Drainage, Drainage, Drainage

The Importance of Drainage On Local Roads

WORKSHOP NOTEBOOK

March 2007

A Workshop Presented by:
UNH Technology Transfer Center - A Cooperative Effort to Assist New Hampshire Towns with Local Transportation Issues –
This notebook was prepared by Peter M. Coughlan and George W. Greenwood, the Director and Consultant respectively for the Maine Local Roads Center. It was intended as a two-day workshop on roadway drainage. The UNH T² Center workshop covers only a portion of the material. The original notebook is furnished to provide a comprehensive reference for participants.

Peter and George wrote the notebook for people from small towns or other small government agencies who are involved in the day-to-day business of maintaining their local road system—councilors, selectmen, road managers or superintendents, elected town officials and volunteers. They described the principles and practices for adequate drainage in the plain everyday language of those doing the work. They left out complex theories, designs, or equations. Most of the material is basic, easy-to-understand and very user-friendly.

Drainage is a concern to any road manager and the contents of this notebook should apply to local officials in any state. Obviously, it is difficult as New Englander’s prepare a useful drainage course than for those folks in Arizona, but we’ve tried to be as generic as possible.
# TABLE OF CONTENTS

## CHAPTER 1. INTRODUCTION
- OVERVIEW ............................................................................................................. 1
- PURPOSE OF THE MANUAL ................................................................................ 1
- SCOPE OF THE MANUAL ...................................................................................... 2
  - Roadway and Drainage Fundamentals ................................................................. 2
  - Causes and Treatments of Drainage Problems ....................................................... 2
  - Cost Control Issue ................................................................................................ 3
  - Wetlands and Erosion Control .............................................................................. 3
  - The Law – Regulations and Tort Liability ............................................................. 3
  - Snow Removal and Drainage .............................................................................. 3
  - Local Operations .................................................................................................. 4

## CHAPTER 2. BASIC DRAINAGE CONCEPTS
- DRAINAGE PRINCIPLES ....................................................................................... 5
- FACTORS AFFECTING ROAD LIFE ...................................................................... 5
- CONTROL WATER CONTENT IN ROAD STRUCTURE ......................................... 7
- HOW WATER ENTERS THE ROAD SYSTEM ...................................................... 8
  - Methods of Cutting Off a Road’s Water Sources ............................................... 8
- POOR ROAD MATERIALS – RECIPE FOR EARLY FAILURE ............................... 11
- SURFACE AND SUBSURFACE DRAINAGE ...................................................... 12
- GOOD ROAD DESIGN BASIC TO GOOD DRAINAGE ....................................... 12

## CHAPTER 3. TYPES AND FUNCTIONS OF DRAINAGE FEATURES
- LIABILITY FOR DRAINAGE ACTION .................................................................. 14
- ROADWAY DRAINAGE FEATURES ................................................................... 15
  - Road Crown ....................................................................................................... 16
  - Road Shoulders ................................................................................................. 16
  - Surface Materials ............................................................................................. 18
  - Ditches ............................................................................................................... 18
  - Curbs and Gutters ............................................................................................. 21
- CULVERTS ............................................................................................................. 22
  - Culvert Shapes ................................................................................................. 22
  - Culvert Materials .............................................................................................. 22
  - Minimum Size .................................................................................................. 23
  - Minimum Cover (Design) .................................................................................. 24
  - Maximum Cover ............................................................................................... 24
  - Spacing Between Multiple Pipes ....................................................................... 24
  - Minimum Slope ................................................................................................. 24
TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Special Design Considerations</td>
<td>24</td>
</tr>
<tr>
<td>Factors Affecting Culvert Life</td>
<td>25</td>
</tr>
<tr>
<td>Sizing of Culverts</td>
<td>26</td>
</tr>
<tr>
<td>Culvert Location</td>
<td>30</td>
</tr>
<tr>
<td>Stream Relocation</td>
<td>33</td>
</tr>
<tr>
<td>Culvert Length and Grade</td>
<td>33</td>
</tr>
<tr>
<td>Improved Culvert Inlets</td>
<td>36</td>
</tr>
<tr>
<td>Inlet Control</td>
<td>37</td>
</tr>
<tr>
<td>Outlet Control</td>
<td>37</td>
</tr>
<tr>
<td>Culvert Headwalls and Endwalls</td>
<td>39</td>
</tr>
<tr>
<td>Culvert Installation</td>
<td>41</td>
</tr>
<tr>
<td>Pipe Load Support Characteristics</td>
<td>41</td>
</tr>
<tr>
<td>Installation Procedures</td>
<td>42</td>
</tr>
<tr>
<td>Excavation</td>
<td>42</td>
</tr>
<tr>
<td>Bedding</td>
<td>44</td>
</tr>
<tr>
<td>Assembly</td>
<td>46</td>
</tr>
<tr>
<td>Backfill</td>
<td>46</td>
</tr>
<tr>
<td>Trenching Safety</td>
<td>48</td>
</tr>
<tr>
<td>Other Topics</td>
<td>48</td>
</tr>
<tr>
<td>SUBSURFACE DRAINAGE</td>
<td>50</td>
</tr>
<tr>
<td>Base Course Gravel</td>
<td>51</td>
</tr>
<tr>
<td>Interceptor Drains</td>
<td>51</td>
</tr>
<tr>
<td>Longitudinal Drains</td>
<td>51</td>
</tr>
<tr>
<td>Laying and Backfilling Underdrains</td>
<td>52</td>
</tr>
<tr>
<td>Hydraulics of Closed Drainage Systems</td>
<td>53</td>
</tr>
<tr>
<td>Catch Basins and Manholes</td>
<td>54</td>
</tr>
<tr>
<td>Closed system</td>
<td>54</td>
</tr>
<tr>
<td>CHAPTER 4. GEOTEXTILES IN ROADWAYS</td>
<td>55</td>
</tr>
<tr>
<td>INTRODUCTION</td>
<td>55</td>
</tr>
<tr>
<td>GEOTEXTILE TYPES</td>
<td>56</td>
</tr>
<tr>
<td>PRIMARY USES</td>
<td>56</td>
</tr>
<tr>
<td>Separation or Stabilization</td>
<td>57</td>
</tr>
<tr>
<td>Drainage</td>
<td>57</td>
</tr>
<tr>
<td>Erosion Control</td>
<td>58</td>
</tr>
<tr>
<td>SELECTING GEOTEXTILES</td>
<td>58</td>
</tr>
<tr>
<td>INSTALLATION TIPS</td>
<td>59</td>
</tr>
<tr>
<td>THREE PRACTICAL USES</td>
<td>60</td>
</tr>
<tr>
<td>CHAPTER 5. TYPICAL DRAINAGE PROBLEMS</td>
<td>62</td>
</tr>
<tr>
<td>INTRODUCTION</td>
<td>62</td>
</tr>
<tr>
<td>DRAINAGE PROBLEMS ON LOW VOLUME ROADS</td>
<td>62</td>
</tr>
<tr>
<td>DIAGNOSTIC AID FOR DRAINAGE PROBLEMS</td>
<td>64</td>
</tr>
<tr>
<td>Table 5-1</td>
<td>64</td>
</tr>
<tr>
<td>CHAPTER 6. MAINTENANCE FOR GOOD DRAINAGE</td>
<td>67</td>
</tr>
<tr>
<td>INTRODUCTION</td>
<td>67</td>
</tr>
</tbody>
</table>
# TABLE OF CONTENTS

PREVENTIVE MAINTENANCE .................................................................67  
MAINTENANCE MANAGEMENT ..........................................................68  
GRADING GRAVEL SURFACES .............................................................69  
PAVEMENT MAINTENANCE .................................................................70  
DITCH MAINTENANCE ........................................................................71  
ROADSIDE VEGETATION CONTROL ...............................................74  
CULVERT MAINTENANCE ....................................................................74  
  - Culvert replacements vs. liners ....................................................77  
  - Winter preparation ........................................................................78  
BRIDGE MAINTENANCE .....................................................................78  
FLOOD-PROOFING YOUR ROADS -- BEFORE, DURING AND AFTER ....78  
  Emergency Route Planning .............................................................79  
  Road Crew Safety ............................................................................79  
  Floor Proofing Techniques ..............................................................80  
  
CHAPTER 7. WORKER SAFETY – ON THE ROAD AND IN THE TRENCHES 92  
INTRODUCTION ....................................................................................92  
WORK ZONES FOR SAFETY ...............................................................92  
RESPONSIBILITY ................................................................................93  
REQUIREMENTS FOR SAFE WORK ZONE TRAFFIC CONTROL .........94  
  Sign Spacing ....................................................................................95  
  Delineation ......................................................................................95  
  Worker Safety .................................................................................97  
PREVENTING SUCCESSFUL TORT CLAIMS ......................................97  
  Traffic Control Plan .........................................................................98  
APPLICATION OF STANDARDS .........................................................98  
CONCLUSIONS ....................................................................................99  
SAFETY IN THE TRENCHES ...............................................................100  
  Trench Excavation ..........................................................................100  
  Myths Exposed .................................................................................101  
  Excavating Hazards ........................................................................102  
  New Rule Needed ............................................................................102  
  Terms Redefined ............................................................................102  
  Engineer Required ..........................................................................103  
  Causes of Cave-Ins ..........................................................................103  
  Competent Person ..........................................................................104  
  General Requirements ....................................................................104  
  Protective Systems ...........................................................................106  

APPENDIX A: CULVERT INSPECTION AND REPAIR ............................107  
REFERENCES CITED ........................................................................110  

BIBLIOGRAPHY .................................................................................112
1. INTRODUCTION

- Local Operations

OVERVIEW

DRAINAGE

DRAINAGE

DRAINAGE

“The three most important factors which affect the life of a road.” Without good drainage, the best of construction methods and materials would be wasted.

Roadway departments across the country spend over 25 percent of their highway construction dollars on road drainage. The importance of providing good drainage should be obvious. Too much surface water can weaken a roadbed resulting in rutting, alligator cracking, potholes, edge cracking, shoulder erosion, side slope and ditch washouts, clogged culverts, and hydroplaning. Water flowing too slowly deposits sediment and clogs channels and culverts. Standing water can weaken the subbase and hasten surface failure. It almost seems like a “no win” situation. But wait, it can get worse when you include freezing temperatures!

Water expands when it freezes and the resulting pressure is strong enough to cause the earth to swell and pavements to heave. As long as the roadbed remains frozen there is no problem because ice can carry heavy loads. But when it thaws, subgrades become saturated and mushy and heavy wheel loads cause damage. For each freeze-thaw cycle, the damage becomes worse.

Every engineer is expected to know that good drainage is the most important part of roadway design and maintenance. Yet, the lack of recognition of poor drainage, of poor soil support conditions, and of frost susceptible soils is a common occurrence and will lead to billions of dollars being spent to repair U.S. roads. It is too bad that so much money will be wasted when the use of inexpensive routine and preventive maintenance practices by roadway crews could save thousands in repairs.

PURPOSE of the MANUAL

The purpose of this manual is to help local road officials who have little or no technical background or experience in local road matters to understand:

1) what kinds of road/street problems can result from poor drainage,
2) how easy it is to waste road money by not following good drainage practices, and
3) how to prevent many of the problems caused by poor drainage conditions.

It is not an objective of this document to appeal to all areas of the country equally. To attempt such a goal would result in a “watered down” publication that would be so generic as to be of little value to anyone. If there is any bias, it is toward those parts of the country
1. INTRODUCTION

where snow, ice and freezing temperatures are common place. These topics should be omitted where they are inappropriate.

This notebook is for people who supervise small highway departments, who work on road crews, or are otherwise involved in maintaining public.

There is a clear need to have information presented in plain everyday language. We intend to present this information without complex theories, designs, and formulas. Since our goal is to provide the best roads possible in the most cost effective manner, it is important that we start with the basics.

SCOPE of the MANUAL

These pages will cover aspects of roadway drainage on public ways that are important to small governments. If these entities can learn to control the runoff of water by using good drainage practices, the life of the supervisor and road crew can be relatively simple and pleasant. If they can’t take the time to learn or if they continue to ignore the problem, it won’t go away. Instead, it will likely become a continuing and expensive problem. Good road work carefully done is expensive but reacting to one crisis after another can destroy a budget in a hurry. There is no place for waste in a roadway budget.

Topics to be discussed include, but are not limited to, the following:

Roadway and Drainage Fundamentals

Basic to any good public way is proper design, construction, and maintenance. Roads properly designed and constructed cost less to maintain and result in a happier public. Understanding and practicing drainage fundamentals is one of the most important parts of a successful road system.

Causes and Treatments of Drainage Problems

The roadway conditions that result in poor drainage generally fall into categories such as

- poor base soils,
- insufficient ditches,
- no crown,
- “leaky” road surfaces, and
- frost susceptible materials.

Road managers, read the road defects as symptoms of an underlying problem. Analyze the symptoms, and diagnose and treat the cause of the defect. In many cases, symptoms are spotted before the defect becomes serious, and corrective actions can usually be applied to typical problems with good results. Managers can predict what will happen when a culvert is plugged, a ditch is clogged, or a road surface becomes porous, and act accordingly. Remember that a culvert left partially plugged may end up clogging a ditch, saturating the base, and
1. INTRODUCTION

causing the road surface to fail. Recognizing potential problems before they occur is probably the best corrective action one can take.

Cost Control Issues

It is rare to find a road manager who has not faced a shrinking budget coupled with increased demands from the public. It is necessary to look at every job in the most cost effective manner. Controlling tight budgets, especially in the area of purchasing, is important. Equally as important, as planning, is doing each job with a continued emphasis on saving money. Work toward completing long range goals usually represents the best opportunity for savings, but sometimes entire projects must be completed as quickly as possible. The extra short-term costs may mean not achieving original long range goals as quickly as planned, but completing a job one stage at a time is a good way to spread the cost out over several budgets and perhaps allow you to keep more than one major project going at once. It also keeps the public happy when they see work being done on their road.

Wetlands and Erosion Control

It is necessary to know what wetlands are, how they contribute to the environment, how they interrelate with roads, and what problems you can run into when you mix road work and wetlands. Whether excavating, filling, or doing regular maintenance work, erosion control is important because nearby wetlands may be affected. The possible damaging effects of road work needs to be recognized and avoided. It is important to secure proper permits.

The Law – Regulations and Tort Liability

Knowing how the law is essential to a well run organization. Compliance with environmental laws is aggressively enforced. Road hazards that exist and aren’t fixed, or work performed on a public way that creates a hazard, may result in tort claims for damages and/or injuries. Working within and adjacent to public rights-of-way can often result in conflicts with land owners. If the bottom line is the best job for the least money, then it is essential to avoid the high costs and lengthy time delays that are part of legal suits and court action.

Snow Removal and Drainage

Snow removal and drainage is a little like the “chicken and the egg.” Do you get the snow off and away from the road to improve drainage or do you improve drainage to make it easier to get rid of snow and ice? No matter, it works either way!
1. INTRODUCTION

Get the snow off and away from the road improves drainage and decreases the amount of infiltration into the roadbed and allow the surface to dry out. Improve drainage with wide ditches, crowned traveled ways and shoulders, and a smooth compact riding surface makes it easier to get rid of snow and ice. Erosion caused by the melting roadside snow banks can be a particularly troublesome problem. Less sand reduces shoulder, ditch, and vegetation maintenance and less salt reduces the risk of polluting adjacent property.

Local Operations

The goal is to properly design and maintain the roads, the realities of too little time and too little money may require that we get there in stages with whatever resources are at hand. The only available means of compacting the backfill during a culvert installation may be with a homemade hand tamper. A powered compactor would work better and be easier to use, but the hand tool will give a better job than no compaction at all.

Ditch work is often done without properly shaping backslopes because time and money are limited. However, ditching a mile of road in this manner instead of doing 1000 feet by strict engineering standards maybe more important initially. It affords drainage protection to five times more of the road system and should reduce some of the maintenance costs. But remember, the savings will accrue only when municipalities continue to maintain the ditch, do the backsloping work, and protect the project with seeding as time and money become available. Otherwise, the early occurrence of erosion, siltation, and finally failure of the ditch and associated culverts can make it much more expensive than it would have been to ditch the 1000 feet correctly in the first place.

Spread the cost of road construction or maintenance work over an extended period of time. Do work in steps or stages. There is more than one way to get a good job. It requires understanding, ingenuity, careful planning and doing good quality work while keeping a careful eye on the bottom line.
2. BASIC DRAINAGE CONCEPTS

DRAINAGE PRINCIPLES

There are several basic truths or principles that come to mind when you think about roadway drainage. Many of them are self explanatory, for example:

- Water runs downhill
- Gravity is cheaper than plumbing
- Erosion depends on how fast the water flows
- Erosion problems are easier to prevent than fix
- Puddles mean problems

FACTORS AFFECTING ROAD LIFE

There are five major factors that affect the ability of a roadway to survive and serve the needs of the traveling public over a long and useful life.

1) Traffic loads. Road damage depends more on the number and weight of heavy trucks than it does on the number of lighter vehicles using the road. A figure often quoted is that one 80,000 pound truck does as much damage as 9600 cars.

2) Subgrade quality. Because roads have to depend on the natural ground or build up embankments for support, the quality of the available materials can greatly influence road performance and life.

3) Workmanship and construction practices. The best of materials is of little use unless good construction practices are used along with high standards of workmanship.

4) Maintenance program. From the day it is built, a road requires routine and preventive maintenance on a regular basis.

5) Water. It is said that 80 percent of existing roadway problems can be traced to the presence of water from poor drainage either in or on the roadway. Figures 2-1 and 2-2 illustrate the effect of heavy wheel loads on a water soaked subgrade below an asphalt pavement.
2. BASIC DRAINAGE CONCEPTS

The amount a pavement deflects is strongly related to the amount of moisture in the subgrade. If the subgrade soils are wet, there can be a great deal of deflection under the wheel loads. The deflection will be much less for the same soil when it is dry.

Water is only one of the five factors mentioned above. But, if it were not for the presence of water in the roadway, all four of the other factors would either be eliminated or be much less of a problem.
2. BASIC DRAINAGE CONCEPTS

CONTROL WATER CONTENT IN ROAD STRUCTURE

Proper roadway drainage is absolutely critical if we expect roads to stand up to the damaging effects of weather and traffic. *Long-term trouble-free roads cannot be built without providing good drainage.* However, not all water is bad for a road.

<table>
<thead>
<tr>
<th>POSITIVE EFFECTS OF WATER</th>
<th>NEGATIVE EFFECTS OF WATER</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Helping to get good compaction;</td>
<td>• Softening and reducing the load carrying ability of subgrades and shoulders;</td>
</tr>
<tr>
<td>• Establishing and maintaining vegetation for erosion control;</td>
<td>• Increasing the disintegration of pavements and gravel surfaces;</td>
</tr>
<tr>
<td>• Working gravel road surfaces;</td>
<td>• Eroding roadside surfaces;</td>
</tr>
<tr>
<td>• Providing dust control; and</td>
<td>• Depositing sediment and debris in ditches, pipes, catch basins and waterways; and</td>
</tr>
<tr>
<td>• Cleansing the pavement surface.</td>
<td>• Contributing to frost heaves and spring break-up.</td>
</tr>
<tr>
<td></td>
<td>• Creating driving hazards for motorists.</td>
</tr>
<tr>
<td></td>
<td>• Damaging adjacent property.</td>
</tr>
</tbody>
</table>

Control and/or elimination of the water that contributes to these types of roadway damage is the primary reason for establishing a drainage system in the first place. The critical need to prevent costly road repairs caused by too much water can be plainly stated in the form of another basic drainage principle.

However, it is unfortunate but true, many officials in small governments and many road supervisors still can’t bring themselves to plan ahead, to look beyond today’s “bottom line,” and spend some of the town’s limited road money on drainage now in order to save many more dollars later.

The principles of good drainage are the same for gravel or dirt roads as they are for paved roads. There may be a need to shift emphasis or change procedures a bit to fit specific conditions but the goal remains the same. Regardless of the approach, keeping water out of the road system is the result we’re after.

