerned), and the openings could be as large as 4 in. square.

• Some states have approached the bicycle problem by setting the slots in their grates perpendicular to the flow of traffic. This eliminates most of the hazard but can greatly decrease the hydraulic efficiency of the grate as fast-flowing water may jump the transverse slots.

• Other special grate configurations may be used that will accept water but exclude bicycle wheels.

The FHWA report (*1, 2, 3*) also found the smooth top surface of grates (especially cast grates) to be hazardous because bicycles might skid on them. FHWA recommended roughening the smooth surface.

KEEPING RUNOFF AWAY FROM VULNERABLE AREAS

Runoff should be prevented from running down through expansion joints, running down the faces of girders and piers, and leaking from drain pipes.

Drip grooves should be used extensively on every structure. Because water will not run uphill, a groove is placed across the flow pattern so the water is forced to drip off. Figure 25 shows several types of drip grooves. For drain holes through the deck, double drip grooves are recommended. On pipes and smooth faces where drip grooves cannot be used, raised collars or ridges, such as a weld bead, can be used to give the same effect.

When drip grooves cannot be used, pier tops should be sloped or a small lip cast around the edge to keep water from running over the edge and down the pier faces. Some states coat their pier tops and stems with epoxy to seal the surface and prevent concrete discoloration. Then the tops of the piers can be sloped to shed the water.

When unpainted steel is used and allowed to rust, great care should be taken to prevent runoff from the steel from dripping or running onto concrete. The resulting rusty stains are unsightly and almost impossible to remove.

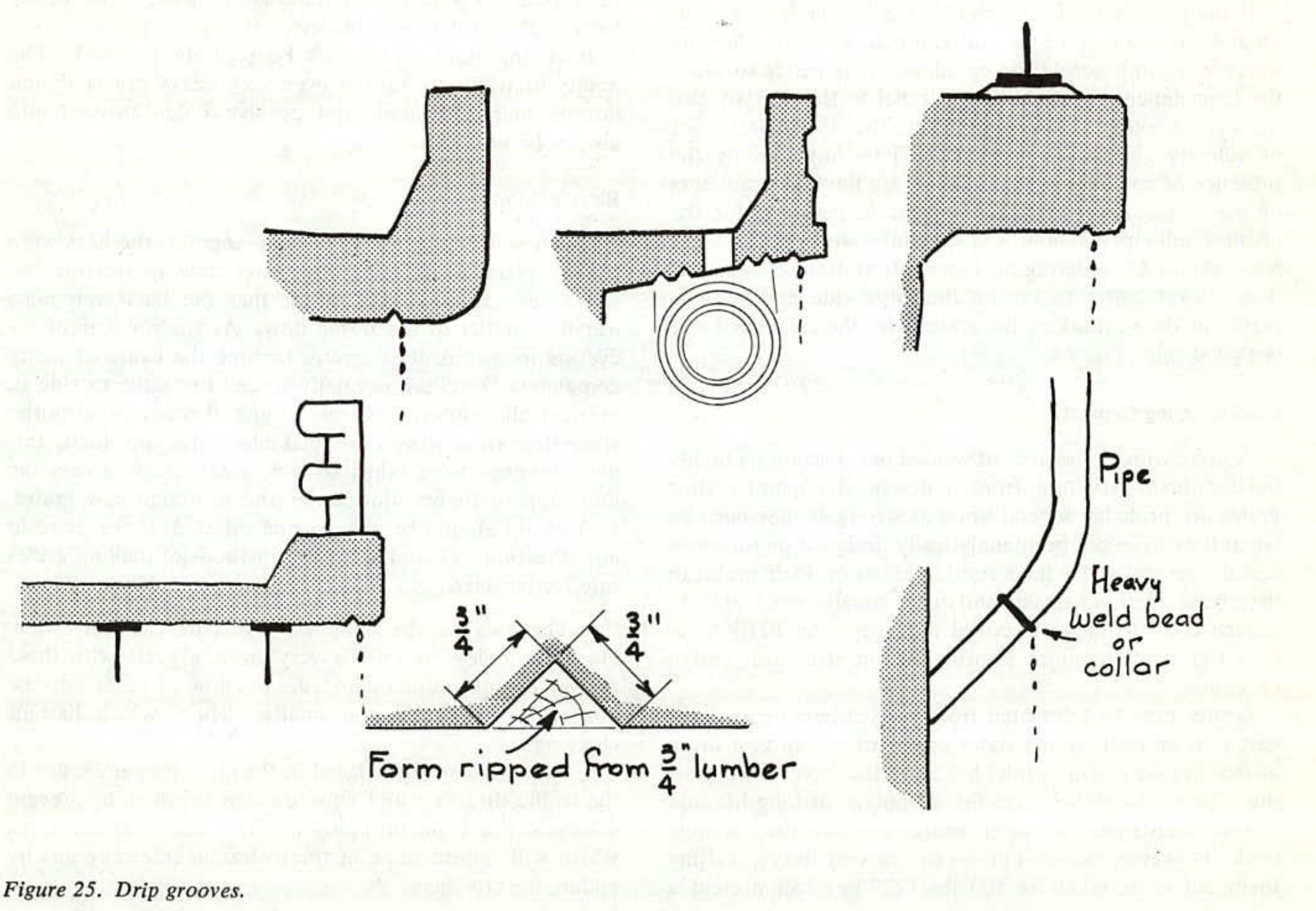


Figure 25. Drip grooves.

CHAPTER FOUR

TRANSPORTING AND DISPOSING OF THE RUNOFF

DESIGN PROVISIONS AND CRITERIA

General

Once runoff leaves the inlet box and enters the outlet pipe, it becomes a hydraulic problem. Practically speaking, however, because pipes are generally large and entrance conditions are generally restricted, the hydraulic characteristics of the system seldom limit the flow.

Exposed piping is unsightly. Wherever possible, drainage pipes should be buried in concrete or hidden (Figs. 26 and 27). Cold states hesitate to bury pipes in columns because when they plug, fill with water, and freeze, they may split the columns. To avoid this, pipes may be run in slots up the backs of the columns or may be hidden behind decorative pilasters. The basic idea is to avoid the messy appearance of pipes tacked onto the exterior faces of structures, running at odd angles, and spoiling the design's aesthetics.

Minimum Pipe Sizes

Most states agree that 6 and 8 in. (150 and 200 mm) are the minimum pipe sizes to be used. The piping should be cast iron or welded steel when exposed to the air. The minimum wall thickness of steel pipe should be ⅛ in. (3 mm). PVC pipe is allowed to be buried in concrete by some states, but special care must be taken with all pipe joints and bends. Corner joints and mitered joints are to be avoided. A minimum radius of 18 in. (450 mm) for bends is common. Some states permit 45 degree elbows in cast-iron pipe. The interior surfaces of all joints should be smooth.

Minimum Velocity

Few states specify any minimum velocity for runoff water in pipes. They all understand, however, that it is desirable to have the highest velocity possible and usually require that the pipe runs be placed on as steep a slope as can be obtained (vertically if possible). A slope of 8 per-

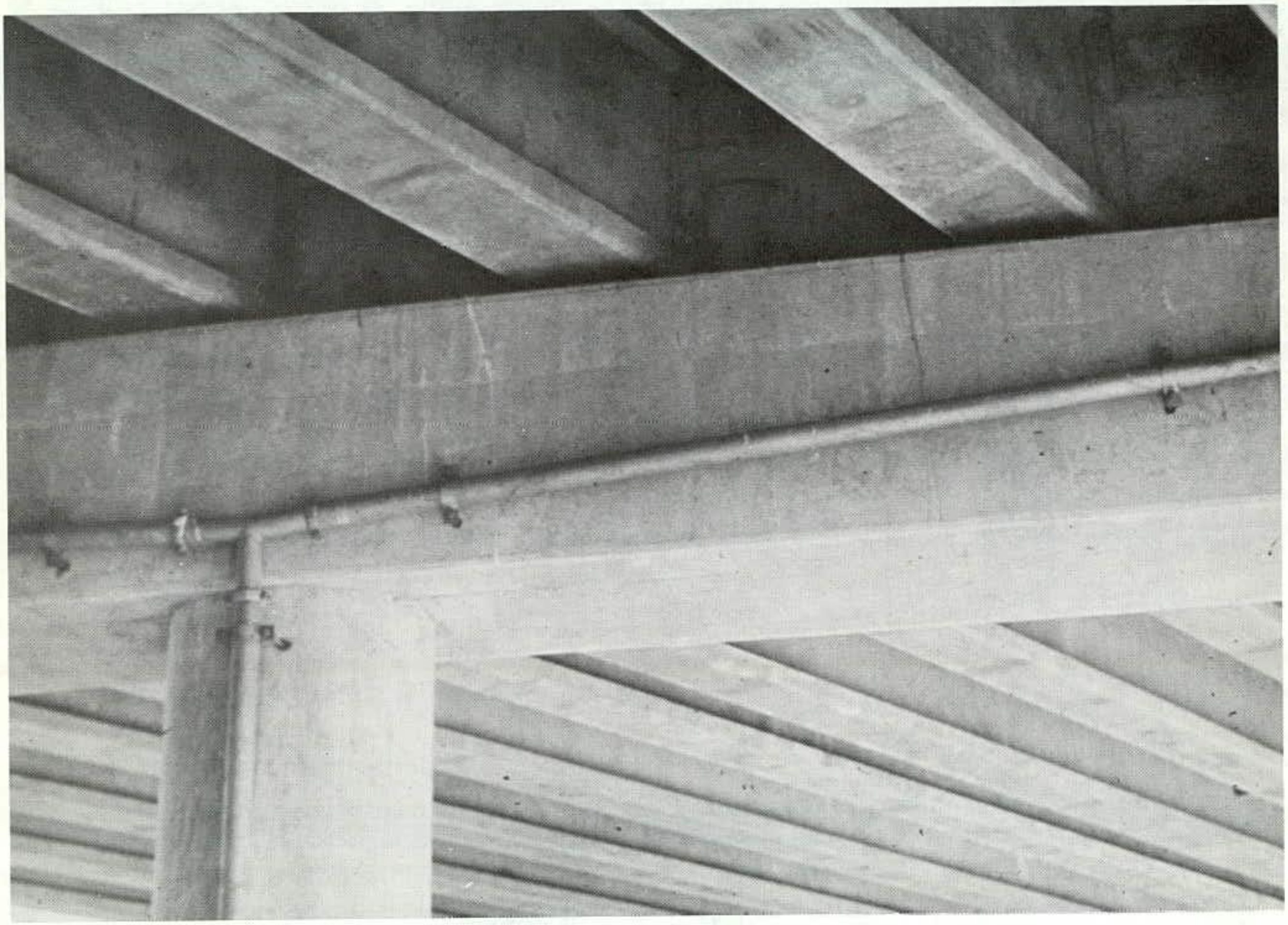


Figure 26. Exposed pipes on bridges are not aesthetic additions. They should be placed where they show the least—generally parallel to the lines of the structure. The T-joint here is almost certain to collect debris and become plugged.