The least expensive and most effective way of doing this is with good design and construction methods. When this is not possible, as is often the case with older roads, maintenance crews should work toward correcting the deficiencies on a step-by-step basis.

“A dollar spent on constructing good drainage systems will save more than twice that amount in reduced maintenance fee.”
How Water Enters the Road System

The analogy is often made between a roadway and a building. The subgrade represents the basement, the subbase is the first floor and the road surface or pavement represents the roof. It easily follows that the entire system, roadway or house, should be built with the best materials, workmanship and design techniques available. No one part should be poorly built at the expense of the other two. It would be a waste of money.

However, this situation often happens in the case of roads and road maintenance. The road surface seems to get most of the attention from citizens and road officials. The result is that the “roof” gets patched when the real problem is a “leaky basement.”

In real life, a roadway is exposed to more damaging attacks from water and other weather conditions than the house is. And the road structure doesn’t have insulation wrapped around it and a nice warm furnace inside to protect it from freezing winters and hot summers.

Figure 2-3. Ways Moisture Gets into the Roadbed

Methods of Cutting Off a Road’s Water Sources

√ Lowering the ground water table.
Some roads are built at or very close to the natural ground water table. In addition, seasonal changes in the water level after heavy rains are to be expected. In cases where the road grade can’t be kept above the ground water table, interceptor drains or lower ditches may be needed to draw down the water level under the roadway. The use of free-draining embankment gravel will be necessary to prevent drawing moisture up into the road structure.

√ Reduce hydrostatic pressure.
Another way water can enter the road system is by hydrostatic pressure. Water builds up pressure as it travels down hill in the form of an underground spring. When the roadbed or ditches of a road come close to or intercept the underground water, the water is no
2. BASIC DRAINAGE CONCEPTS

longer confined and pressure causes it to push upward into the road and ditches. Some type of interceptor drain is needed to cut off the downhill seepage or flow.

√ **Minimize water vapor movement with good soils.**
Water, in the form of moisture vapor, moves upward from warmer soil areas to cooler soil areas. Moisture also flows downward from the warm surface of a pavement to its cooler underside at night during the summer time. So in northern zones in the United States there is a natural tendency for moisture vapor to flow downward in the summer and upward in the winter. The result could be saturation of the roadway structure below the pavement layer, especially if there are excess fines which will wick up this moisture.

√ **Remove water penetrating the surface.**
Surface runoff entering through cracks in the pavement or soaking through the shoulders is a common source of water problems. This source can usually be kept to a minimum by sealing surface joints and cracks and by keeping the shoulder shaped up to promote rapid runoff.

√ **Prevent frost heaves.**
Frost heaves can be a major problem in colder climates. The heaving results from the formation of ice lenses in wet soil when freezing temperatures drive the frost line below ground. There must be three conditions present before frost heaves can occur.

1) Water must be in the soil;
2) The soil must be a fine-grained frost susceptible type; and
3) There must be freezing temperatures.

*If any one of these three factors can be eliminated, frost heaves will not happen.* Freezing temperatures are a fact-of-life in northern climates so we can forget about trying to get rid of the cold. If the soils are fine-grained silty materials, *it is an accepted fact that water cannot be removed by any type of drainage system.* The only way to correct this problem is to take out the silty soil down to the frost line and put back some free draining material.

Figure 2-4 shows how water is pulled up from the water table to form ice lenses. The water is pulled up by capillary tension in much the same way as kerosene rises in the wick of a kerosene lamp.

Water will freeze in the large voids first. Then water will continue to rise up through the smaller openings, allowing ice lenses to form.
Figure 2-4 shows that the height of frost heave will be equal to the thickness of ice lenses. The depth of frost penetration is dependent upon a number of things, the most important of which are air temperature, amount of sunshine, surface, snow cover, soil type, and moisture content.

**Figure 2-4. ICE LENSE FORMATION AND CAPILLARY RISE IN A SOIL**

Table 2-1 illustrates how water can be drawn upward for considerable distances in different soil materials. *Note that the fine-grained soils are the trouble makers.*

**TABLE 2-1: HEIGHT OF CAPILLARY RISE**
2. BASIC DRAINAGE CONCEPTS

POOR ROAD MATERIALS – RECIPE FOR EARLY FAILURE

The basic drainage concepts noted previously refer to a variety of important subjects, many of them overlapping to some degree. For example, the need to somehow manage the presence of water for the ultimate good of the roadway is a common theme.

Water can:

- weaken the roadbed,
- erode embankments,
- be a driving hazard, and
- destroy roads in the spring.

**Gradation** of material is the measure of the proper aggregate to use in the base and sub-base. Gradation is the distribution of the particle sizes from the coarsest to the finest and the proportion of material on the fine end of the scale is most often the problem.

“Fines” are dust-sized particles of silt and clay that can attract and hold any moisture. If fines are present, the water is trapped and will not drain. Too much trapped water makes the material spongy and soft, robbing it of its load-carrying strength during much of the year. The freezing temperatures of the winter season turn the excess moisture into frost heaves and the road surface inevitably breaks up in the spring thaw.

The type and gradation of soil available for road building in areas where frost penetration is a problem varies widely. No single set of specifications will satisfy everyone’s needs but the basic problem is still the same. What percentage of “fines” is OK in a road base or sub-base and how much is too much?

The best source for this information is likely the New Hampshire Department of Transportation or the UNH Technology Transfer (T²) Center. For example, in New Hampshire, most local governments who are aware of the need to use gravel with a certain range of particle size, would look to the New Hampshire DOT “Standard Bridge and Highway Specifications” for details. Acceptable material might contain particles ranging from up to six inches in diameter to dust size. They would also find that good road material needs components of gravel, sand and fines (silts/clays) in proper proportions for use as a surface, base or subbase material.

The specifications would also state that: up to five percent (5%) by weight of fines is acceptable in base gravel, up to seven percent (7%) by weight of fines is acceptable in subbase gravel and seven to twelve percent (7% - 12%) of fines is acceptable in untreated surface gravel.

The NHDOT specifications for basecourse (see CD in back of manual) contain a more thorough discussion of roadway aggregate. It explains how gravel is separated into its different size particles to show the gradation of the material. The separation is done by shaking the sample of material through a set of sieves with each sieve having smaller openings than the
2. BASIC DRAINAGE CONCEPTS

preceding one. Compare this information to acceptable gradations shown in the specification manual. This information indicates the quality of your material and when to apply your own quality control to help prevent early road failure. The use of free draining, non-frost susceptible road soils is an important factor in extending useful road life.

SURFACE AND SUBSURFACE DRAINAGE

There are two main kinds of drainage: *surface* drainage and *subsurface* drainage.

*Surface* drainage includes collecting and removing all the water that is draining from the roadway surface, side slopes, and adjacent properties. This runoff should be intercepted and carried to the existing drainage systems and waterways.

*Subsurface* drainage is provided to drain water that has gotten into the pavement structure by any of the ways shown previously in Figure 2-3.

Subsurface water can be grouped in three general forms:

- Free water that “leaks” downward into the roadway substructure;
- Water vapor flowing up through he soil due to differences in temperature; and
- Capillary water which is pulled up through fine-grained soils by capillary action.

Unfortunately, many roads and streets in small government locations have not been designed by an engineer. Most of them have been “upgraded” over time but the substructure is often weak, rights-of-way are narrow and drainage is poor. Nevertheless, *some expensive subsurface drainage methods can be cost-effective in the right places.*

GOOD ROAD DESIGN BASIC TO GOOD DRAINAGE

Proper roadway design is basic to good roadway drainage. A few local road departments have the luxury of working with many “engineered” roads or streets.

This manual includes frequent comment on design and maintenance of the road components that contribute to good drainage. There are many more design factors that can’t be ignored. Examples of some of these other design considerations include:

- Design speed
- Grades on hills
- Sharpness of curves
- Superelevation of curves
- Sight distances needed for safe stopping and passing
- Traffic loads and road load carrying strength
- Type of road surface
2. BASIC DRAINAGE CONCEPTS

- Skid resistance for safe operation

*Without question, good drainage is probably the most important single factor leading to maintenance and long life of roads.*
INTRODUCTION

This chapter discusses roadway features and materials which help to control the flow of both surface and subsurface water. Local governments want to avoid damage because it costs money to repair. On the other hand, lack of knowledge about proper drainage practices or failure to follow them can cost money also, maybe lots of it!

LIABILITY FOR DRAINAGE ACTION

Liability is one of the major concerns facing any government agency or individual who is believed to have “deep pockets.”

The law can vary considerably from place to place. Generally, the owner of a roadway is responsible for the drainage and discharge of water from and onto adjoining properties. A road department has to provide drainage by building ditches, putting in culverts and building embankments. This responsibility is an artificial collection of surface water and can result in changing the natural drainage patterns. Care should be taken to ensure that collected water is not discharged in such a way as to cause damage to an adjacent property owner.

The previous paragraph refers to the proper handling of surface runoff but the problem doesn’t stop there. If an owner (or the road department) makes any change (installs a culvert, diverts the flow, changes the water level and/or the velocity or makes other significant modifications) in a brook, stream, river or other natural watercourse that causes damage to another property owner, that action might end in court. Check State and local laws to handle drainage responsibilities legally. A brief review of the basic concepts from which most drainage laws are derived may be of help in this respect.

Seventeen states currently operate under the ENGLISH COMMON LAW concept which presumes that the water is a “common enemy” and each property owner is justified in protecting their property from the flow of water from a higher elevation. In turn, the owner of the higher land cannot improve the drainage in such a way to cause the flow of additional water onto the neighbor’s land.

This concept is followed by: Arkansas, Connecticut, Indiana, Kansas, Maine, Massachusetts, Missouri, Nebraska, New Hampshire, New Jersey, New Mexico, New York, Oklahoma, South Carolina, Virginia, Washington and Wisconsin.

Fourteen states follow a natural drainage concept derived from ROMAN CIVIL LAW. Here the owner of the higher land may make improvements to speed up the drainage of his property so long as the point of discharge onto the adjacent property is not changed from the natural outlet of the area. Any changes to this requirement must be reached through mutual agreement, just compensation, or the like.

Other states follow a third rule developed as a result of modifying the common enemy concept and the natural drainage rule by legislative action. It is somewhat of a compromise between the two basic concepts and is known as the “REASONABLE-USE” RULE.
allows the owner of the land to make a reasonable-use of it even though changing the flow of
the surface drainage may cause injury to adjacent lands. Liability for this injury occurs only
when the interference with the normal flow of the surface water is believed to be “unreason-
able.” What is determined to be unreasonable has to be established for each individual set of
circumstances.

In addition to the common law arising out of court interpretation of the customs of the
locality and times, there are the additional complications rising out of codes and ordinances
passed by counties and local governments and the statutes and regulations put forth by
states. Local officials must be familiar with the state and local laws pertaining to drainage
in their jurisdiction in order to avoid unnecessary litigation.

ROADWAY DRAINAGE FEATURES

The cross-sectional shape of a roadway is designed to meet the needs of traffic and for
the purposes of providing good drainage. All of the cross-section elements are there to help
get water off and away from the road as quickly as possible.

This section discusses these elements in addition to other features and devices that con-
tribute to the overall purpose of road “drainage, drainage, drainage.”

The figure on page 3-4 provides a ready reference for much of the following discussion.
The figure illustrates desirable minimum widths and slopes for a low volume gravel road. It
also shows the common terms for the basic parts of the roadway substructure. It also in-
cludes the same kind of information for a low-volume asphalt paved roadway.

In the following sections we will look at commonly employed methods of draining sur-
face water and ground water away from roadways.

Surface drainage is the control and disposal of surface water caused by direct rainfall,
melted snow, or surface runoff from areas adjacent to the road surface. Factors which make
it easier to get rid of road surface water include:

- pavement surface as waterproof as possible
- crowned and smooth road surface to allow water to flow freely
to the pavement edge,
- shoulder flush with the pavement and smooth to hasten the free
flow of water away from the pavement edge and across the shoulder
to the side ditch in cut sections or the downslope of fill sections
- side ditches and culverts to carry water away from the roadway to a
natural drainage channel, and
- curbs and gutters where needed.
3. TYPES AND FUNCTIONS OF DRAINAGE FEATURES

**Road Crown**

The roadway crown provides drainage flow to the side of the pavement. On curves, the outside edge of the road is raised (superelevation) moving water across the pavement to the lower side. On straight sections the height of crown should be sufficient to cause storm water to reach the edge of the roadway or gutters quickly. Gravel surfaces require the most crown of all. Minimum recommended values for both paved and gravel roads are given on page 3-4.

Note that gravel surfaces require a cross slope between 1/2 inch and 3/4 inch per foot of lane width. These steeper slopes help to eliminate potholes on unsurfaced roads by removing the surface water as rapidly as possible without eroding the surface or creating traffic hazards. Chemical treatments (i.e. calcium chloride) help to compact the surface and prevent water from seeping into the base. When specifying crowns, remember that while they help minimize water ponding, cross slopes that are too steep are objectionable to driving comfort and safety and can make it difficult to remove snow in the winter.

**Road Shoulders**

Road shoulders serve a number of useful functions. They transfer water accumulated on the traveled portion of the road to the sideslope and ditch; serve as a safety zone and parking area for motorists; help to support the road surface; and help to separate the traveled way from sideslopes and ditches. They also act as collectors of winter sand and debris removed from the traveled way. Paved shoulders either continue at the same cross slope as the traveled way or a slightly steeper slope. Unpaved shoulders are sloped at about twice the rate of the traveled way and often consist of less suitable material than the traveled way. This sometimes results over a period of time as winter sand and debris accumulate, or as ditches are maintained. The use of shoulder materials such as crushed gravel and calcium chloride can improve drainage, decrease erosion, and lessen the amount of water entering the base.
### Average Daily Traffic (vehicles/day)
- 0-50
- 50-200
- 200-750
- 750-1500
- 1500 & over

### Pavement Width (feet)
- 18 (min.)
- 20
- 20
- 22
- 24

### Shoulder Width (feet) (Note 1)
- 2
- 2
- 4
- 4
- 8-10

### Center of Road to Ditch Line (feet)
- 15
- 16
- 18
- 19-21
- Varies

### Cross Slope of Roadway
- 4%
- 3%
- 2%
- 2%
- 2%

### Wearing Surface Type (Note 2)
- Gravel
- Double chip seal or HMA
- Hot mix asphalt
- Hot mix asphalt
- Hot mix asphalt

### Wearing Surface Thickness (inches)
- 3
- Varies
- 1 ½
- 2
- 2

### Wearing Surface Specification (Note 3)
- UNH T² Handout
- UNH T² Handout or Type C
- Type C
- Type B
- Type A

### Pavement Base Thickness (inches)
- 3
- 3
- 4
- 4
- 6

### Pavement Base Specification (Note 3)
- Type F
- Type E
- Type D

### Crushed Gravel Thickness (inches)
- 3
- 4
- 4
- 6
- 6

### Crushed Gravel Specification (Note 4)
- NHDOT 304.3
- NHDOT 304.3
- NHDOT 304.3
- NHDOT 304.3
- NHDOT 304.3

### Gravel Thickness (inches) (Note 5)
- 12
- 12
- 12
- 12
- 18

### Gravel Specification (Note 4)
- NHDOT 304.3
- NHDOT 304.3
- NHDOT 304.3
- NHDOT 304.3
- NHDOT 304.3

**Notes:**
1. For average daily traffic over 1000 vehicles/day, paved shoulders should be considered.
2. Gravel surfaces should be paved where steep grades occur.
3. “Type” is defined in Section 401 of NHDOT *Standard Specifications for Road and Bridge Construction*.
4. “NHDOT 304.3” is defined in Section 304 of NHDOT *Standard Specifications for Road and Bridge Construction*.
5. Gravel base course thickness should be increased in areas of poor soils.
3. TYPES AND FUNCTIONS OF DRAINAGE FEATURES

Surface Materials

In order for a **gravel-surfaced road** to shed water properly, it should have a tight, impermeable surface. This calls for a higher percentage of “fines” than the base gravel under an asphalt pavement. Surfaces with a small amount of fines don’t have enough “binder” to hold the surface together when the weather is dry. As the surface falls apart, the loose material is thrown to the shoulders and ditches by traffic. Ruts, corrugations and potholes then appear. The NHDOT specifications for basecourse materials (see CD in back of manual) have a more thorough discussion of “Roadway Gravel.”

*Under average traffic volumes a typical untreated gravel road will lose at least an inch (1”) of surface per year or about 500 tons per mile*

Hot mix surfaces have a dense surface that prevents the entry of surface water into the subbase materials, so long as cracking does not occur.

Cold mixes tend to be less dense than hot mixes and therefore may allow more surface water to penetrate. It is common practice in some states to use a sealcoat to reduce infiltration. Steeper cross-slopes are sometimes used to speed up the surface runoff to the ditch line.

Ditches

Ditches are used to collect and disperse surface water in a controlled manner. They also assist in the drawdown of groundwater under conditions such as is shown in Figure 3-2. The “old water table” line represents the level of the water table after the roadway was constructed and the ditches built.

![Figure 3-2. Using a Ditch to Lower the Water Table](image)

**FIGURE 3-2. USING A DITCH TO LOWER THE WATER TABLE**

There are two main types of ditches used in roadways -- the *side ditch* and the *diversion (or berm) ditch*.

The *side ditch* collects the drainage from the in-slope and backslope and conducts it to a point where it can be carried under the roadway or away from it, depending on the layoff the
natural drainage. To a limited extent, ditches also serve to conduct subsurface drainage from beneath the roadway to points where it can be carried away from the road. **A ditch is the simplest, cheapest, and most efficient method of handling surface water.** It gathers and discharges runoff from the highway right-of-way to the natural drainage system. Done properly, this removes the runoff from the site quickly and thereby reduces seepage into the subgrade.

Side ditches or channels should be safe for vehicles, blend into the natural terrain, be pleasing in appearance, and dispose of collected water without damage to the abutting property.

The three basic types are V-ditch, parabolic ditch (rounded bottom), and trapezoidal ditch (flat bottom).

The grade of roadside ditches should have a desirable minimum slope of 1.0% and should never be less than 0.5%.

The depth of roadside ditches is important. The goal is to keep water out of the roadway gravel, so the bottom of a ditch must be lower than the bottom of the adjacent road gravel. If the depth of gravel is unknown, yet it appears shallow, then the ditch should be a minimum of 18 inches lower than the shoulder. Some road departments tend to dig too deeply and create canals or deep trenches. This practice creates a greater potential for ditch erosion and sloughing, and a serious safety concern for motorists. A motorist who becomes injured because of crashing into a “canal” could claim to be a victim of a highway “defect” which is a hazard to the motoring public.

**Berms (earth dikes),** diversion ditches or a combination of both may be located along the top of back slopes. Their purpose is to intercept the surface runoff from the slopes above, reducing the likelihood of erosion, and conduct it to natural water courses on milder slopes. Much of the surface water originating on the higher slopes can be intercepted and carried to an outlet beyond the cut. This not only reduces the volume of flow that has to be carried in the roadside drainage system, it also protects the cut slope from excessive runoff and greater erosion problems.
The *velocity* and *volume of water* in side ditches determines the type of lining to use. If water flows too slowly, sedimentation will occur and the ditch will have to be cleaned more frequently. On the other hand, too rapid flow will cause erosion and unnecessary maintenance. Table 3.1 shows maximum allowable velocities for a variety of ditch linings. (6) These velocities assume that the fully developed or constructed linings are in place. In general, the type of lining is selected based on the steepest grade of the channel or ditch.

Check local practices as soil conditions vary drastically from one area to another. New Hampshire uses the following guidelines in deciding what ditch lining treatment might be appropriate. (15) (These guidelines assume that the volume of water progressively increases with slope.)

1. 0% - 4%: Use an erosion control blanket and seeding.
2. 4% - 6%: Use sod or an erosion control blanket.
3. >6%: Use plain riprap or stone ditch protection.

<table>
<thead>
<tr>
<th>Table 3-1. Maximum Allowable Flow Velocities for Various Types of Ditch Linings</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type of Lining</strong></td>
</tr>
<tr>
<td>Natural Soil Linings</td>
</tr>
<tr>
<td>Rip-rap sides and bottoms</td>
</tr>
<tr>
<td>Clean gravel</td>
</tr>
<tr>
<td>Silty gravel</td>
</tr>
<tr>
<td>Clean sand</td>
</tr>
<tr>
<td>Silty sand, clay</td>
</tr>
<tr>
<td>Clayey sand, silt</td>
</tr>
<tr>
<td>Vegetative Linings</td>
</tr>
<tr>
<td>Average turf, erosion resistant soil</td>
</tr>
<tr>
<td>Average turf, easily eroded soil</td>
</tr>
<tr>
<td>Dense turf, erosion resistant soil</td>
</tr>
<tr>
<td>Gravel bottom, brushy sides</td>
</tr>
<tr>
<td>Dense weeds</td>
</tr>
<tr>
<td>Paved Linings</td>
</tr>
<tr>
<td>Gravel bottom, concrete sides</td>
</tr>
<tr>
<td>Mortared rip-rap</td>
</tr>
<tr>
<td>Concrete or asphalt</td>
</tr>
</tbody>
</table>
Curbs and Gutters

Curbs are used in urban areas and occasionally on rural highways where some form of separation is needed between the road and sidewalks or other restricted areas. Curbs are also used to:

- provide a physical barrier for vehicles,
- combine with the gutter to channel stormwater,
- define the edge of the traveled way,
- provide locations for stormwater inlets to underground drainage], and
- present an attractive appearance.

Gutters are channels at the edges of pavement or shoulders formed by a cut or by a shallow depression or they may be part of the curb section. Gutter sections are provided on the travel side of a barrier or curb to form the drainage system for the roadway. A gutter section is often constructed of the same material as the wearing surface of the roadway. The curb confines all storm water runoff from the pavement surface to the gutter section with overflow onto the adjacent paved surface. Runoff will be carried along this section until it reaches either a curb opening for release to a natural drainage path, or it is guided into a drop inlet. Figure 3-4 shows some common arrangements of curve and gutter with types of inlets often found in developed areas.

![Diagram of curb and gutter showing inlet types](image)

FIGURE 3-4. TYPICAL CURB AND GUTTER SHOWING INLET TYPES

The curb and gutter sections are most often found in urban areas and deep cuts, where the gutter and underground pipe drainage system is cheaper than the added cost of excavation needed for the wider section of roadway channels. However, there are opportunities to use curbs in rural locations. Intersections, ramps, and locations on long grades where runoff needs to be controlled to prevent embankment erosion are examples. One curb treatment provides an opening to channel runoff to a pipe which carries the water down the embankment and the other figure shows an innovative means to intercept curb flowage and divert it...
3. TYPES AND FUNCTIONS OF DRAINAGE FEATURES

into a paved ditch. Where winter snow removal is a common activity, curbed sections in rural areas require special care by the plow operator to avoid the need for frequent maintenance.

Advantages of curb and gutter system:

- conserve space in urban areas, and other limited right-of-ways,
- eliminate the side ditch,
- control erosion by releasing runoff at designated, protected areas,
- reduce pavement failure, and
- provide driveway and traffic control.

The design of a curb/gutter section is controlled by the maximum expected runoff and by the allowable amount of water that will be permitted to run in the roadway.

Curb details are not standardized. There are multitude of sizes, shapes and types in use. Concrete, asphalt concrete, or granite is commonly used and construction procedures vary considerably. In single curb construction the curb is built first and the pavement is placed against it. Its primary purpose is to channel runoff, combined (or integral) curb and gutters are generally preferred. Single curbs formed by extrusion machines can be effective when they are placed on existing pavement. Precast curb sections have been advantageous in many situations, too.

CULVERTS

Culverts that exceed a 10 foot span (20 ft. by Federal definition) are considered bridges. This is a common definition but not standard.

Culvert Shapes

Culverts come in a variety of shapes including circular pipes, pipe arches, elliptical pipes, arches, metal boxes and box culverts. The two most common shapes are the *circular pipe and the pipe arch*. Figure 3-5 shows the cross-section shape that gives these pipes their name and illustrates the advantage of the pipe arch. In situations where there is limited head room for cover over the culvert, the pipe arch can carry more water than a full round pipe of the same opening size and cost. Also, the wide base of the pipe arch is advantageous to fish movement through the pipe.

Culvert Materials

*Culverts can be bought in a variety of materials.* Concrete, steel, aluminum, and plastic (ADS) are the basic types. Each has its own particular characteristics, advantages and disadvantages. *Corrugated metal pipe* (CMP) is available in circular shapes from 6 inches in diameter to over 120 inches. Typically, CMP’s are designed with a corrugation pattern such as 2” x 1”. See the next page for a diagram of common corrugation patterns. CMP is also
shop-fabricated in pipe arch shapes. For extra large culverts, individual plates can be assembled in the field in a few days time to form structural plate pipes.

**FIGURE 3-5.**

*Metal pipes* are available in a variety of gauges or shell thicknesses. For example, a 14 gage metal pipe has a greater wall thickness, it is structurally stronger and it will last longer than a 16 gage pipe of the same material. It will also cost more. However, the thicker gauges may still be cost effective based on an extended service life.

*Concrete pipe* is also used for a variety of drainage purposes. Reinforced concrete pipe (RCP) is available in sizes ranging from 12 to 144 inches. It can be made in round, arch, elliptical or box shapes and it is available in five different strength classifications, I through V. The higher number designates the higher strength pipe.

Several types of *plastic pipe* (ADS) are offered for subdrainage purposes and as culverts. They are corrugated polyethylene pipes with and without a smooth interior lining; PVC pipe; and other materials.

**Minimum Size**

The minimum sizes of culverts used by New Hampshire DOT are as follows:

1. Driveways. Use minimum 15” diameter pipe.
2. Cross Culverts. Use minimum 18” diameter pipe.
3. TYPES AND FUNCTIONS OF DRAINAGE FEATURES

Minimum Cover (Design)

Desirably, the pipe will be placed with a cover of at least 2 feet below the top of the subgrade. The minimum cover for any type of pipe is 1 foot below the subgrade. (Driveway culverts may find it difficult to meet the minimums.) Obviously, as the pipe diameter and minimum cover increases, the depth of ditch must increase also.

Maximum Cover

The maximum allowable cover over a culvert depends upon the size of the culvert, its material and shape, and the type of bedding it is placed upon. Gauge for steel or aluminum and strength class for concrete pipe is also very important.

Spacing Between Multiple Pipes

The minimum spacing allowed between multiple pipes is as follows:

Minimum Slope

Except where the culvert is used as an equalizer, a minimum slope of 0.5% should be used for any type of culvert at any site.

Special Design Considerations

For pipe sizes greater than 48 inches, the following should be considered:

1. Foundation. The type of soil at the site may dictate the type of culvert to be used. For example, in soils susceptible to settlement (e.g. marshes/boggy areas), the culvert may settle more than the area around its entrances. Therefore, the designer should use a flexible pipe or reinforced concrete pipe with an imperfect trench or similar treatments.

2. Step-Beveled Ends. Where used, step-beveled ends should be well anchored with a toe wall, or other approved method, especially at the culvert entrance. Otherwise, uplift may occur at the opening. This problem may be especially dramatic for metal culverts.
3. Types and Functions of Drainage Features

3. Camber. For some culverts under high fills, it may be appropriate to provide a “camber” or upward bend in the culvert. This allows the culvert to settle and “level out.” Culvert manufacturer’s handbooks and construction manuals provide criteria for the camber technique. A Soils Engineer could assist in determining whether the native soils are susceptible to settlement and will assist in calculating the amount of camber in the culvert.

4. Increased Structural Support. For extremely high fills, certain gauges of metal pipe and rigid pipes may need to be center strutted and fitted with compressible wooden caps. This would be necessary during the placement of the fill, and the increased support would be removed after placement.

Factors Affecting Culvert Life

Culvert pipe should provide good service and last for many years if reasonable care is taken and common sense is applied in design, installation, and maintenance. On the other hand, merely following proper procedures does not automatically insure that a culvert will live out its full life in a quiet, uneventful manner. There may be unforeseen events occurring that can drastically effect the predicted performance of the various elements of the highway drainage system. All the more reason to know and use accepted practices in order to minimize the total number of pipe failures by making sure that no failures occur that can be traced to improper techniques, sloppy workmanship or any other type of human error.

There are many conditions that can result in pipe failure and subsequent replacement. The purpose of this manual is to present information to help reduce such occurrences.

Reasons to Replace or Repair a Culvert

- Poor culvert bedding resulting in settlement, or structural failure.
- Improper compaction under the haunches, around the pipe and throughout the trench backfill.
- End-crushing due to errant vehicles.
- Corrosion from salt water or acid soils.
- Erosion due to high flow velocities carrying sand and gravel.
- End scouring and/or piping around or under the pipe resulting from poor end treatment and compaction.
- Pipe capacity insufficient for runoff needs.
- Washout due to flow overtopping the road.
- Poor endwall or slope treatment resulting in embankment loss.
Sizing of Culverts

The methods to size culverts depend on estimating (“calculated guessing”) how much water is going to runoff through the culvert, how bad the storm will be, the type of culvert, how well the water flows through it and many more factors that are equally uncertain. Engineers often use four or more calculation procedures and average the answers to improve their chances of being right. It is impossible to write an accurate mathematical formula that can include all the factors influencing how much rain from a given storm is going to reach a culvert which could be miles away.

The methods used to find out what size culvert should be installed in a particular location are, in kindly terms, inexact. The process appears unnecessarily long, complicated and full of doubtful assumptions which are not of much value to local road departments.

To simplify an incredibly complex process to the point where we can describe it with an equation, we:

1) make some reasonable assumptions based on field experiments,
2) use statistical studies to measure how often rain storms of different intensity occur,
3) do research to find out how much water soaks into the ground and how much runs off for forests, cultivated land, grassland, steep slopes, minimum slopes, flat slopes, etc., etc.

The results of this research by many people over the years are a variety of procedures for calculating what size culvert should be sufficient to handle the water runoff from a particular drainage basin.

To illustrate how difficult it is to develop procedures that give reasonable similar runoff estimation results, look at the following listing. Using an example, this shows the results of five commonly-used methods to find the 50-year peak discharge rate for the same drainage area.

<table>
<thead>
<tr>
<th>Method</th>
<th>Calculated Peak Discharge (cfs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potter’s Method</td>
<td>93 cfs.</td>
</tr>
<tr>
<td>BPR 1021 Series</td>
<td>92 cfs.</td>
</tr>
<tr>
<td>Benson’s Method</td>
<td>53 cfs.</td>
</tr>
<tr>
<td>Rational Method</td>
<td>144 cfs.</td>
</tr>
<tr>
<td>USGS Method</td>
<td>37 cfs.</td>
</tr>
<tr>
<td></td>
<td>Average = 84 cfs.</td>
</tr>
</tbody>
</table>

When installing a new culvert in a new location, get advice and assistance from the State Highway Department, the Soil Conservation Service Office, a qualified consultant engineer or some other competent source and do the necessary sizing calculations.

When replacing an existing culvert, generally replace with a new one of the same size but before doing so, do a little checking.
3. TYPES AND FUNCTIONS OF DRAINAGE FEATURES

√ find out how long the existing culvert has been in place. Town or, more likely, a local resident can help.

√ inquire from older folks or nearby residents how well the culvert has done its job during storms. Has there been any flooding upstream during periods of high flow like spring thaw or heavy rain? Has water ever flowed over the road? What are the high water extremes?

√ check downstream as well as upstream. If the next culvert downstream has also done its job well, one can be pretty sure that the size of the old culvert was adequate.

√ put in the same size culvert if there have been no major problems or increase the culvert size a little if you have some doubts. (For example, an 18” culvert has about 50% more capacity than a 15” culvert and costs little more.)

√ When increasing the size of the replacement culvert, be aware that the increased flow may disrupt downstream conditions, especially of the existing culverts have only marginally been handling current high flow quantities. Some flooding may result.

√ if questioning the adequacy of the old culvert or a new development has changed runoff conditions, get help from a competent engineer, do the complex calculations and resize the series of culverts along that drainage channel.

Another option to sizing culverts in an existing drainage way, is to use this practical, easy-to-apply procedure. It is routinely used by the New Hampshire State Department of Conservation and is illustrated in their “Land Use Handbook.”

In abbreviated form, the method involves measuring: 1) the cross-sectional area (A) of the stream under high water conditions, 2) measuring how fast the stream is flowing and 3) estimating a coefficient to account for roughness of the stream bed. With this information, calculate the quantity of water flowing (Q in cubic feet per second or cfs). Then adjust the flow to estimate Q for a “10 year” storm or a “25 year” storm. This provides a safety factor consistent with the rest of your drainage system and you can select a culvert with the appropriate diameter.

Incidentally, the volume of flow (Q) and the speed of the flowing water is useful information when deciding what type of erosion control to apply for a worst case situation. The procedure is applicable to ditches as well as flowing streams.

The steps to apply this simplified procedure are illustrated in the following example:

CALCULATING VOLUME OF FLOW BY FIELD MEASUREMENTS

STEP 1. Select test section and take measurements to find average width, average depth, and speed of flow.
3. TYPES AND FUNCTIONS OF DRAINAGE FEATURES

a. Measure 100 feet of a straight section of stream “L” with few, if any, obstructions to the current.

b. Measure the average both width “W” and depth “D” at each end of the section and at the middle.

c. Drop a float into the water at the upper end of the section and time its run in sections to the lower end. Average the three times to find the value of “T.” Select a time during a heavy runoff or meltoff period for best accuracy.

\[
Q = \frac{W D a L}{T}
\]

Q = Volume of flow (cu.ft./sec)

W = Average width (ft.) at three locations

D = Average depth (ft.) at three locations

a = Constant for correction

L = Length of section (ft.)

T = Average time (sec.) for float to traverse the distance L

STEP 2. Calculate average width and average depth of flow.

a. For Average W in the 100’ Section:
3. TYPES AND FUNCTIONS OF DRAINAGE FEATURES

\[ W_1 = 4.5' \]
\[ W_2 = 5.0' \]
\[ W_3 = 4.8' \]

\[ \text{Avg. } W = \frac{4.5' + 5.9' + 4.8'}{3} = \frac{14.3'}{3} = 4.77' \]

b. For Average D in the 100' Section:

3 depths @ loc. 1 = 2.5', 3.2', 1.5'

\[ \text{Avg. } D_1 = \frac{2.5 + 3.2 + 1.5}{4} = \frac{7.2'}{4} = 1.80' \]

3 depths @ loc. 2 = 1.9', 2.8', 2.4'

\[ \text{Avg. } D_2 = \frac{1.9 + 2.8 + 2.4}{4} = \frac{7.12}{4} = 1.78' \]

3 depths @ loc. 3 = 2.1', 4.1', 3.0'

\[ \text{Avg. } D_3 = \frac{2.1 + 4.1 + 3.0}{4} = \frac{9.2}{4} = 2.30' \]

2) Average the 3 depths just computed for an overall average for the entire 100' section.

\[ \text{Avg. } D = \frac{1.8' + 1.78' + 2.3'}{3} = \frac{5.88'}{3} = 1.96' \]

STEP 3. Find how fast the water is flowing (seconds) over the test section.

Trial # 1 = 34 seconds
Trial #2 = 27 seconds
Trial $3 = 36$ seconds

\[ \text{Avg.} T = \frac{34 + 27 + 36}{3} = \frac{97}{3} = 32.2 \text{ seconds} \]
STEP 4. Calculate the volume of flow in cubic ft. per sec. (CFS) using the formula:

\[
Q = \frac{WdAL}{T}
\]

\[
Q = \frac{4.77\times1.96\times0.8\times100}{32.2 \text{ seconds}} = \frac{747.9 \text{ cu.ft.}}{32.2 \text{ sec.}} = 23.2 \text{ cfs}
\]

STEP 5. Adjust the flow for the “selected” design storm.

Multiply “Q” by 2-1/2 for “10 year storm” or 3-1/2 for a “25 year storm.” Select whichever factor conforms to the practice in your locality and then use the resultant \(Q_{10}\) or \(Q_{25}\) to select the culvert(s) that will accommodate the computed flow.

\[
Q_{10} = 23.2 \text{ cfs} \times 1-1/2 = 58 \text{ cfs}
\]

\[
Q_{25} = 23.2 \text{ cfs} \times 3-12 = 81 \text{ cfs}
\]

**Culvert Location**

Culvert location is concerned with the alignment and grade of the culvert. Ideally it is best to have culvert alignment coincide with the natural location of the stream. *Disturb the natural system as little as possible and minimize impact on the land.* This approach has the advantage of minimizing erosion and sedimentation problems, maintaining aquatic life, caus-
The general rule for CULVERT LOCATION: “don’t mess with Mother Nature!”

Generally, alignment of a streambed is not altered if the angle between the stream and the road is 45° or more. (See Figure 3-6). When no old drainage channels exist, install culverts at right angles to the centerline of the road except for ditch relief culverts. These are placed at 60° to 90° to the centerline to direct flow of the water into the culvert and minimize culvert length.

![FIGURE 3-6](image)

Figure 3-7 illustrates the location of a ditch relief culvert in relation to the centerline of the road. Figures 3-7a and b show two ways to redirect the ditch flow into the ditch relief culvert. Figure 3-7a shows a section of an old culvert cut in half with part of it inside the relief culvert and part of it sticking out to intercept ditch flow. Figure 3-7b tries to accomplish the same results with carefully placed large rocks. Be sure to protect the outlet area against scour and erosion in all cases.

A rule of thumb for spacing ditch relief culverts is to space them according to the road grade (20):

- Gentle slopes of 1 – 2%, space 300 ft. + apart.
- Moderate slopes of 3 – 10% space 150 ft. + apart.
- Steep slopes over 10%, space 100 ft. + apart.

*Remember that these are purely rule of thumb guidelines, road managers would be wise to check for appropriate local requirements that might be more appropriate.*
3. TYPES AND FUNCTIONS OF DRAINAGE FEATURES

Figure 3-7
Ditch Relief Culvert Location

Figure 3-7a
Directing Flow into a Culvert

Figure 3-7b
Directing Flow into a Culvert
Stream Relocation

Stream relocations cannot always be avoided and may lead to use of a shorter culvert and lower costs for the pipe. However, savings in the price of the pipe can be quickly lost in the additional cost of slope protection, energy dissipaters, check dams and other types of environmental controls that may be necessary to maintain a stable stream channel.

Nevertheless, there may be times when realignment of a water course must be undertaken. An example might be a severely meandering stream that would require excessive costs for multiple roadway crossings. When such conditions occur, environmental permits will probably be required by State and/or Federal agencies. If approved, place the culvert at the best possible location and straighten the stream. Use special attention to prevent scouring or undercutting when the original stream is redirected.

These changes in alignment (and Mother Nature) can cause major hydraulic and environmental problems. Shortening the length of a stream causes faster flows and accompanying erosion that will likely upset downstream conditions for a considerable distance. If stream relocation is really necessary, try to keep the length of the flowage as close to that of the original channel as possible. This will help keep the rate of flow close to the original water speed and minimize the environmental impact of the relocation. Channel stability should be a prime consideration.

Culvert Length and Grade

The length of a culvert is determined by the width of the roadway embankment from toe-to-toe. There are 2 methods of measurement:
1) Measure the distance from inlet to outlet horizontally, or
2) Use the following figure.