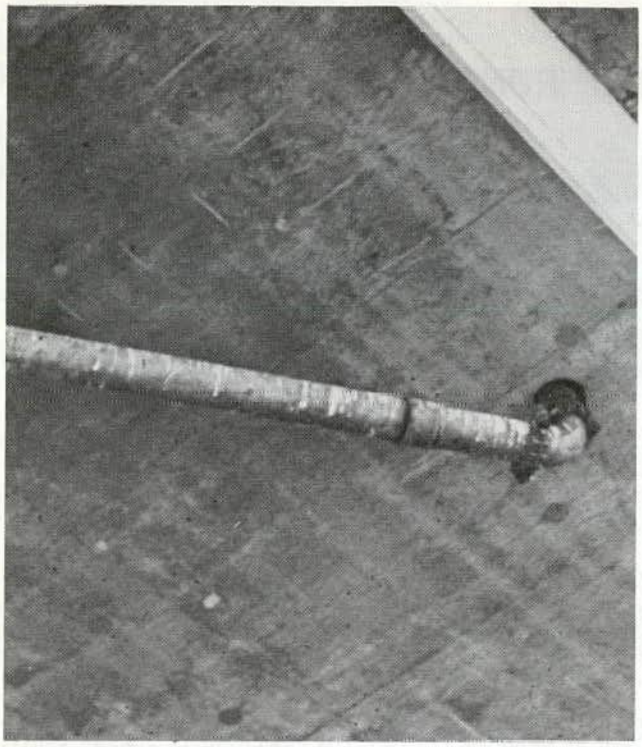


Figure 27. If this pipe had been thought of ahead of time, it could have been buried in the concrete. Apparently it had to be added later when the drain was found to be dumping water in the wrong place.

cent (1 in./ft) is a good minimum to observe so that the half of the debris that is sand and silt is transported through the pipes.

Closed Pipes, Troughs, and Cleanouts

Closed pipes usually cannot be avoided on structures, but on approaches or where runoff is being carried away from the structure, open troughs should be used. An open trough is far less likely to plug than a pipe. Water will rise and overflow, but still manages to escape. As extensive piping is sometimes unavoidable, the best safeguards are large diameter pipe, steep runs, and plenty of easily accessible cleanouts.

Cleanout plugs should be located so the maintenance crew can get to them from underneath the bridge and preferably from the ground. Figure 18 and Appendix B show some arrangements. It is most desirable to drop the water straight down as far as possible from the inlet box. When it is necessary to curve the pipe, the cleanout opening leading to the next straight run should be reachable from under the bridge without special equipment. These criteria represent ideal conditions that are not always attainable. Bends often must be placed in difficult locations, and cleanouts are not always easily accessible. However, attaining the most convenient arrangement is worth considerable study and effort because cleanouts that are inaccessible or difficult to reach simply will not be cleaned.

When the pipe run is not too long from inlet to outlet, it may be possible to run a long plumber's auger through to clean it out. If this can be done, care should be taken that a cleanout is not located so as to provide a blind alley for the auger to run into (Fig. 28).

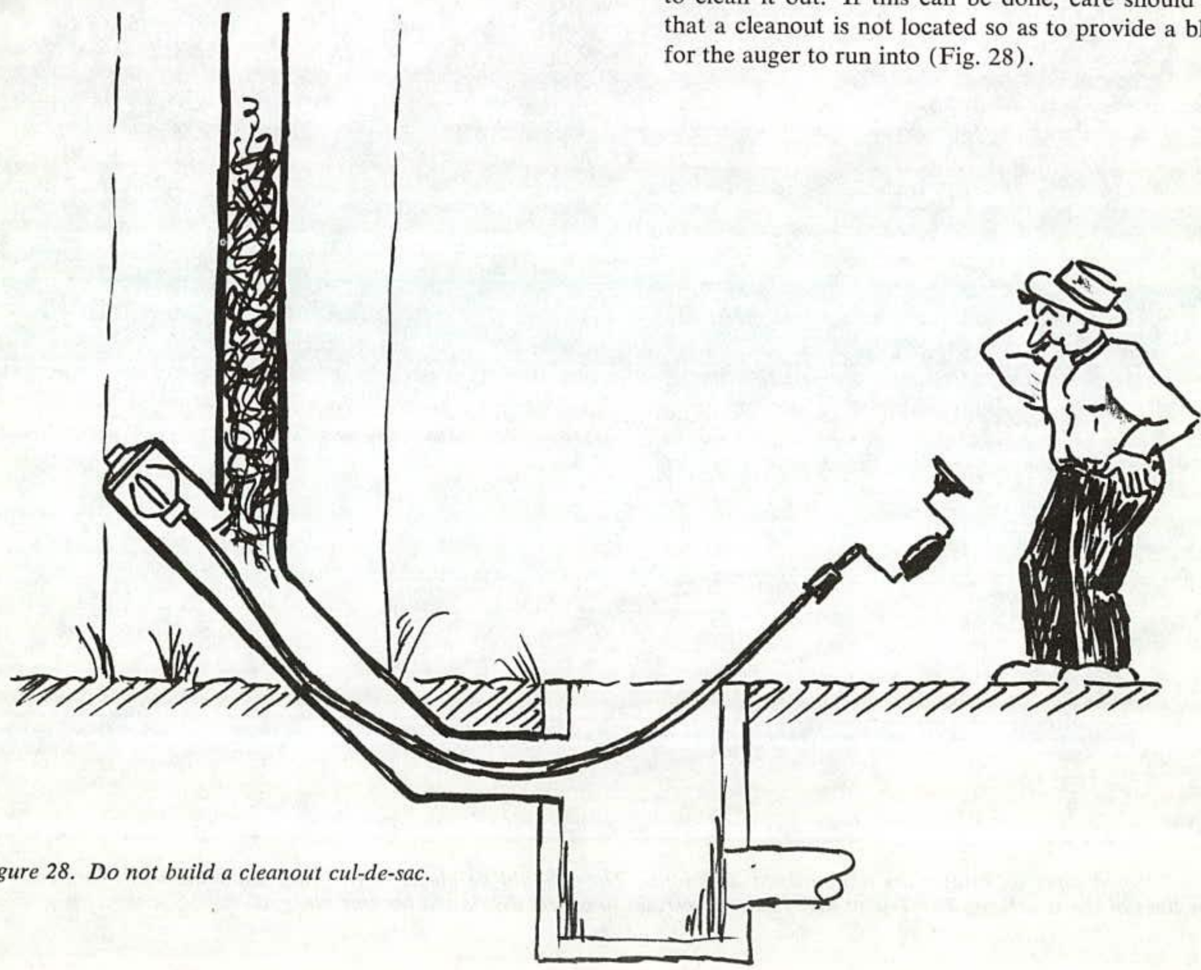


Figure 28. Do not build a cleanout cul-de-sac.

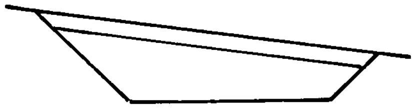
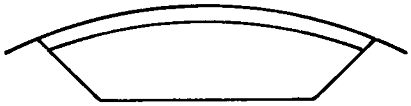
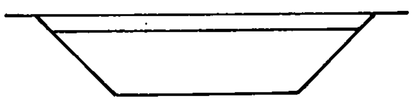
CASE	GRADE AT BRIDGE	RURAL PAVING (No curbs on approach pavement)	URBAN PAVING (Curbs on approach pavement)
A	 One end higher than the other	Use catch basins at low end only	Use Catch basins at both ends
B	 Both ends lower than center	Use catch basins at both ends	Use catch basins at both ends
C	 Both ends higher than center	Use no catch basins. Use drains on bridge deck	Use catch basins at both ends and drains on bridge deck
D	 Flat grade	Use catch basins at both ends only when no drains are used on bridge deck	Use catch basins at both ends

Figure 29. Minnesota's criteria for bridge drainage.

Gutters and Ditches

A number of states do not put drains on short bridges. They carry the drainage in the gutter to the end of the bridge and dispose of it there. The question is, how long is a short bridge? As with many other things, the answer depends on the circumstances.

Figure 29 shows criteria used by Minnesota for drains. Obviously, for a bridge sloping all one way, or both ways (cases A and B), if the grade is steep enough, 300 or 400 ft (90 or 120 m) of bridge might be drained easily to the ends. However, if the grade is rather flat, a heavy rain may not run off fast enough and ponding may occur. If the bridge is in a sag vertical curve, drains are essential. If the grade of the bridge is flat, the gutters must be sloped to make the water run to the ends. Obviously, water cannot run very far under these circumstances, and drains must be provided.

At the end of the bridge paved gutters must be provided to carry water to a suitable drain or catch basin. Figure 2 shows a typical arrangement used by Minnesota. A catch basin is provided at each corner of the bridge, where runoff is collected and deposited. Such a system should be built as a part of the bridge contract to make certain that the bridge drainage is not dumped onto the approach highways for disposal.

Catch Basins

Catch basins are usually considerably larger than inlet boxes because they are buried in the ground and do not have the confining restrictions of deck thickness and girder spacing. Their principal function is to trap debris and provide access to the drainage system on the bridge when the pipes leading to the catch basin are plugged. In a bridge drainage system, if the pipes coming down the columns feed directly into a sewer system without any access, it can be very difficult to clear a stoppage.

Several systems of backflushing with air or water will be discussed later. To make these systems work, there must be access to the lower end of the bridge piping. Therefore, it is good practice, even though the system does empty into a large sewer, to collect the water and debris first in a catch basin, which will keep a great deal of debris out of the sewer system (Fig. 30).

The design of a catch basin is based on the same principles as an inlet box except that the size can be much greater and there will be more room to store debris. This greater volume has many advantages, chiefly the longer periods of time between maintenance visits. The size and depth can make the box harder to clean.