<table>
<thead>
<tr>
<th>DEPTH OF FILL</th>
<th>WIDTH OF ROAD AT CULVERT LOCATION -- “W” (including any shoulders)</th>
</tr>
</thead>
<tbody>
<tr>
<td>“D” 12 ft.</td>
<td>14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 54 56 58 60 62</td>
</tr>
<tr>
<td>2 ft.</td>
<td>20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 54 56 58 60 62 64 66</td>
</tr>
<tr>
<td>3</td>
<td>24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 54 56 58 60 62 64 66 68 70</td>
</tr>
<tr>
<td>4</td>
<td>28 30 32 34 36 38 40 42 44 46 48 50 52 54 56 58 60 62 64 66 68 70</td>
</tr>
<tr>
<td>5</td>
<td>32 34 36 38 40 42 44 46 48 50 52 54 56 58 60 62 64 66 68 70</td>
</tr>
<tr>
<td>6</td>
<td>36 38 40 42 44 46 48 50 52 54 56 58 60 62 64 66 68 70</td>
</tr>
<tr>
<td>7</td>
<td>40 42 44 46 48 50 52 54 56 58 60 62 64 66 68 70</td>
</tr>
<tr>
<td>8</td>
<td>44 46 48 50 52 54 56 58 60 62 64 66 68 70</td>
</tr>
<tr>
<td>9</td>
<td>48 50 52 54 56 58 60 62 64 66</td>
</tr>
<tr>
<td>10</td>
<td>52 54 56 58 60 62 64 66 68 70</td>
</tr>
</tbody>
</table>
Example:

Road width “W” = 22 ft. (including shoulders)

Depth of fill “D” = 4 ft.

using the chart, the culvert length must be 38 ft.

FIGURE 3-8.

The grade of the culvert is also set by the slope of the existing channel. *The ideal grade line for a culvert is one that doesn’t cause either high velocities and scour or sedimentation.* The bottom of the culvert at the inlet should be placed on or a little below the streambed. The bottom of the culvert at the outlet end should be at the same level as the streambed. Reducing the slope of a streambed could cause sedimentation in the pipe while increasing the slope will likely cause scouring and erosion at the lower end, and will likely form bars of sediment at some point downstream. Special attention to culvert grade is necessary if fish passage is to be accommodated.

FIGURE 3-9. CULVERT INSTALLATION FOR FISH PASSAGE

Culverts set below level of stream allow easier passage for fish. Note rock end protection and fish resting pools at both ends of culvert.

The normal slope of culverts is between 3 – 4%. The minimum slope is 0.5%. If the outlet is raised above the grade of the existing channel, be sure that erosion protection in the form of riprap or some other material is provided.

Occasionally, it might be more practical to use *two or more small culverts* instead of one large one. This arrangement might be good where there is need to handle a high flow but where the depth of water must be kept to a minimum to avoid flooding adjacent land as in figure 3-10. Typically, many roads are built with shallow fill and don’t have the necessary headroom to allow a larger diameter pipe.
FIGURE 3-10. SINGLE VS. MULTIPLE OPENING

Note that a single large pipe has the least amount of cover and it will cause water to back up and flood the adjacent land. A twin or triple opening offers the best solution because the water level is kept below the flood elevation and there is more gravel cover over the pipes.
Improved Culvert Inlets

Standard highway culvert entrances can be classed as square-edge as compared to tapered, rounded or bell-shaped. *It has been shown that extensive rounding at the entrance to circular pipes and side-tapered or slope tapered inlets for box culverts can increase the flow substantially.* This occurs in long pipes on steep slopes because the pipes can flow full for their entire lengths whereas square type entrances do not flow full. In general, sloped and tapered entrances require careful hydraulic analysis and design. These special designs are beyond the scope of this workshop. Seek professional engineering assistance if such treatments would appear to be appropriate and warrant the considerable extra expense involved in their design and construction.

There are two major types of culvert flow -- *inlet* and *outlet control*. The complexities of hydraulic flow in culverts are confusing but are helpful to know some of the basics when making decisions at the local road level. Figure 3-11 illustrates water flow through culverts under conditions of inlet control and outlet control respectively.
3. TYPES AND FUNCTIONS OF DRAINAGE FEATURES

TWO MAJOR TYPES OF CULVERT FLOW

Inlet control
- Pipe’s capacity is controlled by conditions at inlet
- Inlet may or may not be submerged
- Culvert is on a significant slope
- Culvert outlet is free and open (not submerged)
- There is a free water surface in the culvert barrel
- Culvert length is not a factor
- Type of inlet edge affects flow

Outlet control
- Pipe’s capacity is controlled by pressure difference’s between inlet and outlet ends
- Inlet is submerged
- Culvert is on mild or no slope
- Culvert outlet may or may not be submerged
- The culvert barrel may or may not be full
- Culvert length is a factor
- Type of inlet edge affects flow

FIGURE 3-11.
3. TYPES AND FUNCTIONS OF DRAINAGE FEATURES

Note that in inlet control the culvert does not flow full, even when the inlet is submerged. Water in the culvert barrel is shallow and much of the culvert capacity is not used. This condition is largely caused by flow restrictions or contractions as the water tries to get around the various types of culvert edges and into the barrel of the pipe. The flow line sketches in Figure 3-12 approximate this flow restriction graphically for three different types of pipe edges:

![Flow Contraction Diagrams]

**FIGURE 3-12. FLOW CONTRACTIONS FOR VARIOUS CULVERT INLETS**
Table 3-2 shows a comparison between different culvert end conditions and the amount of water that will flow through under inlet control.

**Table 3-2. Comparison of Flows for Selected Pipe Diameters with Inlet Flow Control (cu. ft./sec.)**

<table>
<thead>
<tr>
<th>End Conditions (Concrete Pipe)</th>
<th>Pipe Diameter</th>
<th>Hw/D Ratio&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Socket End (grooved end)</td>
<td>24”</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>12”</td>
<td>2.5</td>
</tr>
<tr>
<td>Square End</td>
<td>24”</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>12”</td>
<td>2.3</td>
</tr>
<tr>
<td>Socket End w/ 45° Head Wall</td>
<td>24”</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>12”</td>
<td>2.5</td>
</tr>
<tr>
<td>Projecting CMP</td>
<td>24”</td>
<td>11.5</td>
</tr>
<tr>
<td></td>
<td>12”</td>
<td>2</td>
</tr>
</tbody>
</table>

<sup>a</sup>Note: Inlet control seldom exists for Hw/D greater than 3.0. With inlet control, the shape of the inlet is the governing factor in flow. With outlet control, pipe length, slope and roughness will affect the flow volume.

<sup>b</sup>Ratio of the depth of water ponded at the inlet (headwater) to the diameter of the pipe, D. Headwater depth is measured from the bottom (invert) of the pipe.

**Culvert Headwalls and Endwalls**

Headwalls are used on culverts to direct flow into the culvert and endwalls direct flow back to the regular channel. Both protect and embankment from scour, erosion and flood waters. Figure 3-13 shows several common types. *They are an expensive addition to the cost of a culvert and are not used very often with smaller pipes.*

Flared types of inlets are more efficient hydraulically then straight headwalls or projecting culvert ends. These are available both as precast concrete units and as prefabricated steel sections. Cutoff walls that extend below the scour elevation should be used with these end treatments.
3. TYPES AND FUNCTIONS OF DRAINAGE FEATURES

FIGURE 3-13. CULVERT ENDWALLS AND WINGWALLS
(Courtesy NACE Action Guide, Vol. III-5)
3. TYPES AND FUNCTIONS OF DRAINAGE FEATURES

Culvert Installation

Culvert installation is next after deciding on the proper location, alignment, length and grade. Deciding whether to use a rigid or a flexible culvert pipe is a crucial factor in the installation process because these two types of pipe carry the embankment and traffic loads differently. As a result of this difference, bedding requirements and backfilling treatments need to be handled differently.

Pipe Load Support Characteristics

Metal (flexible) pipe is able to support heavy earth and traffic loads because of its flexibility. As the load is applied to the top of the pipe, it tries to flex and squat sideways. However, if the fill has been packed tightly beside the pipe, the pipe can’t deform and so the load is transferred to the soil. The load-carrying ability of flexible pipe depends on the support it gets from the surrounding earth. Without this support, it would simply be deformed and not function properly or be crushed under heavy loads.

Rigid concrete pipe, on the other hand, cannot flex and thus it cannot pass off some of the load to the earth beside it. The structural strength of the pipe itself must be able to carry the bulk of the imposed loads. Therefore, it is important that concrete pipe be given shaped, uniform support throughout its entire length to develop its maximum strength.

Note that the width of the arrows showing the load and reaction forces on the pipes are an indication of the amount of the forces being applied.

Most pipe failures are due to faulty construction methods (like the bedding and backfilling processes noted above), heavy loads during the construction phase or pipe sag due to foundation settlement. Therefore, careful attention to details by trained local road crews is important during the installation of culverts. However, it often appears that both lack of understanding of the load-carrying characteristics of concrete or metal pipes and lack of use of acceptable installation procedures is common at the local level.
Installing culverts isn’t complicated, but training is necessary to avoid blunders and to be reasonably sure of getting the full service life out of the culvert.

**Installation Procedures**

Basic steps to install either a concrete or a metal culvert are the same although the specifics of how each step is done will vary. Those steps are:

1) excavate and prepare the foundation,
2) bed the pipe by shaping the bottom of the trench or using new bedding material,
3) assemble or join pipe sections as required, and
4) backfill and compact thoroughly.

**Excavation**

For road work, culvert construction generally involves digging a trench for the new culvert (or for replacing the old one), building an embankment around a culvert, or occasionally tunneling, jacking or relining if special circumstances require it. Figure 3-14 shows examples of the technical classification of some of these situations in terms of the early load on the pipes.

*A stable, uniform foundation is required for any culvert.* If non-uniform or otherwise poor soils are found, they must be improved to assure satisfactory culvert performance. Remove pockets of unstable soil and suitable backfill (i.e. crushed stone) substituted. If rock or “hardpan” is found, it will be necessary to over-excavate and then bring the foundation back to grade with suitable granular material. If both hard and soft spots are found, it may be necessary to excavate the entire foundation below grade and replace it with select materials to give the required uniform support.

*Make sure that stable, uniform foundations provided, regardless of the type of pipe being used.* The foundation should be strong enough to carry the load of the backfill or embankment material placed on the pipe, and still maintain the established grade.
If the fill over the culvert is 10 feet or more, the culvert foundation is often “cambered,” especially on a soft subgrade. Chamber is simply the rise at the center of a culvert above a straight line connecting its ends. The weight of the roadbed above the pipe can cause the center portion of the pipe to settle somewhat.

---

**FIGURE 3-14. PIPE CLASSIFICATION ACCORDING TO CONSTRUCTION**
(NACE, Action Guide Vol. III-5)

**FIGURE 3-15. CAMBER ALLOWS FOR SETTLEMENT OF A CULVERT UNDER A HIGH FILL**
3. TYPES AND FUNCTIONS OF DRAINAGE FEATURES

In general, enough camber can be built-in by settling the inlet half of the pipe on a flat grade and the outlet half steeper than normal. If camber is used, it should be more than one-half of 1% of the total length of the pipe. (21) For example, a 40 foot culvert would have a minimum of 2-1/2” of camber. (.5% x 40 ft. = 0.2 ft. = 2.4 in.) Without cambering, the settling of the roadbed could cause the center of the culvert to sag. The result would be ponded water inside the culvert at the low point and rapid collection of sediment and debris would follow. For structures under high fills, the ordinates of the cambered pipe should be determined by a soils engineer.

**Bedding**

The ways to bed a culvert differ depending on the type of culvert and the foundation soil. The general rule for both concrete and metal pipe is to shape bedding to fit the contour of the lower portion of the pipe. This is **particularly important for concrete pipe** because it cannot flex and shed part of its vertical load nor can it flex appreciably to fit a changing grade line perhaps due to different settlement along the foundation line.

*The bedding or actual “seating” of a pipe to provide continuous, uniform support is critical to both pipe performance and service life.*

In these two diagrams, the culvert or pipe arch is placed directly on the foundation and then the backfill material is packed under the sides of the pipe. The wide bottomed pipe arch is susceptible to problems arising from poor bedding practice. The nearly flat bottom can cause it to collapse under smaller load than a circular pipe unless the bedding is properly constructed. If the culvert is allowed to settle during the bedding operation, the bottom will likely buckle and the pipe can collapse. For this reason, place the culvert on firm bedding and the critical areas under the “corners” (haunches). Most of the strain occurs in a pipe arch and must be carefully and thoroughly tamped. *It is important that the bedding be carefully tamped under the haunches of any type of pipe.* If not, the pipe may settle randomly causing low spots or ruptures. Drainage flow can also work its way through loosely packed material under the pipe and undercut the embankment.
Another bedding method is to shape the bottom of the trench to fit the culvert. This procedure is good if the ground is firm and won’t settle, however care must be taken to ensure the pipe fits the trench. Any low spots in the trench will cause sagging while any flat surface may cause the bottom of the culvert to cave in. A screed board can be used to accurately shape the bedding area. This method of bedding has the important advantage of reducing the area of tamped fill required – a troublesome part of the construction process.

**FIGURE 3-16. SETTING CULVERTS ON SOFT, WET GROUND**

*If the culvert is to be laid on unstable soil such as a boggy area,* lay the culvert on a new bed of granular material 2 ft. or more deep depending on the size of the culvert. This restricts sagging and prevents the culvert from eventually being buried in the softer ground around it. A geotextile fabric between the gravel and the boggy layer can give good support by preventing the two layers from mixing.

*If a culvert is to be bedded on rock or a very hard packed material,* the trench should be dug at least 12” below the culvert and backfilled with a lightly compacted material that can provide uniform support for the length of the culvert.

**FIGURE 3-17. SETTING CULVERTS ON ROCK OR “HARDPAN”**
3. TYPES AND FUNCTIONS OF DRAINAGE FEATURES

The extreme importance of good bedding for concrete pipe is clearly shown in the drawing on the next page. (16) Four classes of bedding are illustrated – each one supports a different height of fill depending on its bedding type. Note that concrete pipe laid on the flat surface of an excavated trench with no additional bedding (Class D) can carry approximately the same as the test strength of the pipe. This is equivalent to a little less than 7 feet of earth fill. If Class C bedding is specified, the pipe has firmer bedding and it can support approximately 35% more material or about 10 feet of fill. A class A bedding is a concrete bed and can carry 3 times the pipe’s test strength or over 33 feet of fill.

Pipe suppliers and manufacturers can readily supply tables or charts to help local users choose the right culvert size and strength or gauge to meet requirements for any particular job.

Assembly

Proper assembly of pipe sections to avoid joint failures and the resulting wet subgrade problems. There are a variety of connecting bands for metal pipe and joining methods for rigid pipe. Manufacturers and suppliers will provide this information and specific instructions for making the necessary connections. When all else fails, read the directions.

Avoid rough handling of both flexible and rigid pipe. Considerable damage can be done to either by dragging it, rolling it into the trench, banging it against rocks or other hard objects, improper stockpiling, and poor lifting techniques. Normal precautions and reasonable care is all that is needed to avoid damage that may appreciably shorten the service life of culvert before it has even been installed.

Backfill

Too much emphasis cannot be placed on the importance of good compaction of backfill. Poor compaction has led to more trouble with culvert installation for both flexible and rigid pipe than all other factors combined.

Backfill materials should be moist, placed in thin layers of 6” to 8”, and compacted with tampers. Compact the bedding material to the mid point of the culvert or to a height sufficient to hold the culvert in place. The backfilling should continue by placing it equally in layers on both sides of the structure. Extend the compacted layers to the side of the trench or to the natural ground line.

Granular material free of rocks, sod, or frozen earth is good for backfilling. Rocks in backfill materials can punch through metal or damage concrete under the pressure of the backfill. Sod and frozen earth can lead to excessive settlement in the fill. Where frost is a problem it is recommend that the excavated material be used as the backfill in order to prevent differential heaving between the trench and adjacent road sections. At least the road and trench will move up and down together! If the material is completely unsuitable, it may be necessary to bring in new suitable materials.
3. TYPES AND FUNCTIONS OF DRAINAGE FEATURES

<table>
<thead>
<tr>
<th>Class A Bedding</th>
<th>Class B Bedding</th>
</tr>
</thead>
<tbody>
<tr>
<td>$W = 130$ lbs. per cu. ft.</td>
<td>$W = 130$ lbs. per cu. ft.</td>
</tr>
<tr>
<td>Load Factor = 3.0</td>
<td>Load Factor = 1.9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Class C Bedding</th>
<th>Class D Bedding</th>
</tr>
</thead>
<tbody>
<tr>
<td>$W = 130$ lbs. per cu. ft.</td>
<td>$W = 130$ lbs. per cu. ft.</td>
</tr>
<tr>
<td>Load Factor = 1.5</td>
<td>Load Factor = 1.1</td>
</tr>
</tbody>
</table>

Load Factor = \( \frac{\text{Pipe's strength in-place}}{\text{Pipe's lab test strength}} \)

(i.e. load factor of 1.9 means that pipe’s in-place strength is almost twice its test strength.)
3. TYPES AND FUNCTIONS OF DRAINAGE FEATURES

One frequent cause of improper backfilling is having the backfill material dumped in piles along the pipe. Spreading piles by hand is slow work and usually more backfill is dumped before the spreading and tamping (compaction) is complete. The result is inadequate compaction on excessively thick layers of fill and the full load-carrying ability of the culvert is never achieved.

Trenching Safety

There are stringent safety rules to be followed when road crews are excavating pipe trenches and placing the pipe in them. OSHA’s (Office of Safety and Health Administration) or the NH Department of Safety LAB 1400 (see CD in the back) rules responsibility to monitor and enforce a wide variety of Federal safety regulations. It is also safe to say that many road crews ignore these laws. It may not be a very wise move to continue to do so.

Other Topics

Two other concepts that deserve attention are energy dissipaters and debris control devices.

Culverts on steep grades or carrying large quantities of water frequently cause serious erosion problems at their outlet because of high water velocities. An energy dissipater is designed to slow the water down. One means of control is to “catch” the discharge in a stone lined “plunge pool” that absorbs the energy and allows water to flow slowly over a sill or low point on the downstream side of the plunge pool. Figure 3-18 illustrates such an outlet protection device.

Other examples of “energy dissipaters” include cast-in-place or separate concrete blocks, stone riprap, or a locally constructed “bear trap” section of stone-filled corrugated steel pipe buried at the end of a culvert.
3. TYPES AND FUNCTIONS OF DRAINAGE FEATURES

Figure 3-18. Detail of Culvert Outlet Protection

<table>
<thead>
<tr>
<th>PIPE SIZE</th>
<th>X</th>
</tr>
</thead>
<tbody>
<tr>
<td>12in.</td>
<td>2ft.</td>
</tr>
<tr>
<td>18in.</td>
<td>3ft.</td>
</tr>
<tr>
<td>24in.</td>
<td>5ft.</td>
</tr>
<tr>
<td>36in.</td>
<td>7ft.</td>
</tr>
</tbody>
</table>

PLUNGE POOL
1 "D" deep  
2 "D" side  
4 "D" long

GURE 3-18. DETAIL OF CULVERT OUTLET PROTECTION
Debris control is usually applicable only to brooks, streams, creeks or normally dry stream beds when they are under flood conditions. Branches, sticks or other floating debris can easily clog a culvert and cause possible water damage to adjacent property or the road itself. If the culvert cannot be designed with a large enough opening to pass expected debris, racks of wire, timber piling, or other devices may be used upstream to trap floating debris or tumbling rocks where they will do no harm. Of course, such installations must be cleaned by maintenance crews. The need for these types of devices varies greatly between different geographical areas. Local practice is the most useful source of information.

FIGURE 3-19. DETAIL OF STONE CHECK DAM

**SUBSURFACE DRAINAGE**

“Subdrainage” refers to the control of underground water found near roadways. In many cases, excessive amounts of this subsurface water have been the cause of poor roadway performance. Damage to the road often shows up as early rutting, cracking, and roughness and the end result is shortened service life.

**WHY USE SUBSURFACE DRAINS?**

- to drain surface water that seeps into the road base and upper levels of the subgrade,
- to draw-down or lower a high water table under a roadway as in swampy areas, and
- to intercept seepage that moves on top of a layer of impervious material such as clay at cuts and side hill locations.
3. TYPES AND FUNCTIONS OF DRAINAGE FEATURES

**Basic Course Drainage**

During roadway construction or reconstruction it is important to maintain a suitable cross slope and crown throughout the layers of materials. The top of the subgrade (i.e. existing ground) should be crowned prior to placing the base course gravel. When the base course is free draining (limited amount of fines present) and extends the full width of the road-bed, it will act as an excellent drain path. Water seeping into the road from the surface drains through the base and travels along the crowned subgrade to the sideslope or ditch area. In this case, no subdrain pipe would be required.

**Interceptor Drains**

The purpose of an interceptor drain is to cut off the movement of flowing, underground water and lower the water table under the road. Figure 3-20 shows a typical installation. Install a pipe large enough to handle the expected flow. Surround the drain with crushed rock and the trench either “lined” with a geotextile or a filter sand to keep the adjacent soils from washing in and plugging the drain. Note in the figure the top of the trench is sealed to prevent surface water from getting in.

![Figure 3-20. Interceptor Drain](image)

**Longitudinal Drains**

It is common practice to classify subsurface drainage by the location and layout arrangement. For example, the interceptor drain might have been called a longitudinal drain because it is located parallel to the roadway. Underdrains are often installed parallel on each side of the road under the shoulders or at the outer edges of the traveled way to drain water in the upper layers of the road or to lower a high water table sufficiently to prevent capillary action under the road.
Several materials and arrangements for underdrains are illustrated in Figures 3-21 and 3-22.

**Figure 3-21. Two Types of Underdrain Construction**

**Figure 3-22. Geotextile Application**

**Laying and Backfilling Underdrains**

Generally speaking, if the groundwater table is relatively shallow, place the pipe’s flow line below the ground water level for best results. However, do not place the pipe so low that it cannot drain to an open surface outlet.

A minimum slope of 0.15 ft. (2+ inches) per 100 ft. should be used for subdrains. A flatter slope might be used if it would allow a free outlet but a steeper slope would be better and it would help to provide a self-cleaning flow.

The basic construction procedures for installing underdrain are the same as for culverts:

1) excavate an appropriate trench,
2) provide support for the pipe,
3) install the pipe, and
4) backfill with pervious material.
3. TYPES AND FUNCTIONS OF DRAINAGE FEATURES

Trenches are usually shallow with vertical walls. It may be necessary to use some bedding material if unstable soils are found but, for the most part, no special treatment is required as is evident in the examples in Figures 3-21 and 3-22.

Installation of an underdrain normally begins at the outlet end. The perforated subdrain pipe is laid with the perforations down to reduce the possibility of silt or filter material getting into the pipe. Geotextiles are widely used. The geotextile encloses both the drain pipe and the permeable aggregate backfill. It prevents the fines from getting into the subdrain system and clogging it while still allowing the free flow of water to the drain. The geotextile is a filtering medium used in lieu of the graded aggregate. This configuration is less of a problem to construct and it functions with a higher degree of reliability.

![Diagram of underdrain trench installation]

**FIGURE 3-23. HOW TO LINE AN UNDERDRAIN TRENCH WITH GEOTEXTILE**

**Hydraulics of Closed Drainage Systems**

A “closed” drainage system is one in which the roadway curbs and gutters act as the storm water collector and direct the flow to curb inlets, gutter inlets or a combination of both. The inlets feed the storm runoff into underground catch basins and manholes that are connected to the storm sewer lines.

The proper design of a closed system requires engineering know-how, experience, and good judgment. Storm runoff computations are required, the hydraulic capacity of the curb and gutter street flow must be determined, the flow capacity of the inlets need to be calculated and then the underground storm sewer lines must be sized accordingly. This process can be complex and therefore are not included in this manual. Obtain professional engineering assistance to handle the design of closed systems.
3. TYPES AND FUNCTIONS OF DRAINAGE FEATURES

The following two sections merely seek to provide basic information and some “pointers” on catch basins and manholes and on closed storm sewer systems.

**Catch Basins and Manholes**

In more urban areas, storm water runoff is often taken care of by an underground system including curb and gutter, grate inlets, catch basins, manholes and the underground system.

Manholes are required where there is:

- a change in direction,
- a change in pipe size, or
- a junction of two or more lines

The following rules apply to the location of catch basins and to a closed system storm drain in general:

- A maximum of between 200-300 feet is recommended between catch basins to enable easy maintenance. Drainage analysis may indicate closer spacing.
- Place catch basins on the high side of bridge approaches.
- If the location, according to the hydraulic analysis, falls within an intersection, driveway entrance area, curb-cut ramp or pedestrian crosswalk, place the catch basin on the high side of the area.
- Place catch basins to intercept the side street flow before it reaches the major highway.
- On superelevated curves, place catch basins in areas to prevent water from sheeting across the highway.
- In sag locations where the catch basins will be the only outlet for storm water (i.e., no overflow path is available), install catch basins at the low point.
- As a rule, the additional catch basins should be approximately 4 inches higher than the low point of the sag.
- Where granite curb is proposed, the catch basin must be located in a full-height curb section and not within a terminal curb section.

**Closed System**

- Do not use pipe sizes less than 12”.
- It is desirable to have a 0.25 per foot difference in elevation between the inlet pipe and the outlet pipe. This is so the pipe will be self flushing.
- Desirably, the pipe will have a cover of at least 2 feet from the top of the subgrade. The minimum cover for any pipe is 1 foot below the top of the subgrade.
- Use non-perforated when pipes run transversely from catch basin to catch basin.
- Use perforated when pipes run longitudinally from catch basin to catch basin.
INTRODUCTION

“Geotextile” – any permeable, man-made textile material used as an integral part of a roadway, structure, or man-made project.

In relation to roadway use, geotextiles are typically used to improve soil conditions, provide better drainage, and protect against erosion.

This chapter will explain some basic terms and applications of geotextiles on local roads. (Other popular products like geogrids, geowebs, geoblocks, etc. will not be discussed here).

Many local roads suffer moderate to severe problems throughout the year, but they’re usually more pronounced in the springtime. Some roads require almost continuous maintenance and cannot be solved without more funds than usually available in municipal road budgets. Examples of these problems can include underground springs, boggy conditions due to poor soils and lack of road gravel, severe drainage problems due to the local topography, erosion on slopes, around culverts, and in ditches.

These types of problems can be eliminated or at least significantly reduced by the use of geotextiles. Their ability to solve these problems is well documented on the local, State, and Federal levels. Geotextiles have been beneficial on many projects and their use is growing.

The idea behind geotextiles is not new. For thousands of years, various materials have been used to improve soil conditions so that roads could be built. Whether it was bamboo, brush mats, or logs laid side-by-side (corduroy), the materials was used to support road gravel. Geotextiles are the modern day version of these methods – they are permeable sheets of man-made textiles such as polypropylene, nylon, polyethylene, etc. With the advent of these synthetic fabrics in the mid 1960’s, the methods of improving soil strength and building better roads has taken a giant leap forward. In fact, use in the United States and Canada reached 300 million square yards in 1988 alone – three times that used in 1980!
4. GEOTEXTILES IN ROADWAYS

**WOVEN**
- Very strong
- Do not elongate or stretch when a force is applied
- Made of woven synthetic fabric (usually polypropylene or polyester) by weaving yarns together...just like your dress shirt or a linen tablecloth.

**NONWOVEN**
- Stronger as thickness increases
- Highly permeable
- Able to stretch and take the shape of the adjacent surface
- Made from fibers that are arranged in a random pattern and are bonded together

3 General Types:
- “slit tape” (or film)
- monofilament
- multifilament

A “slit tape” fabric has a flat tape-like strand produced by slitting and weaving a solid sheet of extruded film. These fabrics are the cheapest woven and typically used in road stabilization/separation applications.

A “monofilament” fabric has strands which are like individual fishing liens. It is much higher quality than the slit-tapes and is correspondingly more expensive. Monofilaments are typically used for erosion control and drainage purposes.

A “multifilament” consists of many fine continuous filaments that are held together by twisting or intermingling the strands. Generally, multifilament fabrics are not commonly used for routine projects.

Nonwoven fabrics can range in thickness from a thin, lightweight material (4 oz./s.y.) to a fairly thick felt-type material (over 16 oz./s.y.). They are typically used for drainage purposes, such as in gravel underdrains.

**PRIMARY USES**

There are three primary uses of geotextiles in roadway construction and maintenance:
1) separation or stabilization,
2) drainage, and
3) erosion control
In each of these functions, a significant advantage of the geotextile is the simplicity of construction and its relatively cheap cost over traditional roadway construction practices. These are two excellent reasons why geotextiles have such a potential in the maintenance and construction of lower budget roadways, such as town or city streets!

1. **Separation or Stabilization**

   The geotextile is used to permanently separate two distinct layers of soil in a roadway. The classic example is where a road is to be built across a poorly drained, fine-grained soil (clay or silt) and a geotextile is laid down prior to placing gravel. This keeps the soft, underlying soil from working its way up into the expensive gravel and it keeps the gravel from punching down into the soft soil. The full gravel thickness remains intact and provides full support for many years.

   On an existing gravel road, a geotextile can be used to separate new gravel from the soil in the road bed underneath. Without the fabric, a roadbed becomes saturated with water, a muddy slurry is formed by passing vehicles. This “mud” is pumped upward into the new gravel and the aggregate loses its surface friction and disappears into the roadway underneath, leaving a rut behind.

   A geotextile can permanently separate the “good” and the “bad” gravel. The openings in the fabric are selected to allow water to pass through but the soil “fines” cannot rise to the top.

   Typically, woven and nonwoven Geotextiles are used in this application. If a woven product is used, it should be at least 4 oz./sq. yd. and could be a “slit-tape” or “monofilament” type for routine, non-critical situations. If a nonwoven product is used, it should be at least 8 oz./sq.yd. for survivability during construction.

2. **Drainage**

   The geotextile acts as a filter through which water passes while it restricts fine-grained soil from entering into coarse-grained soil (sand or gravel). An example is in an underdrain where gravel-filled trenches lined with a geotextile fabric are constructed along the edges of roads. The fabric allows water to drain into the trench, while it permanently separates the soil materials. The gravel remains clean and cannot clog with fine material. Geotextiles can be used under parking lots, walls, athletic fields, lawns, tennis courts, and other areas.

   In addition to underdrain use, it can be used for interceptor drains on wet, cut slopes, drains behind retaining walls, or as a drainage filter behind rock-filled gabions. In most subsurface drainage applications, strength is not a primary concern. It is only critical during installation.

   Normally, nonwoven fabrics are used because of their small pore size (opening size) and high flow capacity. They should be at least 4 oz./sq.yd. If installation stresses are more severe such as where sharp angular aggregate is in contact with the fabric, or a heavy degree of
4. GEOTEXTILES IN ROADWAYS

Compaction is required, then use a heavier nonwoven with a minimum of 8 oz./sq.yd. **Woven fabrics** can be used but they should be of the “monofilament” variety. “Silt-tape” wovens should **NOT** be used for drainage applications because of their poor capacity to pass water.

3. **Erosion Control**

A layer of heavy stones or broken rocks (rip-rap) is commonly used to provide erosion protection for streambanks, culverts, ditches, stream channels, shorelines, and bridge structures. A geotextile placed between the rock layer and the underlying soil surface anchors the underlying soil and protects it from erosion and wave attack.

The geotextile is used in lieu of a conventional graded granular filter. In this application, the geotextile can provide substantial savings with far greater control during construction, particularly in underwater applications.

Two key properties are important for proper erosion control. It must have sufficient capacity to pass water, especially if water is coming from behind the fabric. Second, the geotextile must be able to retain the finer soil particles under the fabric.

Typical geotextiles used for erosion control are medium weight (8 oz./sq.yd.) **nonwoven** fabrics or “monofilament” **woven** fabrics. In some instances where the riprap is rounded or the fabric is protected by a thin sand cushion before the riprap is placed, a lighter weight fabric (4 oz./sq.yd.) could be used, if care is exercised during riprap placement.

**SELECTING GEOTEXTILES**

All geotextiles will work in some applications, but no one geotextile will work in all applications. Even though several types of geotextiles (monofilament wovens and an array of light to heavy weight nonwovens) may meet all of the desired design criteria, it may be preferable to use one type over another to enhance the performance of the system. Selection will depend on the actual soil and hydraulic conditions as well as the intended function of the design. The following general considerations seem appropriate for the soil conditions given:

1. Graded gravels and coarse sands – Very open monofilament or multifilament wovens may be required to permit high rates of flow and a low risk of blinding.

2. Sands and gravels with less than 20% fines (very “dirty” or silty sand and gravel) – Open monofilament wovens and needle punched nonwovens with large openings are preferable to reduce the risk of binding. For thin heat-bonded nonwoven geotextiles and thick needle punched nonwoven Geotextiles, filtration tests should be performed.

3. Soils with 20% to 60% fines (silt or silty sand) – Filtration tests should be performed on all fabric types.
4. GEOTEXTILES IN ROADWAYS

4. Soils with greater than 60% fines (silt or silty sand) – Heavy weight needle punched and heat-bonded nonwoven geotextiles tend to work best as fines will not pass. If blinding does occur, the permeability of the blinding cake would equal that of the soil.

5. Gap graded cohesionless soils – Consider using a uniform sand filter with a woven monofilament as a filter for the sand.

6. Silts with sand seams – Consider using a uniform sand filter over the soil with a woven geotextile to prevent movement of the filter sand; alternatively, consider using a heavy weight (thick) needle punched nonwoven directly against soil as water can flow laterally through the geotextile should it become locally clogged.

These general observations are not meant as recommendations but to provide insight into the various considerations for selecting the optimum material. They are not intended to exclude other possible geotextiles.

INSTALLATION TIPS

Geotextiles can save money and provide a longer roadway life, however, there are limitations to their use. The major problem is their potential for damage during installation if proper care is not taken. The effectiveness of the geotextile could be severely reduced if it is torn or punctured during placement. It is very important that the fabric be adequately protected to prevent damage from construction vehicles or from sharp rocks that are dropped directly onto it. Most geotextiles are also susceptible to ultraviolet rays from the sun, thus making it critical to cover them within days before, during, and after installation.

For all drainage applications, the following construction steps should be followed:

1) The surface on which the geotextile is to be placed should be excavated to provide a smooth, graded surface free of debris, large holes, or obstructions which could tear or puncture the fabric.

2) Between the preparation of the subgrade and the construction of the system itself, protect the geotextile to prevent any possible deterioration due to the elements.

3) After excavating to design grade, cut the geotextile to the desired width, including allowances for “loose” ends of adjacent rolls, or at the top of the trench after the placement of the drainage aggregate.

4) Care should be taken during construction to avoid contamination of the geotextile. If it becomes contaminated, remove it and replace it with new material.

5) Place the geotextile with the machine (long) direction in the direction of water flow in the drainage system. It should be placed loosely (not taut), but with no wrinkles or
4. GEOTEXTILES IN ROADWAYS

folds. Care should be taken to place the geotextile in intimate contact with the soil so that no void spaces occur behind it.

6) Overlap the ends for subsequent rolls and parallel rolls of geotextile a minim of 1 to 2 feet, depending on the severity of anticipated hydraulic flow and the placement conditions. Increase the overlaps for high hydraulic flow conditions and heavy construction such as with deep trenches or large stone. For large open sites with base drains, overlaps should be pinned or anchored to hold the geotextile in place until placement of the aggregate. Always overlap the upstream geotextile over the downstream shingle-style.

7) Place drainage aggregate immediately following the geotextile installation to limit exposure of the geotextile to sunlight, dirt, damage, etc. Cover the geotextile with a minimum of 12 inches of loosely placed aggregate prior to compaction. If thinner lifts are planned, use higher survivability fabrics. For drainage trenches, several inches of drainage stone should be placed as a bedding layer below the slotted collector pipe (if required), with additional aggregate then placed to the minimum required construction depth. Compaction is necessary to seat the drainage system against the natural soil and to reduce settlement within the drain. Compact the aggregate vibratory equipment to a minimum of 95% Standard AASHTO density unless the trench is required for structural support.

8) For trench drains, after compaction, the two protruding edges of the geotextile should be overlapped at the top of the compacted granular drainage material. A minimum overlap of 12 inches is recommended to insure complete coverage of the width of the trench. The overlap is important as it protects the granular material from surface contamination. After completing the overlap, the improved shoulder subbase, topsoil or other material should be placed and compacted to the desired final grade.

THREE PRACTICAL USES

Problem No. 1 (culverts)

Every few years, culverts seem to erode or washout during spring runoff, flash floods, or days of heavy rain.

Solution:

A geotextile could be used to protect both ends of the culvert from the “scouring” effects of flowing water. At each end, a piece of geotextile (woven or nonwoven) could be placed against the surrounding gravel and then covered with 12” to 18” of large stones (riprap). Place fabric over the top of the culvert end and “tucked in” or anchor into a six inch deep trench and backfill.
4. GEOTEXTILES IN ROADWAYS

The fabric will prevent water from washing away the gravel around or above the pipe ends. As long as the water cannot get behind or under the fabric, the gravel will be protected from the eroding effects of flowing water.

**Problem No. 2 (underdrains)**

Several roads seem to hold water under the surface. In gravel roads, this creates an unstable and muddy mess. On paved roads, the surface develops cracks and ruts and eventually potholes.

**Solution:**

Assuming there is an adequate depth of roadway base gravel and/or the pavement is thick enough to carry the traffic loads, an “underdrain” could be built with geotextile to drain this subsurface water. Typically, an underdrain is a 3′ to 5′ deep vertical-sided trench under the shoulder which provides underground drainage for the road base. This trench is filled with a slotted or perforated drain pipe and backfilled with free-draining gravel. A typical problem, though, is that water can carry “fines” into the gravel and pipe and clog it. Using a thin non-woven or a woven monofilament can eliminate this problem. First, line the trench with the fabric, install the bedding gravel and pipe, backfill with gravel, and close the fabric flaps on the top to prevent contamination with fines. Then add the surface gravel to cover it over.

**Problem No. 3 (unstable roads)**

Every spring, roads become impassable because of mud conditions. The typical cure is to 1) close the road, or 2) add more gravel to get up out of the mud.

**Solution:**

Eliminate this annual headache with a geotextile. When the road is dry, reestablish the proper crown and do any necessary ditch or shoulder work to get the water off the road. Unroll a layer of geotextile (any woven product or a heavier nonwoven) lengthwise down the road. Subsequent lengths should be properly overlapped at the sides and ends by 2 or 3 feet. Backfill the fabric with a minimum of 8” (compacted) surface gravel, shape to the proper crown and compact. On local roads which carry a significant percentage of trucks, it is probably wise to consider 12” or more of gravel.
INTRODUCTION

Successful drainage and subsurface maintenance depends on early detection of the problems before conditions require major action. Symptoms of drainage problems requiring attention include:

- puddles on the surface area,
- poor surface flow,
- slope erosion,
- clogged ditches,
- pavement edge raveling,
- preliminary cracking,
- pavement spalling or pumping, and
- surface settlement.

These symptoms indicate the start of failures which occur as soil particles are gradually washed away and as excess water seeps into the roadway reducing the load-carrying ability of the subgrade. Major failures caused by poor drainage conditions include washouts, slides, slipouts, pavement breakup, frost boils, and flood damage.

Standing water on or beside the roadway is a common sight after a storm yet it is a symptom of future problems. Water soaks into the roadbed unless the soil around and under it is relatively waterproof. Water in or under the roadbed has the same effect as paving on a layer of mud.

The purpose to drainage design is to control the surface runoff and to control the free water in the subbase and subgrade. Many of the types of drainage features are discussed in Chapter 5, “Types and Functions of drainage Features.” A summary table listing symptoms and possible solutions to help in diagnosing drainage problems is presented in the following sections.