Because catch basins are larger and out in the open, they can usually be provided with 12-in. (300-mm) or larger

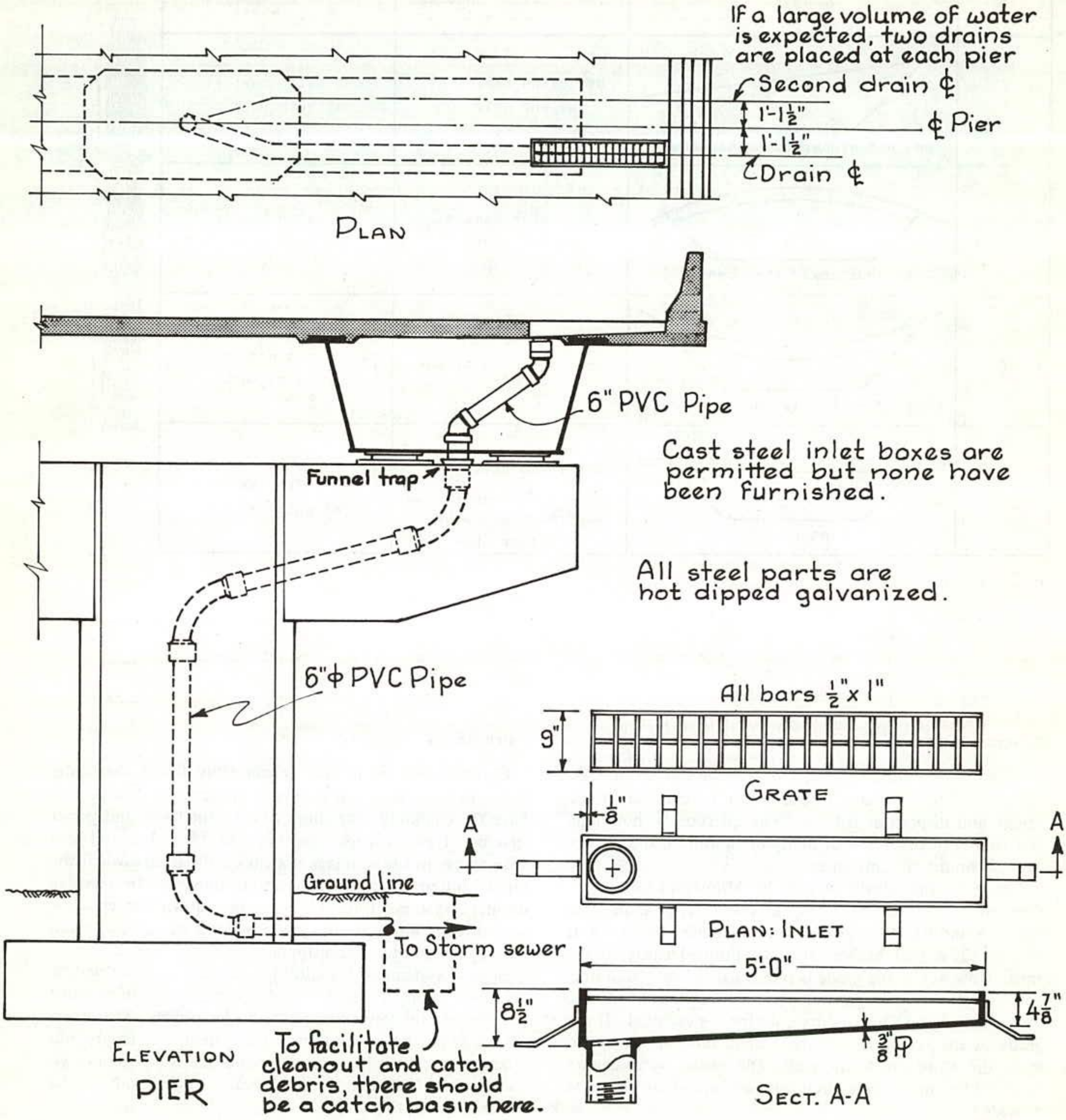


Figure 30. Typical contained drainage installation (Florida).

pipes. Some boxes open into paved ditches that conduct the water either down the face of the fill or away from the roadway. In any event, greater debris-trapping capacity and larger outlets usually keep the water flowing even when pipes are only casually maintained.

An adaptation of the catch basin idea that works quite well is the funnel trap. Where drainage is to be discharged into a sewer system but there is no catch basin, the vertical pipe can be cut and the runoff dropped through several feet of open air into a large funnel. If there is a debris problem and the funnel plugs, the water overflows with the debris onto the ground. The funnel is easy to clean, which makes collecting and removing the debris simple. This arrangement keeps any flooding on the ground rather than lets it back up and flood the roadway. An overflow is usually much easier to cope with on the ground than it is on the roadway. Some states have used a similar funnel arrangement under the deck (Fig. 30). This placement has the advantage of also handling the expansion between the deck and the pier without having to install a flexible pipe connection.

Water Disposal by Open Fall

When holes in the deck or short vertical pipes are used to release water into the air, care must be taken that no erosion or damage occurs underneath. Water should never be dumped onto an embankment surface that lacks erosion protection such as riprap, a paved slab, or an open basin. In locations where the free fall exceeds about 25 ft (7.6 m), the natural air movement will disperse the water enough to not erode the ground surface. Thus, bridges high in the air can be allowed to discharge water freely into the air. However, when the water is discharged into the air but is supposed to be collected again in a basin underneath, air dispersion can be very annoying.

To prevent dispersion, a heavy steel chain can be hung from the opening above to the basin below. The water will follow the chain and, unless the wind is very strong, little will be lost. The device is used architecturally to lead water from eave drains into a disposal system on the ground. It looks better and is far more effective than a downspout. In addition, the water loses all the debris on the way down.

Erosion and Scour Prevention

As already discussed, runoff should never be allowed to fall on or flow over unprotected embankments, which it will quickly erode. A velocity of more than 1 ft/sec (0.3 m/sec) may cause scouring. The runoff should be kept away from the foundations of the bridge itself and of abutments and walls. The scouring action of running water can soon undermine and cause structural damage.

Dumping Runoff on Adjacent Property

Runoff should not annoy adjacent landowners. Even though the water collected might well have fallen on the same area before the bridge was built, the fact that it has been collected and then released in one or more concentrated streams changes the conditions. Whereas a swale may have carried drainage water before, the bridge should not dump all of its runoff into that swale and convert it to a substantial stream. The runoff must be transported to some point where the added volume of water does not profoundly change conditions.

Provisions for Hazardous Spills

Some agencies have special arrangements for handling spills of hazardous materials. These include provision for diverting the runoff into a controllable area. This requires some sort of valving arrangement or a bypass ditch that will carry the material to a diked-off area or a natural sump where it may be dealt with safely. Sometimes, where having hazardous material run into a sewer system would be especially dangerous, a control device is placed at the sewer entrance and may be closed to prevent the material from entering. Some alternate method of receiving and holding must be provided. If the likelihood and consequences of hazardous spills seem especially threatening, additional catch basins might be provided to collect the material sooner and carry it to some controllable spot.

All of these special systems are costly and are warranted only if there is extreme likelihood of a spill or the consequences of such a spill would be intolerable. In most cases, the chances of such a spill's occurring at any specific location are so slim that a great expense does not seem justifiable. Most agencies remain fully aware of the possibility and adapt their existing systems to handle the noxious materials insofar as possible without undue expense.

MAINTENANCE

General

Maintenance is the key to the success or failure of any drainage system. It is not possible to design a drainage piping system that will clean and maintain itself. Periodic attention is essential. The designer must arrange the system to be easily maintained. If maintenance is difficult, the system will be neglected. The designer must also build all possible safeguards into the system: large capacities to store debris, large openings to prevent clogging, easy curves in pipes, steep slopes for greater velocity and scouring power, and numerous points of access for cleaning.

The more frequently a crew services a drainage system, the less work has to be done each time. But cleanouts are often placed in locations that are hard to reach. Logically, when the pipe changes direction the designer will call for a cleanout plug. The fact that it may be tight up under the deck 25 ft (7.5 m) off the ground, may not occur to the designer. However, access to such a cleanout requires some sort of "giraffe truck," lift truck, scaffold, or long ladder. If such cleanouts must be high, they should be on top of piers where there is some place to stand and support a ladder for access. Cleanouts should be placed where there is ample room to get to them and to run hoses, probing rods, or snakes (plumber's augers) into them.

Continuing Costs

The dollar cost of maintaining drainage facilities may vary as the years go by, but the amount of labor to be expended is almost a constant if the system is to function properly. The frequency of attention will vary widely with conditions.

In a dry climate not subject to summer rains, the drainage system often gets little attention during the dry season. Yet it may be desirable to flush the drains during the dry season just to make sure they are not packed. Well before the rainy season starts, the drains should be thoroughly cleaned and flushed.

Where rain is intermittent all year round, the maintenance schedule will depend on the need. Some locations seem to develop more debris than others; three weeks may be an ample time for an inlet box to become completely filled. Other locations may endure for longer or shorter periods.

Nevertheless, the schedule developed must be rigidly adhered to if the drainage system is to work well.

Safety of Maintenance Personnel

The designer who wishes to have the drainage system function well should provide for the safety of the maintenance personnel as they clean and flush the system. Numerous studies have indicated that the inlet box that cannot be serviced safely and easily does not get serviced. A Chicago maintenance crew who went out 12 times to service the inlet boxes on a heavily traveled elevated expressway were involved in a traffic accident every time.

Where shoulders are provided, the maintenance vehicle has room to park out of the traffic stream. Inlet boxes should be on the edge of the shoulder as far as possible from the traffic stream. Providing shoulders on a long viaduct is expensive, and just a few years ago (maybe even today) it was difficult to get funds. However, with the added emphasis on traffic safety and, in this case, the safety of the workers, the cost of shoulders on a bridge can be well justified.

Unorthodox Solutions

Maintenance crews faced with severe maintenance problems will find solutions. Where ponds develop and no drains are available, holes have been drilled or jackhammered through the deck. Where drains are prone to clog or are inaccessible or in dangerous places, maintenance crews have sometimes filled the inlet boxes with concrete. The same "solution" has been applied where grates were being regularly flipped out of the boxes and into traffic. In other cases, where the piping continually clogged, they have disconnected the pipes under the deck and let the water fall free to the ground. The designer must avoid these unorthodox solutions by providing a drainage system that works well and is easy and safe to maintain.

Cleaning Procedures and Gadgets

The equipment the maintenance crew uses to service drainage systems ranges from simple to complex. First is a shovel, next comes a steel bar to probe the outlet openings and possibly break through a jam. Many maintenance trucks carry a water tank and high-pressure hose. Minnesota crews occasionally use a steam boiler and hose to melt ice in drains.

If someone could give each inlet box a little attention every day, a system could probably be kept operating with the simplest of tools. This is not practical, however. Unless there is an organized maintenance program, no one seems to think of drainage systems in dry areas until the season's first rain is either in progress or impending. By then the summer's dirt and debris are packed into the drainage system, and sophisticated efforts are required to free it. In wetter areas, year-round rainstorms demand that drains be given continual attention to keep them open.

Water under high pressure has been traditionally used to clear pipes. But the water must be able to break through and an outlet must be available. However, when the stoppage covers an extended length of pipe, the water pressure will not reach far enough to cut through and, in fact, may only pack the debris in tighter. Because sand and silt amount to about half of the debris, a very hard, dense plug can build up in a pipe. The best solution seems to be some sort of backflushing. The plug was formed by water and debris flowing from above, and reversing the flow will usually loosen the plug so it can be washed away.

California has found in many instances that high-pressure air is a more effective backflush than high-pressure water. The backflushing procedure developed by California is described in a Federal Highway Administration publication (Fig. 31) (*5*). The procedure requires access to the outlet end of the system. (This is a good argument for having the system empty into a catch basin.) A rubber plug is locked into the pipe at the lower end of the drainage system. The plug is made up of soft rubber between two large washers that are slightly smaller than the inside diameter of the pipe. Through the center of the assembly runs a threaded pipe with a large threaded nut on the inside and a large wingnut on the outside end (Fig. 31). The assembly is then thrust into the pipe and the wingnut tightened. This squeezes and expands the rubber to lock the plug inside the pipe. Beyond the wingnut there is a tee in the pipe for an air connection and a pressure-relief valve. The air connection is for high-pressure air, and the valve is to release the pressure after the pipe is unclogged and before the plug is withdrawn. The rubber plug provides a seal that makes the piping airtight up to the clog. However, it does not grip the pipe tightly enough to remain in place under high pressure. For safety, the plug must be held in place by external bracing or strapping. Communication between the two ends of the pipe is essential; radio has been used in some cases with success. The plug is secured in the bottom end of the system, and air is applied in short bursts to backflush it up through the debris. At the same time, water is fed into the upper end of the drain. The air and water "liquefy" the obstruction so that it will flow to the bottom of the drain. If it does not come down, it may blow out the top. In this case, the obstruction will release with an eruption of water, mud, and debris out of the inlet box. Once it has been blown through, water from above can usually wash everything through and clean the pipes. The eruptions can be violent, so California recommends that a vehicle be parked over the inlet box while air pressure is applied.