DRAINAGE PROBLEMS ON LOW VOLUME ROADS

Drainage problems can occur over long stretches of road or may be restricted to smaller areas. Signs of the problems usually show up in the road surface, where damage has already occurred. Early symptoms can point to potential problems and immediate action can limit the amount and cost of the damage.

- Shallow side ditches.
  When side ditches are too shallow to effectively channel all surface runoff water away from the traveled way, they become sources of water for subsurface seepage. Shallow ditches usually are associated with older roads and narrow rights of way. Occasionally they are the result of widening a pavement in a cut section.
Increasing the thickness of the traveled surface may temporarily improve the riding surface, but it will not affect the level of water in the subgrade as long as the ditches remain shallow. It is important to deepen side ditches where needed and to keep clean to permit runoff of surface water. However, use care not to dig ditches so deep as to create roadside hazard.

- **Broken and clogged pipes and outlets.**
  Broken and clogged, drainage pipes may act as underground reservoirs. Stopped-up drain pipes, perforations and broken joints under the road surface are not easily detectable. Poor drainage is obvious from the condition of the road surface and replacement of the pipe may be necessary. In other instances, a thorough cleaning, or repair of a damaged inlet or outlet may be all that is required.

- **Permeable shoulders.**
  Unpaved shoulders are a potential source of seepage water. They can be deformed by frost action, erosion, traffic, and snow plowing. As they lose their shape, they lose their ability to transmit the surface runoff to the ditches. Water pools at the edge of the traveled way and infiltrates the base or subgrade.

- **Aggregate base layers.**
  Slow-draining aggregate base courses can be found on nearly all “older” local roads. Often those made of free draining materials have no outlets or insufficient outlets to meet drainage needs. One way of reducing the problem is to intercept the water before it gets to the base.

- **Trench or box sections.**
  Trench sections typically occur when the base under the traveled way is built of different material than the shoulders. Water entering the base has difficulty penetrating the adjacent shoulder material and accumulates in the base instead of being discharged into the ditch.

- **Frost susceptible soils.**
  Frost susceptible soils (clay, silt, mud, etc.) have high capillary (“wicking” ability) action and only excess free water can drain from them. Capillary moisture cannot be drained. Pockets of fine soil are usually located when weather conditions are conducive to frost heave, but may be difficult to identify during summer months unless surface failure has occurred. Subsurface drainage may be needed to lower the water table and prevent capillary action.

- **Unstable pockets.**
  Pockets of unstable subgrade can be identified by surface distress. These pockets may be highly organic, compressible soils, sinkholes, or areas of an open graded subbase surrounded by relatively impermeable subgrade. Localized springs, ground water seepage, or non-functioning subsurface drainage systems may also be causes of subgrade instability. Problem soils should be replaced, or at least reworked and blended with other soil deposits. Adequate underdrains and interceptor drains are necessary in such cases.
5. TYPICAL DRAINAGE PROBLEMS

DIAGNOSTIC AID FOR DRAINAGE PROBLEMS

Table 5-1 summarizes some of the common types of defects in and around roadways that can be directly related to failures in various parts of the road drainage system. The table shows the defect, the probability cause and suggested treatments.

**TABLE 5-1**
**DRAINAGE PROBLEMS**
- EVIDENCE, DIAGNOSIS & CURE (maybe!)

<table>
<thead>
<tr>
<th>VISIBLE SIGNS</th>
<th>WHAT IT MEANS</th>
<th>SUGGESTED ACTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alligator cracking</td>
<td>The subbase/subgrade is soaked (and has been for a long time) trucks are too heavy for the road to carry.</td>
<td>Regrade shoulders. Deepen and clean ditches. Regrade ditch. Install interceptor drains, if considered economical. Keep passable with minimum maintenance and schedule reconstruction.</td>
</tr>
<tr>
<td>Rutting, longitudinal cracking</td>
<td>Earlier stage of the above.</td>
<td>If saturated soils are the problem, try steps above. If occasionally damp, might save by recycling surface and build-up road thickness. If steps in above work, shim ruts and resurface.</td>
</tr>
<tr>
<td>Edge cracking</td>
<td>Road too narrow, shoulder poorly drained.</td>
<td>Keep shoulders graded.</td>
</tr>
<tr>
<td>Potholes</td>
<td>Extensive – road requires reconstruction.</td>
<td>Use with temporary patches and put on reconstruct/recycle list. Patch carefully – some of the “expensive” new materials are proving to be more economical. Reshape road properly for longer lasting crown.</td>
</tr>
<tr>
<td>Scoured gravel shoulders</td>
<td>False ditch left by grader, turf, guiderail not cleared.</td>
<td>Regrade and slope shoulders. Cut/remove turf and false ditches. Clean under the guiderrails.</td>
</tr>
<tr>
<td>Washouts along edge of road</td>
<td>Substandard shoulder maintenance.</td>
<td>Grade out the false ditches! Bring low shoulders up to grade of new pavement.</td>
</tr>
<tr>
<td>Scour at inlet</td>
<td>Too steep ditch grade, poor loca-</td>
<td>Rip-rap to deflect water.</td>
</tr>
</tbody>
</table>
### 5. TYPICAL DRAINAGE PROBLEMS

<table>
<thead>
<tr>
<th>VISIBLE SIGNS</th>
<th>WHAT IT MEANS</th>
<th>SUGGESTED ACTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Piping holes in gravel shoulder/road</td>
<td>Pipe incorrectly installed. Inlet needs headwall or other form of protection.</td>
<td>Properly bed and compact fill when installing pipe. “Seal” embankment around inlet.</td>
</tr>
<tr>
<td>Culvert washouts due to topping</td>
<td>Culvert too small. Both culvert and road low point at same location.</td>
<td>If it washes out, first install larger or multiple culverts. Armor the upstream and downstream slope for full width of the topping. Regrade ditch so low point not coincide with road low point.</td>
</tr>
<tr>
<td>Frost boils</td>
<td>Frost susceptible soils in roadway and source of free water.</td>
<td>Deepen ditches or install underdrains to try to lower water table. Replace frost susceptible soil if localized. Use open-graded (few fines) material in the subgrade.</td>
</tr>
<tr>
<td>Sides or slipouts on slopes</td>
<td>Subsurface water seeping from a slope or moving parallel to the surface.</td>
<td>Install one or more subsurface drains to lower the groundwater table. Undercut the slope and place a thick blanket of stone or rock on the slope – (good only for shallow slope) so that the wet slope is stable.</td>
</tr>
<tr>
<td>Unstable roadway</td>
<td>Excess water in the subgrade.</td>
<td>Try alligator cracking. Install a geotextile and gravel surface on the crowned and ditched roadway.</td>
</tr>
<tr>
<td>Ponded water in inlet ditch</td>
<td>Clogged culvert or ditch. No ditch grade.</td>
<td>Check for broken/collapsed pipe and replace if necessary. Clean out culverts and ditch and grade ditch to minimum of 1% (1 foot drop in 100 feet).</td>
</tr>
<tr>
<td>Reduced culvert outlet</td>
<td>Clogged pipe, broken joints, col-</td>
<td>Inspect pipe and clean, repair or replace as neces-</td>
</tr>
</tbody>
</table>
## 5. TYPICAL DRAINAGE PROBLEMS

<table>
<thead>
<tr>
<th>VISIBLE SIGNS</th>
<th>WHAT IT MEANS</th>
<th>SUGGESTED ACTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>flow</td>
<td>lapsed pipe.</td>
<td>sary.</td>
</tr>
<tr>
<td>Sinkholes</td>
<td>Fast flowing underground water tunnels through the subgrade causing eventual local collapse.</td>
<td>Install interceptor drains to cut off the underground flow.</td>
</tr>
<tr>
<td>Natural channel to wetland obstructed</td>
<td>Sediment and debris has filled brook channel causing flooding periodically.</td>
<td>Live with the problem. Apply for DES permit to reopen channel when you have a free week.</td>
</tr>
</tbody>
</table>
INTRODUCTION

Drainage maintenance is preserving, repairing, and restoring the features of a road that contributes to keeping it in a safe, acceptable operation condition. The importance of maintenance work is that it protects the big investments communities have made in their roads and streets.

The public is aware of the condition of roads and will voice their opinions about ragged shoulders, bumpy roads, overhanging brush and clogged culverts and ditches. At the same time, as road crews try to keep down the complaints, maintenance costs are growing at 10% per year for the last 10 or 15 years. Road departments have had to squeeze their dollars while trying to increase their budgets to meet growing needs.

Pavement management systems assist municipalities to determine where to spend their maintenance dollars.

PREVENTIVE MAINTENANCE

The road repair “strategies” applied in pavement management programs work well for local road drainage problems. In general, routine and preventive maintenance are the most cost-effective. The idea is to spot the “possible” problem before it gets to be a “real” problem and spend a few dollars now to prevent major repair costs later.

<table>
<thead>
<tr>
<th>Typical preventive jobs</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Inspect periodically.</td>
</tr>
<tr>
<td>• Clean brush before it grows to be bushes or trees.</td>
</tr>
<tr>
<td>• Do spot repairs of minor scour or erosion.</td>
</tr>
<tr>
<td>• Keep shoulders sloped and clear of false ditches or dikes.</td>
</tr>
<tr>
<td>• Seal cracks on a good surface before water penetration becomes a major problem.</td>
</tr>
<tr>
<td>• Get rid of a pothole before it becomes a bathtub.</td>
</tr>
</tbody>
</table>
6. MAINTENANCE FOR GOOD DRAINAGE

Don’t waste money on problems beyond normal repair. Spend the absolute minimum to do what has to be done to provide a passable, reasonably safe road until putting in the extra dollars and do the job right. Managers can’t afford to play “catch-up” forever. Watch for preventive maintenance opportunities. Learn to manage the maintenance work instead of having it manage the department.

MAINTENANCE MANAGEMENT

Crisis work

Crisis work is the most costly of all work. Emergency work due to storm damage happens, but many repairs are put off because of fiscal considerations. Repairs (not) done last year are getting worse, and cause more defects. It doesn’t take long to get through the year meeting one crisis after another.

Inspect all drainage facilities on a yearly basis to plan maintenance and schedules based on safety, cost savings, and convenience. Inspect throughout the year. Keep notes, and put together at budget time, or when planning work or ordering materials. Supervise and inspect the work done. And don’t plan to come back later to do the little things. Finish the job.

Decision making

Careful thought to purchasing materials, scheduling work, and using the most efficient equipment are skills used by a road manager to “save” money. There is seldom enough money to do the required maintenance, “savings” aren’t shown as hard cash but show in terms of higher levels of service and increased productivity for the same amount of tax dollars spent. Group small jobs and review them before commencing, work can result in savings that accumulate rapidly. Another technique is to stretch a job out over several budget cycles instead of six months or a year. Production and cost comparison records can aid this process and the record keeping does not need to be time consuming or expensive.

Evaluate the overall operation

How much does it actually cost per hour for crews to do various jobs?

When all crews are busy and there is still a backlog or work to be done, would it be economical to contract out some of the work? With your cost records, you should be able to decide which work should be contracted and what the fair price for that work is.

Determine priorities by making a list. First on the list are those things that have to be done to keep the roads open such as replacing collapsed culverts and repairing “sink” holes in the road and washouts. Then add the things that need to be done such as reconstructing badly deteriorated pavement, rebuilding eroded shoulders and filling potholes. Don’t forget to add to the “wish” items to save money in the long run if there were some funds to pay for them now.
Working from the master list, establish priorities, decide how many of them can be done, and schedule. Don’t forget to include at least one item from the money saving list. For example, there may be a culvert that floods and washes out every time there is a heavy rain.

**Purchasing**

**Plan ahead when purchasing materials for BIG savings.** Culverts are a good example. Purchasing each one as needed may cost, say, $7.00 a foot. Buying $1500.00 worth at a time may reduce the cost to $6.70 a foot. Buying half a truckload or a whole truckload at a time can drop the price to under $6.00 a foot. These cost figures are only examples, but the percentage of savings is realistic.

**Scheduling work**

Review work projects for the year and try to group projects of similar type or those located in a given area. This thinking can reduce time lost traveling between projects as well as the cost mobilizing equipment. Do projects that would not interfere with other planned projects.

**Equipment**

Equipment should be selected according to the work to be done. Conditions at different sites can vary widely. Suitable equipment at one site may be inefficient or inadequate at another. If the proper equipment is not available, consider renting it. It may be costlier to use equipment not suited for the job than to rent equipment or hire the work done. Another option is to share equipment and operators.

**GRADING GRAVEL SURFACES**

The most important aspect of grading gravel roads and shoulders is to maintain the necessary cross-slope for good drainage. Gravel is porous material even when properly compacted. Free water cannot be allowed to stand in depressions or ruts or it will soak into the surface and every passing vehicle will make the depressions worse. A tight compact surface with a cross-slope of 1/2” to 3/4” per foot of lane width is needed for the traveled way. The shoulder should be sloped more than the roadway. Be careful not to allow buildup from winter sand or turf to trap runoff. Serious erosion can result.
6. MAINTENANCE FOR GOOD DRAINAGE

- Grade when gravel is moist after or during a light rain.
- Grade from the shoulder toward the crown.
- Cut to the full depth of washboards or potholes.
- Operate grader at lower speeds.
- Increase crown if badly potholed. (Liquid calcium may help keep the surface tight and dust free).
- Do not leave a gravel or sod berm between the road and the ditch slope.
- Use a worker to mark and clear culverts, pick stones and trip brush.
- Be sure to crown old surface before graveling.

PAVEMENT MAINTENANCE

From a drainage point of view, pavement maintenance consists largely of sealing cracks, patching, and repairing deteriorated surfaces. Crackseal on an individual basis with the proper equipment. It is a cost effective treatment to extend the life of the pavement before more expensive maintenance will be required.

Patching of potholes is part of routine maintenance. Faulty subgrades or poor drainage conditions should be corrected prior to the repair work.

Recycling is a popular method to repair badly deteriorated pavement. New material can be added, remixed, and compacted in place. Use fabrics used when unstable subgrades are a problem. Normally this type of rehabilitation work will require a new wearing surface.

Roads are seldom perfect. They have their own stories to tell and often the pavement does the story telling.

1) Holes in the middle of the road where a culvert is located can indicate a broken pipe. Temporary repairs can often be made by placing a rigid piece of pavement or stone in the hole and then filling with patch.
6. MAINTENANCE FOR GOOD DRAINAGE

2) Slumping of pavement along both sides of a culvert crossing the road may indicate that the bottom of the pipe is rusted out. Temporarily fill with patch until repairs are made.

3) Frost heave of culvert may indicate ends of pipe exposed to winter weather. With luck, pipe should settle to original position with spring thaw.

4) Frost heave of culvert accompanied by slumping along both sides of the culvert during spring thaw can indicate poor compaction of materials around culvert and/or infiltration of water around pipe. Temporarily plane off the frost heave with a front end loader and fill the slump with patch. Then reset the pipe properly.

5) Slumps in the road surface may indicate underground seepage or unstable soils. Temporarily fill with patch and then intercept seepage and/or replace soils.

6) Rutting of the pavement can indicate inadequate base or unstable subgrade. Improve ditches to reduce infiltration and improve surface drainage.

7) Wet pavement, especially around cracks, indicates saturated base. Improve drainage to allow base to dry out.

8) Alligator cracks and a saturated base during spring thaw can cause pavement to be picked up and pulled away by passing traffic. Temporarily delay this by sanding with a highway sander. The sand will bind the pieces together and keep the pavement in place. Identify the source of water and correct the drainage problem before wasting money on costly repairs.

DITCH MAINTENANCE

A ditch should be built to channel water away from the road system without creating erosion. Ditches are constructed in four basic shapes: “V” shape, rectangular, trapezoidal, and parabolic.

“V” shaped ditches are self explanatory. They are constructed by a grader, front end loader, or by the use of a special ditching bucket attached to a backhoe or excavator. They are easily made with a grader and if the slopes are moderate, vegetation can be established and erosion can be kept to a minimum.
6. MAINTENANCE FOR GOOD DRAINAGE

During heavy flows, the water in a “V” ditch is concentrated and moves more swiftly but a grader operator can improve these flow characteristics by rounding the bottom of the ditch. This is done by running the wheels of the grader along the ditch line, especially while shaping the backspades.

Rectangular ditches are usually constructed by placing a backhoe directly in the ditch and traveling lengthways along it. This is a cheap and fast way to establish or clean a ditch. The flat bottom has the advantage of spreading the water out and slowing it down, but the square sides are difficult to establish vegetation on and cave-ins are common. Emergency maintenance may be required when a blockage occurs. Schedule maintenance more frequently than for any other type of ditch and therefore, this type is not recommended.

The trapezoidal ditch is an efficient means of channeling water away. Sloping sides allow vegetation to be established and the flat bottom spreads the water out and slows it down, reducing erosion. Because of its shape, it has the capacity to carry more water than the “V” or rectangular ditch. It requires more expertise on the part of the operator to construct and it requires more right-of-way width. This shape is more expensive to build but it does require less maintenance.
The parabolic ditch is constructed using the front end loader, backhoe, or excavator. It requires the removal of more fill than either the “V” or rectangular ditch. Sloping sides and a rounded bottom are easily vegetated and reduce erosion. Capacity is roughly equal to the trapezoidal. In terms of efficiency and long term cost effectiveness, this ditch may be the best bet.

GUIDELINES FOR DITCHING

- Ditch maintenance is one of the most important drainage operations.
- Either a grader or a backhoe with a grading bucket can do ditching, but production under normal conditions is much higher with a grader.
- The bottom of the ditch should be both compacted and rounded.
- Avoid high and low points. Keep a uniform grade and check it for accuracy.
- Keep the shoulder width the same.
- Inspect ditches and schedule cleaning every few years.
- Seed, mulch and use fiber mats to assist revegetation.
6. MAINTENANCE FOR GOOD DRAINAGE

CHECKLIST FOR DITCHING

√ Are ditches deep enough to drain subgrade and/or cut off subsurface water?

√ Are ditches broad enough?

√ Is there adequate slope in the ditch line to prevent ponding?

√ Is the ditch free of obstructions (heavy brush and debris)?

√ Has erosion started at spot locations in the ditch?

√ Is a paved or stone-lining needed?

√ Could debris control devices be used effectively at some locations?

√ Are paved and stone lined ditches in good repair?

√ Do the ditches have an outlet?

√ Is the ditch far enough away from the pavement?

ROADSIDE VEGETATION CONTROL

Roadside mowing is done to provide better sight distances, to improve appearance and to improve drainage. The use of herbicides by town road crews is not recommended unless trained and certified personnel are available.

In general, accessible roadside areas should be mowed back and kept clear of brush and weeds. Pay special attention to sight distance obstructions at intersections and to vegetation blocking traffic signs. Cut brush and weeds that block drainage ditches.

The rule is to remove trees and brush before they grow to where they are roadside hazards.

CULVERT MAINTENANCE

General Culvert Principles

- Inspect on a regular basis.
6. MAINTENANCE FOR GOOD DRAINAGE

- Protect inlets and outlets by marking their location, stabilizing entry and exit zones, use headwalls and endwalls, and maintaining ditch linings to prevent erosion.
- Practice preventive maintenance to avoid clogging, collapse, washouts and settlement.

However, culverts do become clogged with eroded soil, rocks, sticks and leaves. *Inspect culverts often, but at least each spring and fall.* A rain event is a good time to check drainage. You can often spot small problems before they develop into larger ones. Sometimes culverts will flush themselves if rocks or sticks are removed. In other cases they may have to be flushed with water. Flush from the outlet and clean the outlet ditch when through if necessary. There are several machines that deliver high pressure water through special nozzles or tips made for this type of cleaning job. If available, a fire truck with a 1-1/2 inch line and a straight tipped nozzle work well.