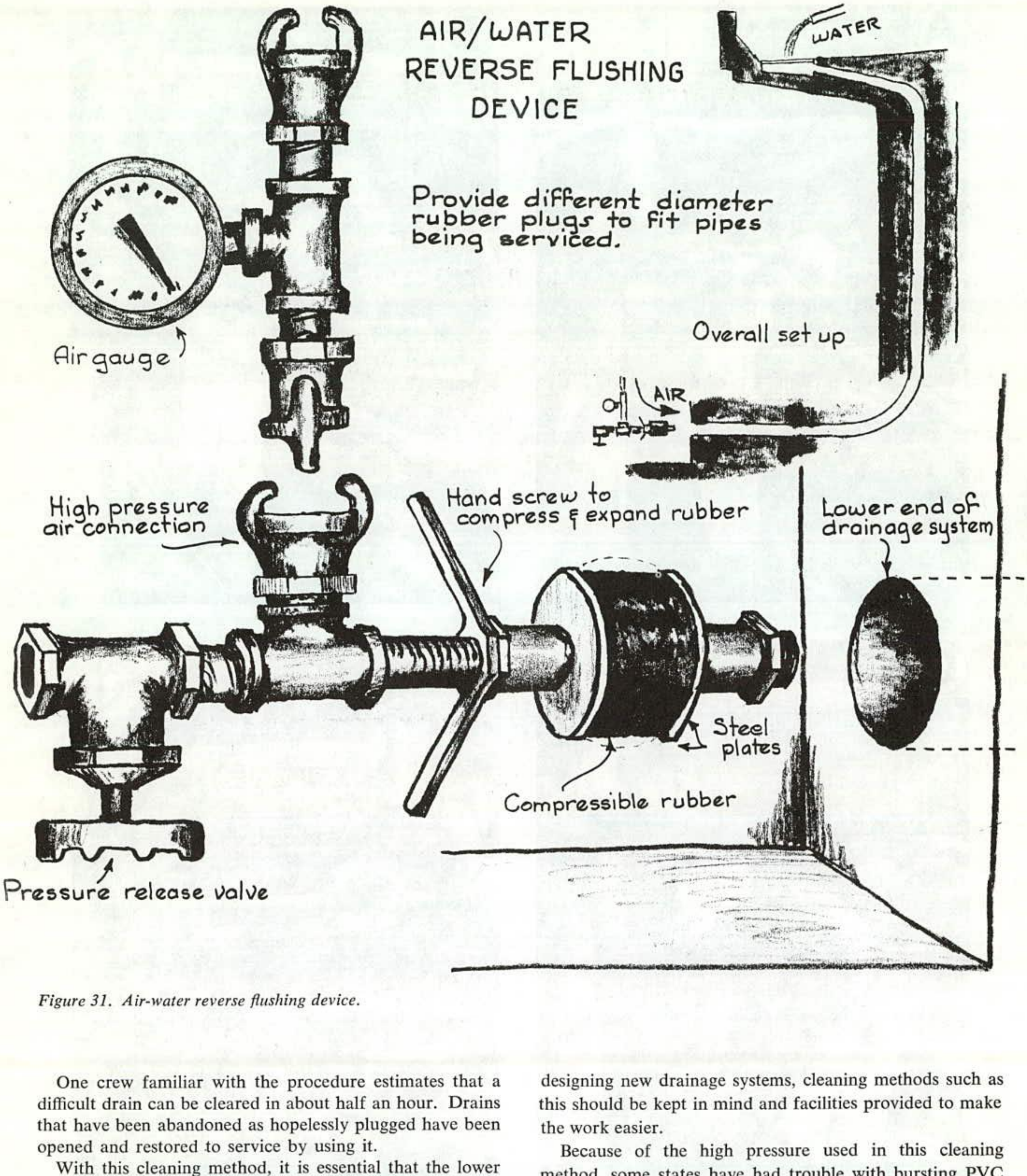


Figure 31. Air-water reverse flushing device.

One crew familiar with the procedure estimates that a difficult drain can be cleared in about half an hour. Drains that have been abandoned as hopelessly plugged have been opened and restored to service by using it.

With this cleaning method, it is essential that the lower end of the system be easily available for insertion of the rubber plug. Where the piping discharges directly into a sewer, a cleaning tee and some means of closing the pipe below the tee should be provided so the system can be pressurized. When the drains empty into a catch basin, the inlet pipe should be placed so it can be reached easily. In designing new drainage systems, cleaning methods such as this should be kept in mind and facilities provided to make the work easier.

Because of the high pressure used in this cleaning method, some states have had trouble with bursting PVC drain pipes not encased in concrete. Caution should be exercised if there are open PVC pipes in the system. This also points up the undesirability of using open PVC piping in a complicated drainage system where pressure cleaning methods might have to be used.

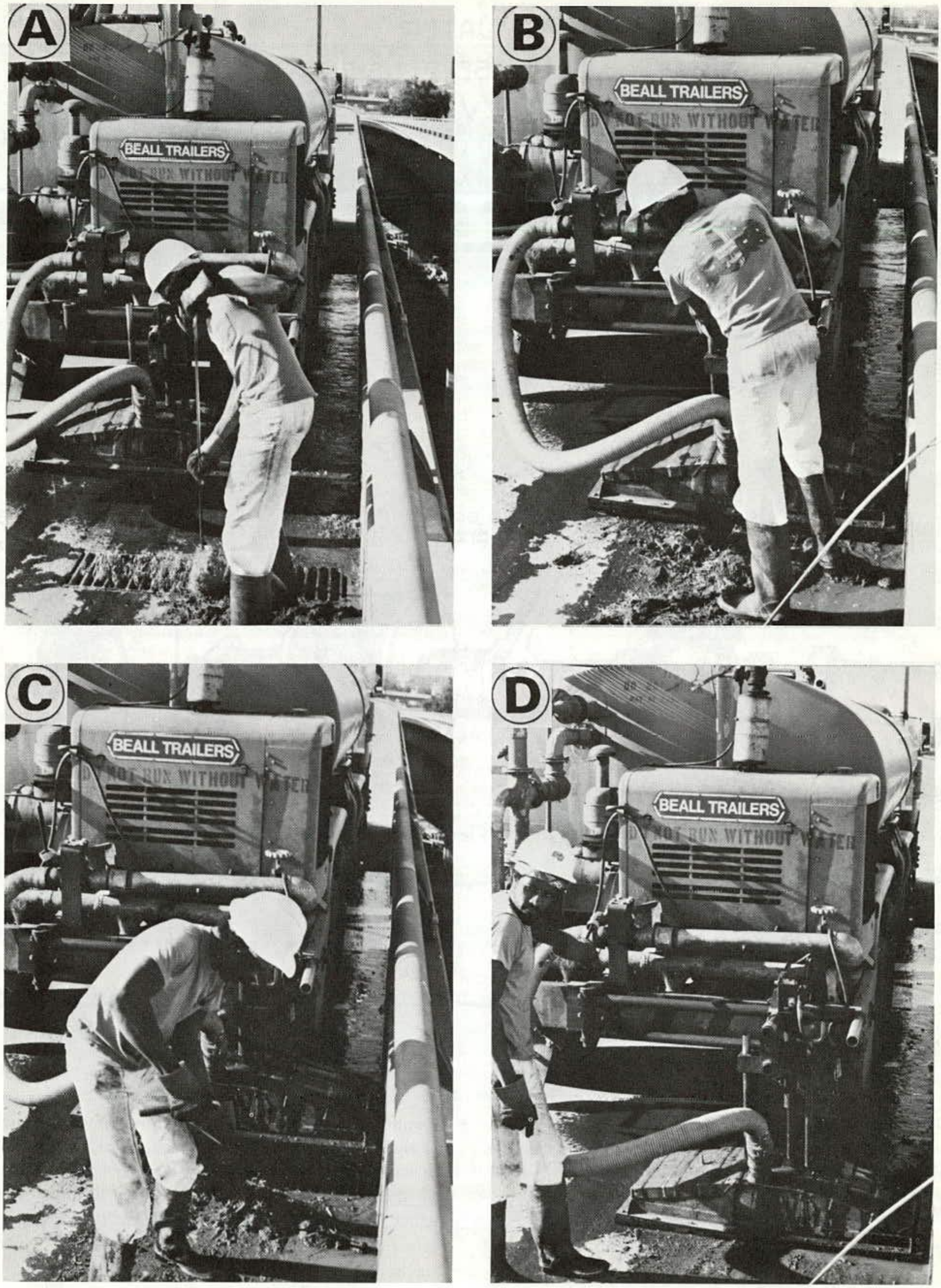


Figure 32. Remote-control drain flushing.

Several devices have been designed so crews can work from a water truck. One such device has a large, rectangular nozzle working on a movable arm from the truck (Fig. 32). The nozzle is rimmed with rubber so it can be pressed down over the entire drain to seal the opening in the deck with the grate in place. After the debris has been removed from the grate (Fig. 32A), the nozzle is lowered into place over the grate and water is forced in under high pressure (Fig. 32B). When the drain is clear, the accumulation from the grate is flushed through the system (Figs. 32C and 32D). This equipment, however, requires some standardization in size and shape of inlet boxes as well as uniformity of location in the deck.

Another device that works well in certain situations is the "Sanovac" cleaner, essentially a large vacuum cleaner mounted on a truck with a long, 12-in. (300-mm) diameter suction hose that can reach into drains, inlet boxes, and catch basins to suck up the water and debris collected there. It is used mostly for catch basins along highways and deep, manhole-type drop inlets. The use of the long suction hose is another way to clean out some of the deep boxes and avoid having to shovel debris out of them. A vacuum cleaner system has limited use for bridge drainage installations because of the smaller inlet boxes and the generally smaller pipes.

Maintenance crews are very resourceful in devising gadgets and equipment to solve problems they find in cleaning drains. The methods described here are certainly not all of those used for drain cleaning, but these have been found effective for their particular conditions.

Procedures to Prevent Clogging

The required frequency of maintenance will vary with the location, the season, the prevalent weather, and the propensity of the drainage system to collect debris. However, there are so many drains and so many varying conditions, and maintenance crews usually have so many demands on their time, that regular attention to drains is a rarity. Therefore, the methods of opening serious stoppages are often of more general interest than are plans for regular maintenance procedures.

If the system was not originally designed for easy maintenance, the maintenance crews should initiate projects to install cleanouts at more convenient and safer locations. These will generally be in places where they can be reached from the ground or with a minimum of special equipment.

Procedures to Prevent Freezing

The drainage system should be designed so that there is no place for the water to collect and stand. However, if there is a stoppage, water freezing in pipes and inlets can result in considerable damage.

Just as it is wise to see that the system is clean and working before the onset of a rainy season, so it is wise to see that all drains are functioning before freezing weather comes. If the system is open and working when the freeze comes, it will generally thaw and function as desired when the freeze is over.

Having the whole system freeze does not seem to present the problem that anyone not familiar with extremely cold country might assume. Minnesota reports little trouble with water in inlet boxes and drains freezing. They have equipment for steaming but rarely have to use it. They do make sure that the system is open and operating before cold weather comes, and they make sure the pipes all have a good slope so that once the water starts running it flushes out the drains itself. Alaska has used heating tapes, placed inside pipes to keep water from freezing or to hasten thawing when the weather warms, which contain resistance wires that produce enough heat to prevent ice from forming in the pipes. In special situations, the convenience of a functioning drainage system may be worth the cost of an installation. When it is very cold and everything is frozen, there is no need for drains.

Practically speaking, when the temperature plummets, there is little that can be done to keep the drainage system functioning. Fortunately, there is also little need for the system in that kind of weather. Observing what Minnesota does to combat conditions probably gives a typical picture of operations in many northern states. They try to plow or blade the snow and slush through or over the bridge railings. Sometimes under slushy conditions a residual windrow piles up along the curb or railing. If the bridge has the newer safety railing with the sloping face, some snow and slush will accumulate at its base. Minnesota recognizes that nothing can be done about this accumulation until the weather warms and melts it away. Sometimes, if the weather is mild, they blade the snow and slush left on the deck and load it into dump trucks with front-end loaders. As the snow melts, the water runs to the catch basins and away. The catch basin outlets are placed on a good slope so that, as soon as the frozen material becomes fluid, it flushes the pipes clean. Figure 2 shows Minnesota's typical drainage arrangement.

A problem of bridge decks in cold country is water getting under an asphalt surfacing and then freezing, heaving, and breaking it. To prevent this, there should be small weepholes provided at the inlet boxes just on top of the sealing membrane and under the asphalt surfacing. Most modern installations have an impervious membrane over the concrete deck and under the asphalt surfacing to prevent salt from getting to the concrete. The water will seep through the asphalt to the membrane and then run downhill to the inlet box, through the weepholes, and away. Figure 12 shows a typical installation. Another method of draining the area under an asphalt surface is shown in Figure 16.

CHAPTER FIVE

RECOMMENDATIONS—A CONSENSUS FROM PRESENT PRACTICE AND EXPERIENCE

DECK CROSS-SLOPES AND BRIDGE GRADES

Deck cross-slopes should be not less than 2 percent or ¼ in./ft. Bridge deck longitudinal slopes should be not less than 0.5 percent. If the longitudinal grade is less than 0.5 percent, additional drains or special sloping of the gutters may be required.

TYPE AND SPACING OF DECK DRAINS

Three types of drains are commonly used:

1. Open holes through the deck. These are usually a minimum of 4 in. (100 mm) round and taper to a larger diameter as the holes go through the deck. Some states use a short piece of 4-in. PVC or ABS (acrylonitrile-butadiene-styrene) pipe or structural steel tubes cast into the deck vertically or on a slight slope for a straight-through drain. Spacing is commonly at 6-ft (1.8-m) centers for the 4-in. round drains. Care should be taken to make sure the inner surface of the drain holes is very smooth or tapered to prevent debris from catching.
2. Fabricated steel or cast-iron inlet boxes with grates. Boxes have also been cast into the concrete deck without metal liners. Spacing of drains is determined by the anticipated runoff quantity. Appendix A gives sample methods of computing drain size and spacing for Idaho and California. Drains should be provided along each low gutter. If the bridge is twisted by superelevation, additional drains may be needed to prevent streams of water from flowing across the traveled roadways. If a center divider curb is terminated short of the end of the bridge on a deck that is superelevated all in one direction, it may also be necessary to provide a drain at the end of the curb.
3. Catch basins just off the lower end of the bridge to collect all drainage. With this type of drainage, no drains are used on the bridge. Similar catch basins may be desirable at the upper ends of bridge gutters to intercept highway drainage that might otherwise run onto the bridge.

SHAPE OF GRATES AND INLET BOXES

The open area of a grate should be twice that calculated as necessary to handle the anticipated water with due consideration given to slope, speed of flow, and approach angle—unless one is absolutely sure that there will be no debris, a very rare condition. Grates generally work most efficiently when the slots parallel the flow of water.

The inlet box should be large enough to be easily cleaned with a shovel. If debris storage is anticipated, the box should be as deep as possible (usually limited by the thickness of the concrete deck) and the outlet hole should be offset—either at the low end of the box or in one of the walls—so the debris cannot fall directly into it.

The grate should be strong enough to carry all highway loads likely to traverse it. It should have a pattern of openings that will not catch or trap bicycle tires. The grate should be firmly fastened so it cannot be dislodged by traffic or vandals. Spring clip arrangements are generally not satisfactory. Positive bolted hold-downs are better.

PIPE SIZES AND MINIMUM SLOPES

Pipes used for a bridge drainage system should not be smaller than 6 in. (150 mm) in diameter and, if there is considerable debris or there are many angle points in the system, 8 in. (200 mm) would be better. Smooth welded-steel pipe is preferred, especially for open runs. When the pipe is buried in concrete, PVC or ABS pipe may be used. Plastic pipe should not be used in open runs where there is likelihood that a pressure cleaning method may have to be used; the plastic pipe may burst if it is not enclosed in concrete. Mitered joints should never be used. Changes in direction should be long sweeps of no less than an 18-in. (450-mm) radius. Cast-iron pipe with bell-and-spigot joints is used in some states. No elbows sharper than 45 degrees should be used. The slopes of all pipes should be as steep as possible but never less than 2 percent, and some feel the minimum should be 8 percent.

LOCATION OF PIPES AND OUTLETS

Pipes hung on a bridge structure do not improve its appearance. If possible, the piping of the drainage system should be buried in the concrete or concealed within the structure. Drains are frequently located adjacent to bents or piers. Drains in this position may conveniently lead into pipes running into the pier caps and then down inside a pier leg. In cold country, some states do not encase drainage pipes in concrete because water in them freezes and cracks the surrounding concrete. Piping for drains out in the span, assuming that the runoff cannot be dropped freely on the ground below, can be run inside box girders or high inside steel or precast concrete girders where it ordinarily will not be seen.

If piping must be exposed, it should be parallel to the existing lines of the structure if possible and painted to match the general color of its surroundings. When piping is enclosed in the concrete of a pier shaft, it should be brought out in the open above the ground line to provide access for backflushing, rodding, or air-pressure cleaning equipment. If the discharge is to be into a sewer, it should first go into a catch basin equipped with some sort of debris trap. The catch basin may be tightly covered, but the cover should be removable for cleaning.

If the discharge is by free fall under the bridge, the pipes should be carried at least 1 in. (25 mm) below the bottom of the adjacent girders. They should not discharge water where it can easily blow over to and run down a column or pier. Water should not be discharged openly over any traveled way (either vehicular or pedestrian), unpaved embankment, or natural ground where it might cause erosion or undermine some structural element. Where the drain is a hole through the deck, the outlet end should be completely ringed by two drip grooves.

CLEANOUTS AND FLUSHING ARRANGEMENTS

Cleanout plugs and elbows must be easily accessible, preferably from the ground without special equipment. Cleanouts should be located according to probable cleaning methods. Access holes should be provided at the bottom end of a system for pressure backflushing. A tee-joint will not be satisfactory for pressure backflushing unless there is also provision for blocking the outlet leg to the sewer. An open hole into a catch basin provides the best backflushing access.

Where manual flushing systems are provided, the valves should be easily accessible without hazard from passing traffic. When grates are flat and of fairly uniform size, a pressure flushing device may be used.

DRAINAGE OF ABUTMENTS

Weepholes should be provided behind abutments to drain water accumulation and prevent a buildup of pressure. A pervious material should be used behind the abutment to allow water to reach the weepholes.

IMPROVED COMMUNICATION

Frequent communication is a vital factor in solving the drainage problem that is so closely intertwined with design, construction, and maintenance procedures. There is a woeful lack of communication between maintenance people and designers. Seldom does a mainenance foreman call a designer to say that the design just does not work and point out its deficiencies and suggest improvements, yet this would be an invaluable tool for general improvement. Designers should take it upon themselves to check with the field forces to find out whether their designs have worked. Without this feedback, inadequate drainage systems have been built year after year in the mistaken belief that everything was working well. Establishing this sort of internal communication is one of the most beneficial things any highway agency can initiate.

REGULAR INSPECTION AND SERVICE

The strongest recommendation of all is that the bridge drainage system, regardless of its nature, be regularly and carefully inspected and serviced to make sure it is open and in good operating condition. Regular service can prevent stoppages and costly blockage-removal sessions.

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APPENDIX A

DESIGN CRITERIA FOR BRIDGE DECK DRAINS

IDAHO

Basic Concepts

The information on the following pages deals with the collection and removal of storm waters within the structure limits of a bridge deck. In the design of bridge drainage facilities, the aim is to keep the traveled way free from hazardous flooding except for infrequent excessively heavy rainstorms.

To remove the storm water from the bridge deck, the standard drain inlet shall be used. The deck is used to carry the storm water to these drain inlets. The drain is placed according to hydraulic principles and located adjacent to the curbing. The collected water should be dropped over the median or slope paving. Flexible sealers are utilized at expansion joints to prevent undesirable leakage through the deck.

Design Criteria

Rainfall intensity for determining deck runoff is shown as follows by district:

District	*Rainfall Intensity*
1 and 6	4.0 in./hr
2, 3, 4, and 5	2.5 in./hr

For channel grades of 2 percent or less, assume drain will take all water 1.75 ft from curb. For grades greater than 2 percent, assume drain will take all water 1.5 ft from curb.

Design Procedure

Find slopes of channel at position selected for drain.
Determine extent of flooding:

Find area of deck contributing to inlet.
Find Q slightly upstream from depression.

$Q = 0.000023\ Ai$

where
A = deck area in ft^2,
i = rainfall intensity in in./hr, and
Q = CFS.

Use nomograph for flow in triangular channels (Fig. A-1) in which symbols N and n are used interchangeably.

Find Y, or depth at curb,
where
$n = 0.015$ for concrete,
$n = 0.016$ for plant mix, and
Z = reciprocal of cross-slope; for example, if cross-slope is normal crown or 0.02, $Z = 1/0.02 = 50$; then $Z/n = 50/0.015$ or $50/0.016$, depending on the surface.

Find turning point on nomograph by connecting Z/n with slope S. Connect this turning point with discharge Q and extend line to right to determine Y.