### COMMON SENSE CULVERT PRACTICES

<table>
<thead>
<tr>
<th>Installation</th>
<th>Maintenance</th>
<th>Inspection</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Lay pipe up hill from the outlet end.</td>
<td>- Replace culverts with the same size pipe if it has been handling flow satisfactorily.</td>
<td>- Inspect culverts every chance you get but at least every spring and fall and following heavy storms.</td>
</tr>
<tr>
<td>- Bed pipe and backfill by the rules!</td>
<td>- Pay special attention to water action at the culvert inlet.</td>
<td>- Mark all drainage facilities to insure that they are not “skipped” during inspections.</td>
</tr>
<tr>
<td>- Use excavated material for backfill to minimize differential frost heave.</td>
<td>- Use high pressure flushing to effectively clear most plugged culverts.</td>
<td>- Identify outlet end of underdrain and keep it clear. Periodic inspection can tell if the underdrain is functioning properly.</td>
</tr>
<tr>
<td>- Try to install culverts so as to allow at least 2 ft. of cover below the top of the subgrade.</td>
<td>- Flush culverts from the outlet end.</td>
<td>- Monitor culverts with running water during freezing weather and take action if they start to freeze.</td>
</tr>
<tr>
<td>- Provide debris barriers upstream of inlets which are subject to frequent blockage.</td>
<td>- Be sure to clean the outlet ditch after flushing.</td>
<td></td>
</tr>
</tbody>
</table>
John Windish of Barnes County, North Dakota devised this technique for opening frozen culverts. He suspends a one-quarter inch diameter wire through the pipes which freeze most often. When ice blocks the pipe, he hooks up a portable welder to the wire and melts the ice around it enough to start water flowing again. The moving water continues to increase the flow opening.

The ends of the wire are attached to steel posts in the embankment at each end of the culvert. The wire remains suspended in the pipe permanently until a freeze-up calls for removing the wire from the posts and hooking up the welder again.

The sketch in Figure 6-1 shows the layout for John’s portable welder culvert thawing technique.

![FIGURE 6-5. CULVERT THAWING METHOD](image)

Figure 6-6 shows a high pressure jet nozzle operating in a drain tile. Commercial systems are locally available, such as:

1) a tow behind that operates at a flow rate of 28 gallons per minute at 1600 psi,
2) a pick-up sized unit or truck-mounted unit that operates at 35 gals. per minute at 2000 psi, or
3) a trailer-mounted unit that operates at 5 gallons per minute at 3200 psi.

High pressure units use much less water (250 gals. should do two or three typical culverts) than the relatively low pressure fire hose treatment.
6. MAINTENANCE FOR GOOD DRAINAGE

FIGURE 6-6. USING HIGH PRESSURE JET NOZZLES IN SUBSURFACE DRAINS
A. Scouring and removing silt and mineral deposits
B. Removing roots

**Culvert replacement vs. liners**

This method involves lining an existing pipe which is buried under a deep fill or under a road with a high traffic volume, instead of digging up the road.

The NHDOT lines the inside of an old culvert with plastic pipe and grouts the space between the two.
6. MAINTENANCE FOR GOOD DRAINAGE

Winter Preparation

- Check culverts, clear away leaves or other debris.
- Mark ends of culverts and drains you need to find later.
- Keep ditches open.
- Repair low shoulder areas.
- Culverts whose ends are covered by snow in the winter often freeze and heave less. Extend the end or try to avoid exposing them while plowing. In some areas, brush or plastic may be bridged over the inlet or outlet. Care should be taken that this material doesn’t obstruct the openings.

BRIDGE MAINTENANCE

In New Hampshire, the state DOT inspects bridges and reports their conditions every two years. Much to do with bridge repair and maintenance is a specialized job that may need to be contracted, but there are maintenance activities that local crews can do.

1) Flush dirt, sand, and salt off a bridge each spring. Consider carrying the material away rather than “flushing” in environmentally sensitive areas.
2) Protect exterior surfaces as recommended by the DOT.
3) Clear channels, as permitted, of all debris, particularly trees and bushes.
4) Repair the deck surface as needed.
5) Cut trees and brushes before their roots grow into foundations or wings and cause serious damage.

Flood impact planning includes additional precautions that local crews can take to greatly reduce serious damage even under extreme water conditions.

FLOOD-PROOFING “YOUR ROADS”

-- Before, During, and After --

Damage to ditches and roadway culverts, while not the most costly to repair, constitutes most of the damage to highways and is the cause of most road closures.

As highway professionals, we can:

1. Plan for that next occurrence. (mitigate)
2. Reduce damage to the roadway system when the next disaster hits.

No one can really plan for a disaster, as each one is unique. We can, do things to improve response time and effectiveness in emergency repair efforts. It is essential to know in
6. MAINTENANCE FOR GOOD DRAINAGE

advance what resources are available in a community for recovery efforts. As highway people, we need to know:

1. where the equipment is in a community,
2. where are the gravel pits,
3. where are the spare culverts, and
4. where are the barricades and warning signs.

See the website: www.t2.unh.edu/ma to learn about public works mutual aid.

Emergency Route Planning

Of extreme importance is knowing what roads in the community are essential to the recovery effort. If a community road system has been extensively damaged, state roads will also have experienced similar damage. These major roads into and through a community may be impassable for a period of time. A community may have to rely on its own resources for a period of time immediately after a disaster.

Periodically meet with all emergency agencies (local, county, state, and federal) to create a familiarity and working relationship essential in emergencies. At the meeting determine how to access all facilities for disaster recovery and how to develop an Emergency Route Plan.

In developing this Emergency Route Plan, the highway department knows the road system and what sections are prone to damage. Bypass these trouble spots when developing the Emergency Route Plan.

When a trouble spot cannot be bypassed, this is an area that should be a prime candidate to “flood proof” or make more resistant to damage. Strengthening the weak links in the Emergency Routes only makes good sense.

The Emergency Route Plan must receive priority repair attention. This plan, if approved by the town’s governing body, also gives the highway department a defendable position when John or Jane Q. Public calls to request repairs to their road.

ROAD CREW SAFETY

Departments can operate in a snowstorm and try to operate in a blizzard but cannot operate in a hurricane and cannot stop a flood. The highway and road system is the primary means for the movement of people and materials necessary for all recovery efforts, it is essential that crews are not put at risk trying to keep the roads passable during the height of a storm.
6. MAINTENANCE FOR GOOD DRAINAGE

Know when to quit and send the crew back to the shed. Establish policies that govern when operations must stop and when to seek shelter. When winds exceed 70 miles per hour, there is little a person can do out-of-doors, and their risk of injury from flying debris is great.

If possible, limit work during severe weather to barricading dangerous areas, especially when complete roadway washouts have occurred. Keep the policies fresh in everyone’s mind, because under the stress of the work they may just want to erect a few more barricades before the storm gets real bad, and - - - -?

“FLOOR PROOFING” TECHNIQUES

The following nine diagrams give some practical tips on how to “flood proof” roads, culverts, and ditches.
Runoff damage to highways and roads starts in the form of ditch washouts. The erosive action progresses into the roadway shoulder and then into and under the pavement. The resulting damage can range from just a little erosion in a ditch to complete loss of a section of highway or road. As the erosion of the highway occurs, the loosened material is carried in the flow to the nearest culvert and further overloads the culvert possibly to failure. Once this occurs, the runoff bypasses the blocked culvert and rushes downhill to the next culvert, adding additional stress and possibly damage to this culvert. This buildup of water continues until it reaches the bottom of a hill.

The culvert at the bottom of the hill usually is not large enough to handle accumulated runoff. Water builds up over the culvert until the water runs over the top of the roadway embankment. Water flowing over the embankment erodes the down slope of the embankment.
and washes it out. Depending on the volume and duration of the runoff, the embankment can completely wash out. This washout is usually severe enough to result in a road closure.

The above described process is repeated wherever uncontrolled runoff is allowed to flow. Anyone familiar with road repair has seen this occur all too frequently.

*The following suggestions should be considered whenever working on drainage features, whether or not you are doing repair after a storm or routine road maintenance or reconstruction:*

1) Remember to consider the Emergency Routes when planning the road work each year. Funding is always a problem which prevents departments from doing all the work needed. However, gradually pick away at the problem areas, to do improvements of critical routes needed to provide a substantially more reliable, storm-proofed or resistant system.

2) It is always best to have a culvert size based on a drainage study and runoff estimated for a 100-year frequency storm. However this method of determining proper size of replacement culverts is usually not how maintenance personnel determine proper sizing. Generally, departments install a slightly larger culvert and hope it will improve the likelihood that it will survive the next major storm.

When installing larger culverts, be advised that departments may be adversely affecting their rights to continue draining onto private property. A drainage easement may have to be obtained. In many cases this will not be easy as no one wants a culvert outletting onto their land and a larger culvert, in their opinion, may mean more water.

Immediately after a major storm has washed out a problem culvert may be the best time to obtain a drainage easement. The road washout is fresh in the landowner’s mind and it probably inconvenienced him/her and done damage to his/her property. A larger culvert at the location might have handled the flow that the smaller, old culvert could not.

3) Many common sense and practical maintenance practices can reduce the detrimental effects of a severe rain and runoff. Well-vegetated slopes and ditches will hold soil from washing into and along drainage ways and plugging culverts. Vegetation will not hold in all cases as the hydraulic forces exerted by rushing water are tremendous.

*Remember water is going to take the path of least resistance.* We have all see cases where someone tried to make water change its course abruptly. Repair work is usually guaranteed here.
“V” ditches are easy to build, especially with a grader, but they are very prone to erosion. If a ditch has to carry heavy flows, *stay away from this shape of ditch and consider a rounded or trapezoidal shaped ditch.* These shaped ditches spread the water over a wider surface which reduces scouring of the ditch.

Consider “armoring” the bottom of these ditches, using either dumped stone, or some type of riprap. Under certain situations, concrete or asphalt can be used as a ditch liner. With these products, use care to ensure water is not allowed to get under the liner, resulting in washouts of the liner.
This diagram shows a culvert with a crushed end. Crushed culvert ends, especially driveway culverts are common and block the flow of water. Typically, debris and sediment accumulate rapidly to further block the culvert.

Driveway plows missing the driveway entrance or vehicles backing over the culvert ends are a fact of life. Use a small hydraulic jack, pry bar and a few wooden blocks to open up these ends. The time and effort to do this, however, can greatly reduce washout repairs.
All landowners want water to run OFF their property but few wants it to run ONTO their property. They want that narrow strip of land on which the road is placed to carry all the water along it to a major waterway. Discourage this practice to prevent water from pooling in ditches. Outlet water whenever possible along the roadway. Don’t let it build up. Water volume and velocity is what causes the damage. If water must stand in the ditch then consider “armoring” it to keep it stable when the ditch must carry high flows.

When outletting water onto adjacent property, it is highly recommended to obtain a drainage easement from the property owners. See the UNH T² Center for a sample drainage easement. Once the easement is obtained, register it with the court.
FIGURE 6-11

Have you ever noticed that we seem to build roads so that the sag or low point is exactly over the river or stream where the culvert has been placed? If the culvert cannot handle a heavy flow of water and water flows over the road washing it out, we lose BOTH the fill and the culvert. In the lower example, we may lose the fill but the culvert has not been lost. It is much easier to rebuild the fill than having to replace the culvert and the fill. There is an added advantage to the clean-up efforts if the low point in the road is not over the culvert. The gravel is likely to end up in the nearby field or woods and NOT in the river or stream. Recovery of this gravel may be much easier in this situation.
If a road is going to flood, you might be able to keep the flooding down to a depth that can be negotiated by emergency vehicles. If a much larger size culvert (and higher road) is too costly, consider two options to reduce the depth of flooding. First, install a series of culverts to handle the flow. Second, consider building a flat, zero percent grade, section of road for a distance necessary to keep the water depth over the road to an acceptable depth.
When considering a bridge replacement, ask how critical is this bridge to the emergency route system? If it is critical, then pay for the larger structure that has the capacity to handle the flow. If the bridge is not on a critical route, considering designing the bridge to be above the flood flow and allow the approaches on either side of the bridge to flood. When the flood waters subside, the bridge will still be there and repairs will be confined to just the approach fills.
Anytime you have water flowing over a roadway fill, the fill acts as a dam, and consider “armoring” the down stream side of the fill. Erosion starts on the downstream end and works backwards. If you can keep this erosion from occurring, you will not lose the fill and the road will be useable when the water levels subside.
When a culvert is placed under a very high “head” and a whirlpool occurs over the culvert inlet, the culvert is placed under tremendous pressure. The water running through the culvert can cause the culvert to vibrate and the saturated soil around the pipe may be washed away. Culverts can blow out from under the fill leaving tunnels where there once were culverts. These tunnels will collapse under traffic loading. Use caution when checking a section of road that has been under water or its culverts under heavy flows. Check every culvert before traffic is allowed to use that section of road.
6. MAINTENANCE FOR GOOD DRAINAGE

A word about the next disaster. First, there will be a next one! Second, take pictures and lots of them, to document road damage. It is easy to get involved in the emergency repairs that we don’t document the damage. Pictures are excellent documentation. Any work records should identify when and where work was done. Take measurements and make sketches of damaged areas. Disaster money may be available and the better departments can document the damage to your roads, the easier it will be to get deserved disaster relief funding.
INTRODUCTION

Protecting public works employees from the dangers they are exposed to while doing their normal job should be a top priority for any road department large or small. Protecting the traveling public from unsafe conditions is equally important. In recent times, the loss of sovereign immunity by many state and local governments and awarding financial judgments as the result of unsafe practices by work crews on their daily job has brought the safety issue into sharper focus. There are two sides to every issue but at least one positive outcome of this one is to bring considerable pressure to bear on local officials to provide safety training and education for local public works people.

There is still a long, long way to go to raise safety awareness of field crews to acceptable levels. Do not pass up the opportunity to demonstrate that SAFETY IS AN INTEGRAL PART of any roadway drainage work. Work zone signing is an inseparable part of maintenance work. Excavating and trenching, with its life threatening potential, is an everyday part of utility and drainage projects.

The remainder of this chapter is devoted to stressing the critical need to make safety a routine part of the days work. Using safety precautions that could save a life should become automatic.

Safety is an integral part of the working environment. No one wants to suffer or to see a fellow worker suffer because of an injury. The family of the injured worker suffers, the job suffers because a trained worker is missing from their position, the budget suffers because new people have to be trained, fellow workers suffer because they have to pick up the load, and the public senses that someone didn’t know what they were doing.

WORK ZONES FOR SAFETY

Whenever work is done on or near a highway, such as installing a sewer, patching a pothole, replacing a culvert or cleaning out a ditch, drivers are faced with changing and unexpected traffic conditions. Usually part of the roadway will either not be usable or it will have a rough surface. Unexpected changes are hazardous for drivers, pedestrians, and for the construction workers.

A workzone on a busy road is a dangerous place. Working on our roads is more dangerous than those other types of careers (often assumed to be more hazardous, such as police work or fire control). Numerous highway workers, flaggers, inspectors and vehicle operators have been killed and recent statistics do not indicate any major improvement. It is mandatory to consider the safety of our citizens passing through work areas, and the safety of the workers themselves.
Every public or quasi-public agency (State, County, City, Town, Utility, etc.) working in the roadway has a duty to provide protective measures for the benefit of drivers, workers, and pedestrians. Damage or injury as a result of failure to perform this duty can result in liability and tort claims.

The Manual on Uniform Traffic Control Devices (MUTCD) is the national standard for traffic control used during construction, maintenance and utility activities. It is applicable to all streets and highways. It serves as the standard for all government and public agencies. It sets forth basic principles and prescribes standards for the design, application, installation, and maintenance of the various types of traffic control devices required for work activities on public streets and highways. Included are requirements for color, size, shape, location and need for the control devices.

In all cases, any work zone traffic control plans must conform to or be based on the MUTCD. Adequate protection of the traveling public, workers, and pedestrians is the primary goal. Protection must be consistent with the information presented in the MUTCD.

RESPONSIBILITY

The MUTCD provisions for public protection are for application by:

- State highway departments and MUNICIPAL forces performing construction or maintenance operations on public streets;
- Contractors employed in road or street construction or maintenance under contract to any governmental authority; and
- All others, including employees of public utility companies performing any work on highways, or so closely adjacent to highways, as to create hazards for the public or themselves.

Adopt the standards, as presented by the Manual on Uniform Traffic Control Devices. THIS IS YOUR DUTY. Employees should be thoroughly versed in standard work zone traffic control procedures and all pertinent instruction should be included in specifications for all contract highway work whenever road and street repair or construction is being performed.

It is important that the authorities having jurisdiction be able to require:

- that proper work zone protection be instituted,
- that responsibility be clearly assigned,
- that adequate training of personnel be provided, and
- that there is adherence to the standards and provisions of the Manual.

A city or town cannot delegate or escape this duty. Even if a contractor is working on a roadway under your jurisdiction, you still have the ultimate responsibility for any damage.
or injury which may occur. You must take proper precautions to protect drivers, pedestrians, and workers. In these cases the contract agreement must spell out the requirements of the work zone traffic control.

**REQUIREMENTS FOR SAFE WORK ZONE TRAFFIC CONTROL**

The requirements for safe work zone traffic control consist of three basic elements.

![Diagram: Advanced Warning, Clear Directions (delineation), Worker Safety]

**Warning Signs**

Warning Signs inform drivers of the hazards ahead. Warning signs must describe the conditions accurately and indicate any special actions required by drivers.

Usually drivers will be expected to choose appropriate actions, but they must be warned sufficiently in advance of the hazard.

Locate warning signs far enough in advance so the driver can read the sign, understand it, and take any necessary action before being presented with the next sign or control device. Remove or cover signs when workers are not present.
SIGN SPACING

<table>
<thead>
<tr>
<th>General Conditions</th>
<th>Speed</th>
<th>Distance from Last Sign to Start of Work Area*</th>
<th>Spacing Between Signs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban, Residential</td>
<td>0-30 mph</td>
<td>300 ft. (0.05 mile or less)</td>
<td>300 ft. (0.05 mile or less)</td>
</tr>
<tr>
<td>Urban, Arterial</td>
<td>30-45 mph</td>
<td>500 ft. (0.10 mile)</td>
<td>500 ft. (0.10 mile)</td>
</tr>
<tr>
<td>Rural</td>
<td>45-55 mph</td>
<td>500 ft. (0.10 mile)</td>
<td>1000 ft. (0.20 mile)</td>
</tr>
<tr>
<td>Expressway</td>
<td>55-65 mph</td>
<td>1000 ft. (0.20 mile)</td>
<td>1600 ft. (0.30 mile)</td>
</tr>
</tbody>
</table>

*“Work Area” includes the entire area being protected from traffic.

Table 7-1

Advanced warning signs should not be closer than 500 feet on rural higher speed highways, or closer than one-half mile on expressways. Lesser distances are permissible on low speed or urban streets and low volume roads.

A “Rule of Thumb” for sign spacing is:

(a) 300 feet minimum for urban, residential or business districts with speeds 50 mph or less.
(b) 500 feet for urban arterials and rural roads, or with speeds 45 mph or faster.
(c) 1,000 feet minimum for expressways.

The location of advanced warning signs may need to be adjusted when special problems are found, such as the different lengths of city blocks; the lack of visibility due to trees, poles or other signs; curve signing; and cases where the warning signs themselves would block the view at driveways and intersections. In all cases, however, the driver must be adequately warned.

Delineation

The proper travel path for vehicles (and pedestrians, if appropriate) must be evident at all times of day or night. Drivers must be able to understand and follow the delineated path. If drivers become confused, then the selected traffic control arrangement is improper and unsafe. It must be revised.
Delineation simply provides directions to drivers. Instead of drivers having to stop and ask, the directions are posted in the form of traffic control devices, such as cones, barricades, signs, flaggers, delineators, flashing arrow boards, etc. The directions tell drivers how to move safely through and around the work area. All signs, cones, barricades, and flaggers work together to guide traffic safely and efficiently. Some of the common delineation or direction devices are described below.