ZY = spread

Find Y′ (see drawing) and $x = 1.75$ or 1.5.
Find carryover flow working back on nomograph; carryover Q is determined by connecting previously determined turning point with the value of Y′ just determined, used as the Y value on the right-hand scale.
Flow taken by drain equals total flow Q_1 minus carryover Q_2.
If Q_2 is greater than 15 GPM, locate another drain not less than 10 ft downstream from the first drain, positioned over slope paving or median. For most bridges, the maximum carryover Q_2 from the last drain should not exceed 15 GPM, or 0.033 ft^3/sec. However, there will be situations where this criterion will not be practical and will require independent judgment.

Suggestions for Deck Drain Location.

Not in locations over highway or railroad travel way because piping will be required.
Over medians, water, or slope paving (if over a median, a suitable landing spot for water to eliminate unsightly erosion must be provided).
In low points.
In flat areas.
In areas with minimum carryover.

CALIFORNIA

Basic Concepts

Bridge drainage covers the collection and removal of water from a bridge deck. To accomplish this, drains are placed next to the curbs to collect water, which is then either dumped directly on the ground or conveyed to a suitable disposal point.

Classes of Bridge Drainage

Class I. All locations, usually urban, where drainage must be carried via piping to some suitable disposal point. Short vertical or nearly vertical downspouts to clear girder flanges are not considered to be in this category.

Class II. All locations, usually rural, where drainage may be disposed of by free fall directly under the drain.

Runoff Analysis

Any recognized method of computing quantity of runoff may be employed. A simple and easy analysis is obtained by the rational method, which converts rainfall intensity for the design frequency storm to runoff by the formula

$$Q = C\,i\,A \qquad (1\text{-}A)$$

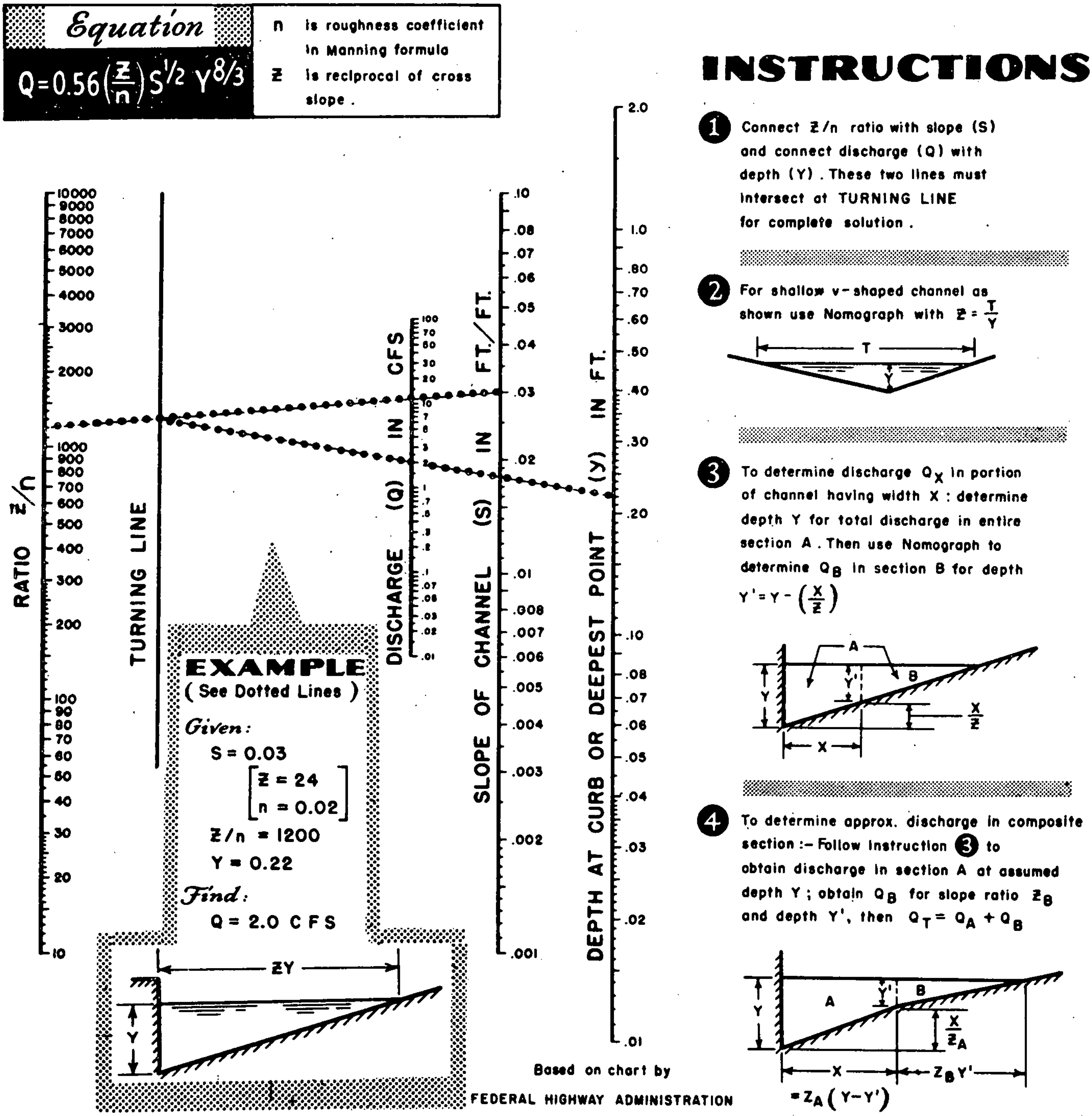

Figure A-1. Nomograph for flow in triangular channels.

where

$Q =$ design discharge in ft^3/sec,
$C =$ coefficient of runoff (1.0 for a paved bridge deck),
$i =$ average rainfall intensity in in./hr for the duration equal to the time of concentration, and
$A =$ drainage area, in acres, to be drained by one inlet.

If precise figures are not available, a reasonable assumption is for a 5-min concentration time and a precipitation rate of 5 in./hr. The formula for Q then becomes $Q = 0.000115\ A$, where $A =$ tributary area in ft^2.

Capacity of Grate Inlets in a Sag

A grate inlet in a sag operates first as a weir roughly equal in crest length to the outside perimeter (P) along which the flow enters. Bars are disregarded, and the side against the curb is not included in computing P. Weir operation continues to a depth (y) of about 0.4 ft above the top of the grate and the discharge intercepted by the grate is

$$Q_i = 3.0\ p\ y^{1.5} \qquad \text{(2-A)}$$

where

$Q_i =$ rate of discharge into the grate opening in ft^3/sec,
$P =$ perimeter of grate opening, disregarding bars and neglecting the side against the curb, and
$y =$ depth of water at grate in ft (average y).

When the depth of water at the grate exceeds about 1.4 ft, the grate begins to operate as an orifice and the discharge intercepted by the grate is

$$\begin{aligned} Q_i &= 0.67\ A\ (2\ g\ y)^{0.5} \\ &= 5.37\ A\ y^{0.5} \qquad \text{(3-A)} \end{aligned}$$

where

$Q_i =$ rate of discharge into the grate opening in ft^3/sec,
$A =$ clear opening of the grate in ft^2,
$g =$ acceleration of gravity, 32.2 ft/sec^2, and
$y =$ depth of ponded water above the grate, in ft (use average y).

Between depths of water over the grate of about 0.4 and 1.4 ft the operation of the grate inlet is indefinite due to vortices and other disturbances. The capacity of the grate lies somewhere between Q_i figures obtained by the two formulas.

Because of the vortices and the tendency of trash to collect on the grate, the clear opening or perimeter of the grate inlet should be at least twice that required by either of the two equations in order to remain within the design depth over the grate. Where the danger of clogging is slight, a safety factor of less than two might be used.

An Example of Drainage Design

The sample structure has the following characteristics:

Deck width between rails of 66 ft (right shoulder of 10 ft, four lanes of 12 ft each, left shoulder of 8 ft).
Structure length assumed infinite. Frame length 750 ft between expansion joints.
Cross-slope at 2 percent or 0.02 ft/ft.
Profile gradient constant at 4 percent or 0.04 ft/ft.
Pavement of portland cement concrete with broom finish, Mannings $n = 0.016$ (roughness coefficients for smooth-textured asphalt, rough-textured asphalt and float-finished PCC are 0.013, 0.016, and 0.014 respectively).

Drainage restrictions are such that no water is permitted to flow over joints or paving notch.

The width of flow can vary, but should not encroach on the traveled way. Where total reception is a requirement, the drain width determines the maximum width of flow. It is free to vary within that limit, provided the grate is capable of handling the flow passing into it as determined by

$$L_b = \frac{V}{2}(y + d_b)^{\frac{1}{2}} \qquad \text{(4-A)}$$

where

$L_b =$ length of clear opening of grate or $= 1.37$ ft for grates in standard drains,
$V =$ mean approach velocity in the width of the grate opening in ft/sec,
$y =$ depth of flow at the curb, and
$d_b =$ depth of the bars making up grate, in ft (2¼ in. = 0.19 ft in this example).

Flow bypassing a given grate will be added to the runoff quantity of the next following drain.

Example 1. For illustrative purposes assume the use of a drain 4 ft wide.

Step 1 Find total flow quantity (Q_T) for a 4-ft width (refer to nomograph in Fig. 1-A).

For $Z/n = 3125$ and $T = 4$
$d = (2 \text{ percent})\ (4 \text{ ft}) = 0.08$ ft,
$s = 0.04$ ft/ft, and
$Q_T = 0.40$ CFS.

Step 2 Check L_b, length of clear opening (use Equation 4-A).

$$\begin{aligned} V &= \frac{Q}{A} \\ &= \frac{0.40 \text{ CFS}}{\frac{(0.08 \text{ ft} + 0.0 \text{ ft})}{2}(4.0 \text{ ft})} \\ &= 2.5 \text{ ft/sec} \end{aligned}$$

$$\begin{aligned} L_b &= \frac{V}{2}(y + d_b)^{\frac{1}{2}} \\ &= \frac{2.5}{2}(0.08 + 0.19)^{\frac{1}{2}} \\ &= 0.65 \text{ ft} \end{aligned}$$

Step 3 Determine drain spacing (use Equation 2-A).

$A = L_d\ W$

where

L_d = length of bridge drained by one drain and
W = width of deck.

Then

$$Q = 0.000115\ A$$
$$= 0.4\ CFS$$
$$= 0.00015\ L_y\ W$$
$$L = (0.4\ CFS)/(0.000115)(66\ ft)$$
$$- 52.7\ ft.$$

Number of drains required — 750 ft/52.7 ft ≅ 15.

Comment. This result is somewhat impractical in that a number of large drains are being used to collect a relatively light flow. If a flow somewhat wider than the drain is used, some of the flow will go on to the next drain and not so many will be required.

Example 2. Flow width — 7 ft. Some water will bypass drain.

Step 1 Find Q_T (see nomograph) for $Z/n = 3125$ or $1/(0.2)(0.016) = 3125$,

where

$$S = 0.04\ y\ \text{(revised)}$$
$$= (2\ \text{percent})\ (7\ ft)$$
$$= 0.14$$
$$Q_T = 1.80\ CFS\ \text{(from nomograph)}$$

Step 2 Find Q′, or flow bypassing grate (use nomograph).

$$d' = (2\ \text{percent})\ (3\ ft) = 0.06\ ft$$
$$Q' = 0.20\ CFS\ \text{(from nomograph)}$$

Thus Q (water intercepted) $= Q_T - Q' =$ 1.60 CFS

Step 3 Check L_b (use Equation 4-A).

$$V = \frac{Q}{A}$$
$$= \frac{1.60\ CFS}{\frac{(0.14\ ft + 0.06\ ft)}{2}(4.0\ ft)}$$
$$= 4.00\ ft/sec$$
$$L_b = \frac{V}{2}(y + d_b)^{\frac{1}{2}}$$
$$= \frac{4.00}{2}(0.14 + 0.19)^{\frac{1}{2}}$$
$$= 1.15$$

= 1.15 ft (just less than 1.37 ft actual opening, a more efficient solution.)

Step 4 Determine drain spacing (use $Q = 0.000115\ A$).

$$Q = 0.000115\ L_y\ W$$

(a) Contributory length to first drain

$$L = \frac{Q_T}{0.000115\ W}$$
$$= \frac{1.8\ CFS}{0.000115\ (66\ ft)}$$
$$= 237\ ft$$

(b) Contributory length to intermediate drains

$$L = \frac{(1.80 - 0.20)}{0.000115\ (66\ ft)}$$
$$= 210\ ft$$

(c) Contributory length to last drain

$$L = \frac{(0.40 - 0.20)}{0.000115\ (66\ ft)}$$
$$= 26\ ft$$

Number of drains required is 5.

First drain is a maximum of 237 ft downstream from the beginning joint. Next to last drain is 26 ft from end of bridge. Last drain is as close as possible to end of bridge. Three intermediate drains will be required.

Comment. In part b of step 4, the flow bypassing the grate causes a reduction in spacing. In part c, the flow bypassing the preceding drain is subtracted from the quantity of flow in a channel 4 ft wide to satisfy the requirement of 100 percent interception.

The advantages of permitting some flow to bypass the deck drain are evident in that 10 drains were saved.

The procedures of this design may be reversed to check drain capacity, width of flow, etc., where spacing has been predetermined to meet other requirements, for example, spacing of bents.

APPENDIX B

CASE HISTORIES

CHICAGO METROPOLITAN EXPRESSWAY SYSTEM

In 1969, an exhaustive inspection and inventory were made of the drainage systems on the expressways in the Chicago area. What was found is probably typical of what might be found in almost any metropolitan area. This experience gives a broad insight into the many-faceted bridge drainage problem (*6*).

The study was triggered by innumerable maintenance problems and was undertaken to determine causes and develop solutions. Each drainage unit was examined and cataloged. Visual inspections with lights were supplemented by hammer soundings on pipes to find out whether they were plugged. Catch basins were opened and checked.

The inlet boxes were of two general designs. Type A had a 17- x 22-in. (430- x 560-mm) grate with seven 1⅜- x 18-in. (35- x 460-mm) openings. The inlet box varied in depth from 3¾ to 5¾ in. (95 to 150 mm) and drained into an 8-in. (200-mm) diameter outlet that reduced to 7 in. (180 mm). Type B had a 20- x 26-in. (510- x 660-mm) grate with sixteen 1¾- x 12½-in. (44- x 320-mm) openings. The inlet box below the grate varied in depth from 2 to 4¼ in. (50 to 110 mm) and drained into a 6-in. (150-mm) diameter outlet.

The material clogging the drains ran the gamut of human and natural debris: wood, rags, cigarette butts, cans, leaves, and large amounts of silt and sand. Most of it originated from vehicles traveling the roadway: from open trucks, from undercarriages, and from littering. Some natural material was probably blown onto the structure by the wind. In some cases, the material found lodged inside the inlet box was larger than the grate openings, and it was assumed that it had been forced through by traffic running directly over the grates.

Many of the inlet boxes were completely filled with debris. In some cases where the piping was plugged, it was found that maintenance crews had disconnected the inlet boxes from the piping system to allow the water to fall directly onto an asphalt surface below. In other cases where the pipes seemed plugged below the ground surface, the cleanout plugs had been removed and left out so the water could escape at ground level.

The following general observations could well apply to most bridge drainage systems:

- Inlets placed at the edge of the shoulder are less susceptible to clogging than inlets placed at the edge of a traffic lane. Also, they are easier to maintain—maintenance crews are more willing to work on them in the less vulnerable position.
- Inlets located in the sags of vertical curves have the greatest tendency to become clogged.
- When more than one inlet box is connected to a pipe system, the tendency to clog is greater than when each inlet box has its own pipe.
- The steeper the slope of the pipe, the less its tendency to clog; vertical is best.
- Ductile and cast-iron pipe systems, because of the inside roughness in the joints at the fittings, have a greater tendency to clog than welded-steel pipe systems.
- Pipe systems outletting into a catch basin within 5 ft (1.5 m) of a pier have a much weaker tendency to clog than systems that outlet into lateral sewers or into catch basins placed farther than 5 ft from the pier.
- There seemed to be no appreciable difference between the tendencies of the 6-in. (150-mm) and the 8-in. (200-mm) pipes to clog.

The investigative team members then made some general comments about the difficulties in their particular systems.

On a heavily traveled elevated expressway (ADT = 208,000) that had no shoulders, maintenance of the drains was especially difficult and dangerous. Consequently, these drains did not get cleaned frequently. In 12 attempts to clean the drains, the maintenance crew was involved in 12 accidents. It is difficult to fault a maintenance crew for lack of diligence under such circumstances.

The maintenance of pipe systems is generally done from the underside of the superstructure. Clogged pipes are cleaned by inserting a high-pressure hose [water jets at 1000 psi (6.9 MPa)] through the cleanouts. This method becomes inefficient when the height of the pipe exceeds 30 ft (9 m).

On one particular elevated expressway, 61 percent of the pipes were not working. To prevent flooding of the roadway, either the cleanout caps of some pipes had been left open or the flanged reducer under the inlet box had been disconnected from the piping to allow water to discharge directly onto the ground below.

In one long [1500-ft (460-m)] stretch of the expressway, 16 pipes had been disconnected or had caps removed to allow water and debris to fall freely onto an asphalt surface under the structure. In one location there were about 140 inlet boxes; of these, 12 had been opened to allow the water and debris to fall freely. The debris that fell from these 12 opened pipes had accumulated in a pile. Over a two-year period, the accumulated debris amounted to 140 tons (130 Mg).

On another expressway, shoulders were provided. These inlet boxes were cleaned more regularly. Nevertheless, 28 percent of the pipes were plugged. In every case where more than one inlet box was connected to a pipe or where the box was at a sag in the expressway grade, there had been trouble. In these areas, the maintenance crews had removed many of the cleanout plugs to let the water escape and not pond on the roadway.

A third expressway of 104,000 ADT had two basic pipe systems: (1) individual piping systems for each inlet box with long-radius elbows to carry the water to a catch basin and (2) a system collecting from two inlet boxes and piped with long-radius curves to a sewer. The first system worked well in all cases, but the second system was sometimes plugged. The expressway had a straight grade with no sags or low points, and only 6 percent of the drains were plugged.

This study gave rise to the following recommendations:

- Elevated structures should be designed wide enough to accommodate a maintenance vehicle on the shoulder. The inlet box should be on the outside of the shoulder.
- A deeper inlet box was recommended (Fig. B-1). Figure 12 shows the drains that were first used. It was also recommended that the grate openings be smaller and have an easily removable secondary screen to filter out the larger debris forced through the grate openings. The overall size of the grate should be increased.
- Each inlet box should have its own system of outlet pipes no smaller than 6 in. (150 mm) in diameter.
- Pipe systems should be as nearly vertical as possible. No bends should be sharper than 45 degrees and should preferably have long-radius sweeps or welded joints.
- Cleanouts should be positioned so that pipe systems can be cleaned from the ground without special maintenance equipment.
- Each pipe system should terminate in a catch basin close to the pipe. Figure B-1 shows the recommended installation details.
- Deck cleaning procedures should be reviewed. Possibly a switch should be made from sweepers that propel much of the debris into the inlet boxes to vacuum cleaners.

Some General Comments on Pipe Systems

In some locations it appeared that the pipe was plugged below the lowest cleanout point. In other cases the stoppage was in the riser pipe near a bend at the level of the pier caps. When a pipe gets plugged, pressure develops and there is seepage through the pipe joints. The only satisfactory preventive measure is periodic cleaning and flushing of all systems.

Where maintenance is not safely feasible, efforts should be made to prevent the entrance of debris into the inlet boxes. This can be done with very narrow grate openings but requires additional street cleaning to get the debris off the roadway.

Larger inlet boxes with a greater spacing between them were suggested. The greater spacing would theoretically increase the quantity of water and improve the flushing action, thus enabling the drains to keep themselves clean better.

Drain pipes should be sufficiently large, with gentle bends and adequate slope to reduce the tendency to clog.

Cleanouts should be provided in sufficient numbers and at convenient enough locations to provide easy access to the pipes.

When a pipe empties into a sewer, there should be a manhole or catch basin with a trap to catch the debris before it enters the sewer.

The maintenance crew should discontinue the practice of mixing sand with salt during snow control operations. The sand creates great difficulties in drains. In cities where only salt is used, reported winter clogging is rare.

Comment: This should not be interpreted as an endorsement of salt in preference to sand.

CALIFORNIA VIADUCT DRAIN STUDY (1961)

The design of drains has been continually changed in an effort to improve them. This study was initiated to evaluate performance and to identify specific maintenance problems. (*7*). The study was made in the San Francisco area at the time of the annual cleanout of all drains on viaducts. Each November, at the end of the dry season, a crew of five, with a watertank truck and small trucks, checks each drain on the viaducts in the area. They remove all debris and flush the drains until they are clear. In 1961, the operation took 20 days for the viaducts then in operation.

On short bridges, the water backed up by plugged drains will run off the ends of the bridges before it becomes a traffic hazard. However, on long viaducts, the water collects on the roads, and ponding can become very serious. If the structure has full shoulders, ponding may be limited to the shoulder area.

The debris consisted of about 50 percent sand and fine silt. Most of the remaining 50 percent was paper products such as cups, newspapers, gum wrappers, cigarette butts, cigarette packages, pieces of cardboard boxes, and match covers and pieces of wood, rags, grain, glass, rope, and metal; remains of emergency flares; rubber; straw; and even some baby mice. Why there should be 50 percent sand and silt is not clear. The decks are not sanded; snow is not a problem. Trucks hauling dirt or sand are few. There are few unpaved roads nearby. However, the quantity of sand and silt seemed greatest after a rain, indicating that most of the material must drop from the undercarriages of vehicles. Wind probably adds some of the dirt.

The other debris (such as wood, grain, or straw) probably drops or blows from passing vehicles. Wood is most often the 2 x 4 or 4 x 4 pieces used to bolster truck loads. On the highway, the wood is soon broken into small pieces by the traffic. Vehicle accidents and litterbugs add their share of debris.

The debris is transported to the inlet box by wind and air currents created by vehicles, knocked in directly by vehicles, deposited by street sweepers, and washed in by the rain.

During the study, two inlet boxes were blocked to see what debris would collect in a 28-hr period. In that time, about 6 in.^{3} (100 cm^3) of sand, grain, cigarette butts, straw, and wood were collected in a 10½- x 10½-in. (270- x 270-mm) opening. A larger, 24- x 24-in. (610- x 610-mm) opening collected 13 in.^{3} (200 cm^3) of similar debris (about 75 percent sand) in 19 hr. The street sweeper did not pass over either drain during this period. The via-

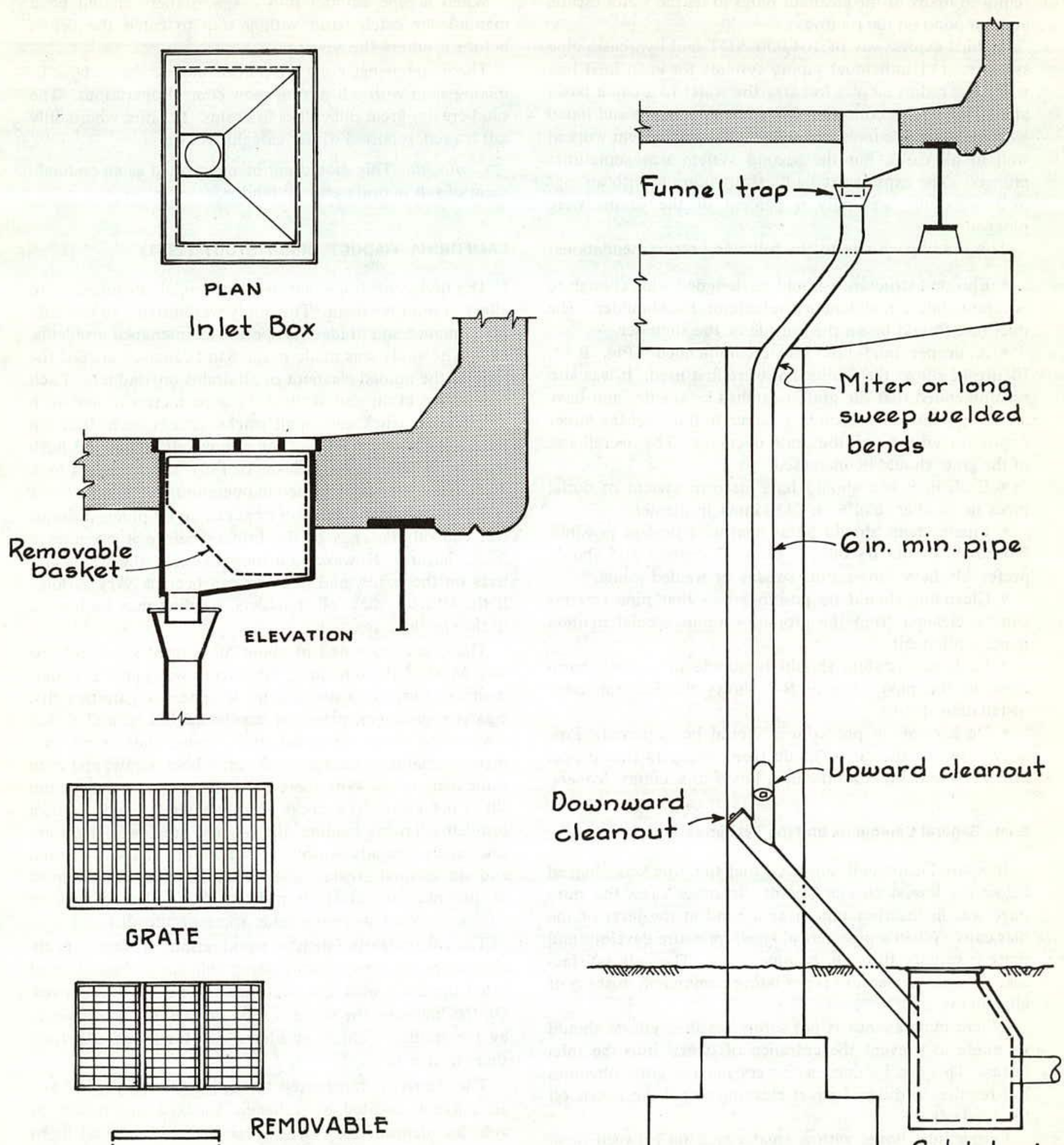

Figure B-1. Chicago pipe system recommendations.

duct gutters are swept twice a week. It was not possible during this study period to determine how much debris sweepers deposit into the inlet boxes.

In all, 148 drains were checked during the study; 113 inlet boxes (77 percent) were completely filled with debris. The study followed two heavy rains, and several drains had either been opened or had opened themselves. Making the study three weeks earlier would probably have revealed even more inlet boxes full of debris.

It is not possible to keep debris out of inlet boxes. Where there is a definite rainy season, the idea of covering the drains during the dry season has been considered, but the weather is not dependable enough to be certain of not getting caught. It was found that a large number of drains, open during the rain, were full of debris and plugged three weeks later.

It is not difficult to clean debris from the inlet boxes but, if it passes into the piping system, its removal becomes more difficult. The solution seems to be to keep the debris from getting into the pipes or to provide a system that can flush itself clean.

Fine sand and silt are the greatest troublemakers. Although individual grains transport easily, as they gather in drains they pack and interlock and become very difficult to move. They act as a filler to the other debris and make a solid plug that ordinary flushing usually will not move.

The location of the outlet pipe in the inlet box is important. When the outlet hole is directly under the grate, it lets a great deal of debris into the pipe. When the outlet opening is in the end of the box, the water must travel across the box and will deposit some of the debris before it runs out into the pipe; with this arrangement, less debris gets into the pipe but, as the box fills, the debris may bridge over the hole and block it.

Observations about inlet boxes revealed that the older designs with smaller grates [8 x 8½ in. (200 x 220 mm)] and longer stretches of relatively flat runs of lateral piping plugged most readily. Larger grates [10½ x 10½ in.

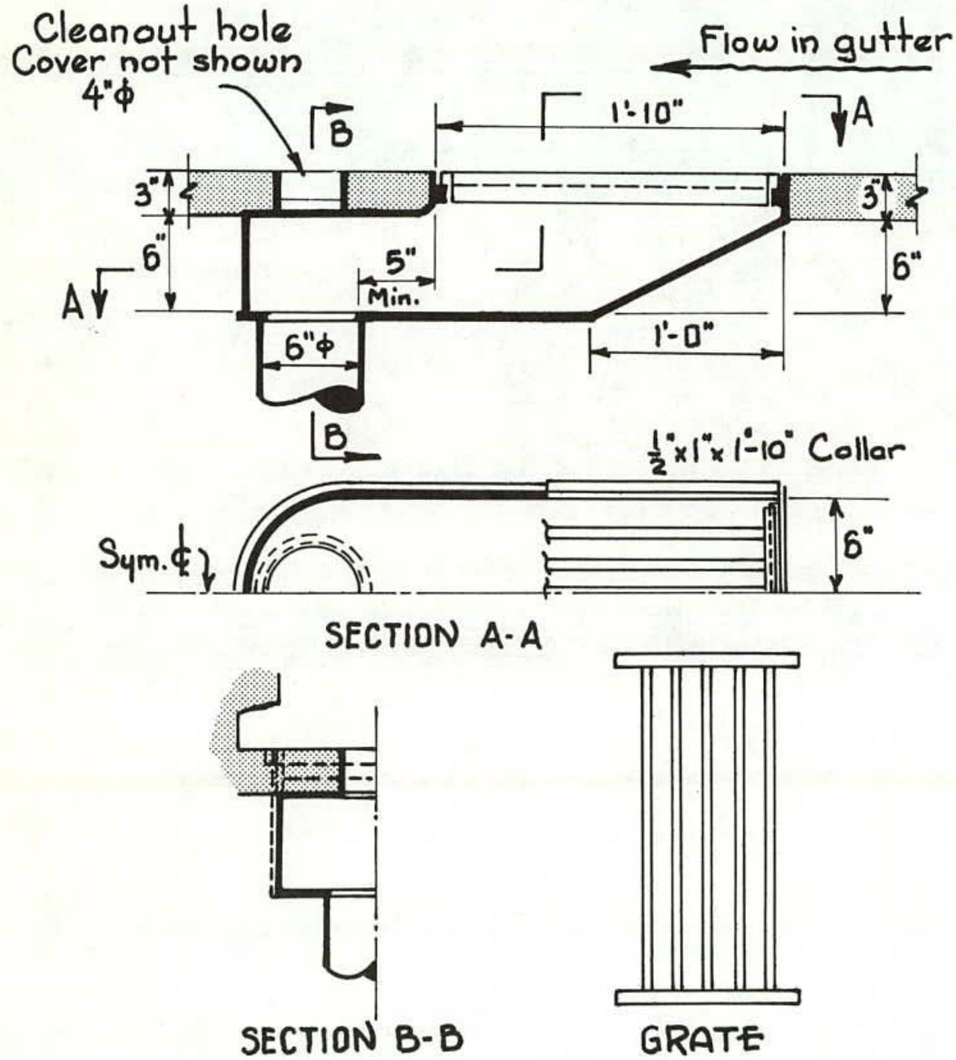

Figure B-2. Proposed inlet box for concrete superstructure (California).

(270 x 270 mm)] cut the amount of plugging about in half. The better drains had large grates [24 x 24 in. (610 x 610 mm)] and mostly vertical piping, and the outlet hole from the inlet box was offset or in the end or wall of the box.

Conclusions from the San Francisco Study

- Open inlet boxes on heavily traveled viaducts will become filled with debris. There is no practical way to eliminate this problem.
- Drains can have outlet holes from the inlet box so the debris can fall directly into the outlet pipe plug very readily. The outlet pipe from the inlet box should be located so no debris can fall directly into it.
- Studies should be made of inlet box design and outlet hole position to determine the best arrangement. Studies should also be made of minimum allowable pipe slope and minimum allowable radius of pipe bends.

SECOND CALIFORNIA HIGHWAY DRAINAGE INLET STUDY (1971)

Ten years after the viaduct study, California made another check of highway catch basins to determine whether a better design could be developed that would produce higher efficiency and lower maintenance costs (*8*). Although much of the study was directed at drainage units used along the highway, certain phases of the study were of interest to bridge designers. The study was directed principally at the cost efficiency of the grate and the box.

Recommendations of the study included the following:

- Heavy cast grates should be abandoned, and a lighter welded design should be used. Although the heavier grates stay in place better, that advantage can be obtained by fastening the grate securely. The welded grates provide a major savings in cost, and their decreased weight makes it much easier for the maintenance crew to remove them and clean the box.
- The practice of galvanizing all of the metal parts is questionable. Galvanizing is costly and does not guarantee protection when it can be abraded. Painting or asphalt dipping were suggested as being cheaper and generally just as satisfactory.
- The recommended inlet box and grate are shown in Figure B-2.

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