(a) Channelizing Devices
Cones, drums, panel markers, barricades and barriers guide traffic away from the work area and into open lanes. These channelizing devices are the primary means of delineating travel lanes. They are also used as tapers to move traffic from one lane to another. They must be kept clean and, if used at night, fully reflectorized. Channelizing devices must also be preceded by adequate warning devices.

(b) Signs
Signs also give directions to motorists. Regulatory and guide signs tell the driver how they must change speed or direction to pass the work area safely. Detour signs and arrows also guide traffic. All signs must be fully reflectorized or illuminated when used at night.

(c) Flashing Arrow Boards
Flashng arrow boards are highly visible directional devices that are particularly effective on highways where both speed and volume are high and an unexpected change in direction or lane closure is used. They are also commonly used at temporary detours around bridge construction sites. Application on low volume roads may be limited.

(d) Flaggers
Flaggers are used to direct traffic around a work area where:
(1) two directions of traffic must use a single lane, or
(2) traffic must be temporarily stopped to allow for movement of work vehicles, or
(3) traffic must be slowed to “squeeze” by a constricted work area.

(e) Lights
Flashing or steady burn lights are used as supplemental devices to indicate particular hazards. Steady burn lights emphasize an especially hazardous area within the workzone during the night. Lights are necessary if channelizing devices are not reflectorized.

(f) Barriers
Barriers are designed to physically prevent vehicular access to some part of the roadway or hazard area. There are four primary functions of barriers:
(1) to keep traffic from entering dangerous work areas, such as deep excavations.
(2) to provide positive protection for workers,
(3) to separate two-way traffic, and
(4) to protect critical construction such as timber falsework, concrete forms or other exposed work from getting hit by vehicles.
The exposed ends of barriers should have special treatment to minimize any impact damage to vehicles. Flared end treatment or crash cushion installations are common.

(g) Pavement Markings
Pavement markings may be used for long term traffic shifts. Remove old ones and apply the new markings before traffic is shifted to avoid any confusion.

Worker Safety

Safety of the worker should have a high priority throughout all stages of the work. It is a duty of public agencies to adequately provide for worker safety when setting up work zone traffic control measures. Some guidelines that may be helpful are as noted:

(a) Follow the standards in the MUTCD. Avoid using severely restricted travel paths or drastic changes in alignment within the work area.
(b) Separate work areas from vehicular traffic flow.
(c) Minimize traffic conflicts with workers and equipment. Use portable barriers.
(d) Provide a buffer space between traffic and workers.
(e) Provide for safe access for employees to work area and storage area.
(f) Properly warn motorists and delineate traffic through work zones.

Failure to perform these duties places the city or town at risk if damage or injury occurs.

PREVENTING SUCCESSFUL TORT CLAIMS

The public official should develop a defense against possible tort claims – a defense centered around the use of sound judgment, due care, and standardized guidelines and principles.

Officials need to know that the risk of tort claim is real and that, without a proper defense, the claim may very likely be successful.

An effective defense requires the application of three basic elements:
(a) Use a standard procedure.
(b) Apply the standard reasonable.
(c) Train employees.
A local government must have standard procedures. It must be based on the MUTCD, be workable, and one that their employees know how to apply. If applied properly the risk of tort claim will be nil. This is what some call a “prevent” defense. **IT ALL TAKES PLACE BEFORE YOU GET TO THE COURT ROOM.**

**APPLICATION OF STANDARDS**

Performing a duty properly means doing what a reasonable and prudent person would do in a similar situation. Or better stated, doing the very best job you know how to do under the existing conditions.

Going by the book is not, and never has been, the sole answer. Thus, any application of standards should consider that where more is required to create “reasonable safety”, then more should be done. But how does a person know where “more” might be required, or when “adjustments” should be made? That is when the reasonable and prudent man comes into play. **DO WHAT YOU THINK IS RIGHT.**

In making such decisions, it helps to know the following basic considerations supporting the use of all of the traffic control devices:

- Warning signs in work zones are always black legend on orange background and typically diamond-shaped.
- Warning signs should be given priority by being placed so to be observed before other devices that are competing for the driver’s attention.
- Legibility is a function of letter size. However, cleaning and maintaining signs are extremely important.
- Signs used at night must be checked for reflectivity.
Signs must be placed where they can be seen.

Warning signs must be placed far enough in advance of the work areas for a driver to react properly (30 mph ≤ 100’; 31-40 = 350’; 40 > 500’).

Channelizing devices are only part of a total signing system. They should not be used without warning signs.

Suggested spacing for channelizing devices is two times the operating speed.

Channelizing devices can be a hazard. Use crashworthy devices. Use lightweight materials that will cause little or no damage when hit. Do not use solid blocks or rocks as ballast.

Taper lengths for lane changes must not be severe or abrupt. Total length should be equal to lane width x speed in MPH.

Provide a buffer space should be provided behind the channelizing devices and before the hazard.

Flaggers are responsible for the safety of traffic and of workers. Their job is important enough and they should not be assigned any other duties (such as dump trucks or check grades).

Whenever a flagger is on duty, the advance flagger sign must be displayed.

Since it is not known when an accident will occur, the key to defending cases in courts of law is a “prevent” defense. Public officials should maintain a careful record of job-related activities to document their efforts to provide good traffic control at the worksite. In case of an accident, project personnel should promptly record and document the circumstances and pertinent factors. Photographs are recommended.

CONCLUSIONS

Public officials must constantly modify and update policies and procedures regarding work zone safety. Managers should not be nearly so much concerned with the lawyers as with attempting to ensure the absolute safest conditions on and along your roadways at a reasonable cost. Certainly, one cannot ignore what is happening in the courts, but some people are concerned that all of our attention may be directed to staying out of court rather than in providing safer roadways.

The days of sovereign immunity are gone – the public demands that State and local highway departments be responsible for their actions. The correct response to this aspect of the work zone safety and liability crisis is not to lambaste the lawyers who are serving their clients, the public, but to insist on proper traffic control techniques and procedures to warn and guide the public. Work zones should be as safe as reasonably possible. Work zone traffic control should be carefully considered, documented, implemented, maintained and inspected. To do otherwise is a disservice to the public which we serve, both from a liability and safety viewpoint.
7. WORKER SAFETY – ON THE ROAD AND IN THE TRENCHES

Contact UNH T² Center, NH Department of Transportation, or American Traffic Safety Services Association (ATSSA) for publications or videos on work zone traffic control.

SAFETY IN THE TRENCHES

The NH Department of Labor and the Occupational Safety and Health Administration (OSHA) have tight regulations on trenching and excavation activities. Also see Department of Labor Lab 1400 rules. *These rules apply to anyone who is digging into the earth for whatever reason.*

In terms of municipal work, all excavations relating to culvert replacement, underdrain installation, utility repair, etc. must be properly stabilized to protect the worker(s). Some of the requirements include:

- protection from cave-in of adjacent soils
- examination of the trench by a competent person
- placement of all material or equipment at least 2 feet from the edge of the excavation
- daily inspections of the excavation by a competent person
- determination of all underground installations (sewer, telephone, etc.) before digging.

TRENCH EXCAVATION

Over a period of several weeks, a plumbing contractor made sewer connections to houses in a new development. Local plumbing inspectors who witnessed connections to 11 houses never objected to the work being done in unprotected trenches – some as deep as 15 feet. The project had progressed well and only one connection remained to be done. While the plumber was making the final connection, the trench walls gave way, burying him beneath 12 feet of dirt.

Investigators determined that the trench, which had been dug the previous day, had remained open overnight. It rained heavily during the night and runoff had saturated the surrounding ground. Even though excessive moisture is a well-recognized hazard in excavating, the plumber ignored it. It was the last mistake he made in his life.

In another case, workers familiar with cave-in hazards refused to follow their forman’s orders when he told them to complete a water connection in an unprotected trench. The foreman accused them of being cowards; then to show how brave he was, he entered the trench and made the connection himself. As he was about to climb out, one side of the trench collapsed on top of him. He did not survive.
In yet another case, two utility workers were buried alive while attempting to repair a broken sewer line. A trench box, which would have provided them with a safe place to work, was lying on the ground not more than 15 feet away. When investigators asked why it was not in the trench, workers said that it was too much trouble to use.

**MYTHS EXPOSED**

All of these trenching accidents were preventable if the people responsible for the project had recognized the serious nature of excavation hazards and had taken protective measures. To some extent, construction folklore may be blamed for the contempt that some workers and construction supervisors have for excavation safety. A few of the more widely held bogus beliefs about cave-ins are:

**MYTH:** It is possible to out-run a collapsing excavation wall.
**FACT:** The laws of physics dictate that dirt falling a distance of only 10 feet will be moving at 25 feet per second. An Olympic runner would have trouble moving that fast.

**MYTH:** Dirt smells or sounds peculiar just before it caves in.
**FACT:** There are no audible or olfactory indications that dirt is about to move.

**MYTH:** A rope tied around the waist and extended to the top of the trench will help rescuers find you if the trench caves in.
**FACT:** It might, but you’ll be dead. Dirt weighs about 90 to 110 pounds per cubic foot depending on its type and moisture content. Once it surrounds and compresses a victim’s chest, breathing becomes impossible. Death occurs within four to six minutes. A cubic yard of dirt contains 27 cubic feet and weighs more than one and a quarter tons. Assuming that under the best conditions dirt could be removed at a rate of two cubic feet per minute, it would take almost 15 minutes to dig a victim out. In most cases, cave-ins involve many cubic yards of soil and require hours of digging.

**MYTH:** Cave-in victims can be dug out easily with a backhoe.
**FACT:** In cases where backhoes have been used, victims were usually disemboweled or decapitated.

**MYTH:** The local fire department has a trench rescue unit that can respond in an emergency.
**FACT:** By the time the trench rescue team arrives, the victim is dead. Trench rescue units are stocked with equipment that provides fire fighters with the protections they need while recovering the body.

**MYTH:** Work can be completed and the trench back-filled so fast that it will not have time to collapse.
**FACT:** A trench can collapse at any time without warning.
EXCAVATING HAZARDS

Excavating is one of the most hazardous jobs in the construction industry and most excavating fatalities are the result of cave-ins. The exact number of excavation accidents that occurs annually is unknown because many are not reported to the Bureau of Labor Statistics (BLS). Those that do get reported are difficult to identify because the accident coding system does not have a separate category for cave-ins. Instead, they are included in other accident categories such as “caught in”, “caught under”, or “caught between” or as asphyxiation’s. As a result, it is virtually impossible for the BLS to differentiate between accidents resulting from cave-ins and those caused by machinery or equipment.

Faced with these obstacles, OSHA attempted to determine the extent of excavation accidents by reviewing newspaper articles and inspection case files. This review led to a report issued in 1975 which indicated that about 100 cave-in fatalities occurred annually. A more recent NIOSH study of inspection data confirmed OSHA’s 1975 estimate and suggested that at least 97 die every year in excavation-related accidents.

NEW RULE NEEDED

OSHA’s standards governing trenching and excavating were among the first issued by the agency. Since their adoption in 1971, they have continued to confuse and confound both contractors obligated to follow them and compliance officers pledged to enforce them. The storm of controversy prompted OSHA to commission the Natural Institute for Standards and Technology, (NIST) to evaluate the 1971 standards to determine their compatibility with today’s “General Protection Requirements”, “Specific Trenching Requirements”, and “Specific Excavation Requirements.” While no one disputed the fact that the “General Protection Requirements” applied to all excavations, there was some strong differences of opinion as to when the other two sections should be enforced.

Since all trenches are excavations, OSHA held that both sets of specific requirements were enforceable during trenching operations. However, if an excavation was not a trench, the agency held that only the excavation requirements applied. Some contractors had a different opinion. They argued that the trenching requirements applied to all other excavations.

The revised standard clarified this ambiguity by establishing one set of requirements for all excavations.

TERMS REDEFINED

The existing standard required construction practices. NIST initiated its study in 1976 and summarized its findings in a series of reports published in 1979 and 1980. These reports, and other studies based on state and private sector data, provided the basis for the revised standards which became effective on Jan. 2, 1990.

The existing standard was divided into three sections: that trenches be protected whenever a hazard was posed by “moving ground.” Unfortunately, the standard never explained...
what “moving ground” was, leaving contractors in a quandary as to when precautions should be taken.

A similar problem was posed by the term “angle of repose”, defined as “…the greatest angle above the horizontal plane at which a material will lie without sliding.” The standard established different angles of repose for different types of soil, but the definitions used to describe these soils were different from those commonly used in industry. To make matters worse, OSHA used the term “angle of repose” differently than it is generally used in civil engineering. Consequently, even technical experts such civil engineers were baffled by some of the standard’s requirements.

OSHA took two steps to address these problems. First, it replaced the term “moving ground” with the term “cave-in.” The standard defines a cave-in as “the separation of a soil or rock material from the side of an excavation, or the loss of soil from under a trench shield or support system, and its sudden movement into the excavation, either by falling or sliding, in sufficient quantity so that it could entrap, bury, or otherwise injure and immobilize a person.” Second, it eliminated the confusing language related to soil types and angle of repose by introducing a three-tiered soil classification system which is based on field tests that are clearly described and easy to perform.

**ENGINEER REQUIRED**

Another problem with the original standard is that it describes accepted engineering practice as being “compatible with standards of practice required by a registered professional engineer or other duly licensed or recognized authority.” The last seven words of this definition were a thorn in the side of many compliance officers because any contractor could declare himself a “recognized authority.” To support this claim of “authority,” some argued that they had been in the business their whole life. Although this may have been true, it was also true that many of these same contractors had compromised workers’ safety because they ignored OSHA excavation regulations their whole life.

The new standard closed this loophole by recognizing professional engineers as the only authorities on accepted engineering practices. The standard also requires that a professional engineer approve all protective systems used in excavations more than 20 feet deep.

**CAUSES OF CAVE-INS**

All soil possesses a certain degree of cohesive strength that tends to hold individual particles together. However, once an excavation is made, the soil’s natural strength is affected by the downward force of gravity. When the cohesive strength is overcome by this downward force, the sidewalls collapse and the trench caves in. The soil strength and downward force are affected by the factors described below.

**Soil type.** Loose-grained sandy soils have little cohesive strength and tend to cave in easily if unsupported. Clays and silts, on the other hand, generally tend to stick together and be self-supporting.
Moisture. Water has a decided effect on the cohesiveness of soil. Too much water affects the ability of soil particles to stick together, allowing them to slide and move more easily. On the other hand, too little water results in drying which can cause soil to crack and collapse.

Recent excavations. Soil that has never been disturbed is stronger than soil that has been previously excavated. The more recently soil has been disturbed, the weaker it will be.

Freezing and thawing. When water freezes, it expands, and when ice thaws, it contracts. Movement resulting from expansion and contraction during freeze-thaw cycles can affect the shoring materials and soil stability. A dramatic example of this hazard occurred during the construction of a shopping mall in Greenbelt, MD, during the early ’70’s.

During the morning, construction workers worked without incident below the frozen face of a 20-foot deep excavation. As the mid-morning sun warmed the excavation’s face, it thawed. Suddenly, and without warning, it collapsed, burying five workers beneath tons of soil. None survived.

Surcharged loads. Construction materials, heavy equipment and the weight of the spoils pile all contribute to the downward force on soil. The greater the surcharged load, the less stable the soil will be and the more likely it will be to fail.

Shock and vibration. Moving trains, highway traffic, pile driving and blasting are all sources of vibration which can affect the cohesiveness of soil and weaken excavation walls.

Intersecting trenches. The point formed by the intersection of two trenches is particularly vulnerable to collapse. If not properly protected, a large wedge-shaped chunk of soil can easily break off and fall in the point of intersection.

COMPETENT PERSON

One element of the existing standard that was incorporated into the revision was the requirement for an on-site “competent person.” To be a “competent person”, individuals must meet two criteria. First, by virtue of training and experience, they must have the knowledge needed to identify existing and predictable excavating hazards. Second, they must have the authority to correct or eliminate any hazards that they observe.

GENERAL REQUIREMENTS

The revised standard, which is contained in Subpart P or 29 CFR 1926, is divided into three sections. The first section describes the standard’s scope and defines terms used in the standard. The second part contains general excavation requirements, and the third describes acceptable types of protective systems.

Some of the general requirements are summarized below.
Surface encumbrances. All surface encumbrances such as trees and boulders must be removed or supported, if they present a hazard to employees. The primary reason to remove surface encumbrances is to protect employees from the hazard posed by undermining structures that could later collapse. However, another reason for removing them is that they often interfere with the smooth flow of traffic on excavation sites.

Utility identification. Employees may be exposed to serious hazards such as flooding, electrical shock, asphyxiation, fires, and explosions resulting from damage to underground installations. As a result, utility lines such as gas, electric, telephone and water must be identified before digging begins. This task can be simplified by contacting one-call services that coordinate the activities of excavators with utility owners.

Access and egress. In trenches deeper than four feet, a stairway, ramp or ladder must be positioned within 25 feet of where employees are working.

Traffic exposures. Employees who direct traffic, on public highways, adjacent to excavations must wear highly visible reflectorized warning vests.

Overhead loads. Employees are not allowed, under loads, handled by lifting or digging equipment. They must also stand clear of any truck being loaded or unloaded so that they will not be struck by spillage and debris.

Mobile equipment. Whenever a mobile equipment operator does not have a clear and direct view of an excavation’s edge, a warning system such as barricades or hand signals must be employed to assure that the equipment does not accidentally roll into the excavation.

Hazardous atmospheres. Excavations dug near gas stations, chemical plants, storage tanks, sewer lines and landfills may contain hazardous atmospheres formed by liquids, gases and vapors which seep through the soil. The “competent person” must be alert for these conditions and conduct atmospheric monitoring when necessary.

Emergency response. Emergency rescue equipment such as self-contained breathing apparatus, stretchers, retrieval harnesses and lifelines must be available in areas where hazardous atmospheres exist, or are likely to exist. In addition, employees who enter bell-bottom pier holes or similar deep and confined footing excavations must wear a harness with a lifeline securely attached. The lifeline must be independent of any other lines used to raise and lower material and must be attended while an employee is in the excavation.

Water accumulation. Water is a trench’s worst enemy. Accumulations resulting from rain, melting snow, or a leakage from damaged sewer and utility lines can saturate the side walls of excavations and weaken them. Flowing water can erode material from shoring systems to the point of failure.

In one rather amusing case, a contractor thought he had punctured a water main because the water level in the trench remained the same even after hours of pumping. He was greatly
relieved when the compliance officer pointed out that the water that was being pumped out was flowing behind the spoils pile and back into the trench.

**PROTECTIVE SYSTEMS**

The standard allows employers to choose from three methods of protection: sloping, shielding or shoring.

**Sloping.** Is the simplest method of controlling cave-ins. Slope the walls back far enough so that loose material does not roll back into the excavation. The maximum allowable slope angle is determined by the soil type, and steeper slopes are allowed for more stable soils. The maximum slope permitted by the standard is not an absolute value and must be reduced to compensate for surcharged loads and heavy equipment traffic, or if there are signs of distress such as fissures, subsidence of edges, slumping, bulging or spalling walls, or heaving of material on the bottom.

**Shielding.** Trench shields do not prevent cave-ins. Instead, they protect employees from cave-ins by providing a sheltered space in which employees may work. A typical shield consists of two steel plates separated by structural members to form a box open at the top, bottom and both ends. The box is lowered into the trench so that the steel plates face the trench’s side walls. Employees climb into the protected area defined by the steel plates. As the work progresses, the box is dragged along the bottom of the trench by a chain or cable suspended from an above-ground backhoe.

**Shoring.** Shoring systems are structures constructed of wood or metal members that press tightly against an excavation side wall to prevent cave-ins. Figures 7-1, 7-2, and 7-3 graphically illustrate the decision process in selecting the right protective system for a given set of conditions.

A review of OSHA’s excavating standards makes it obvious that they are now clearer and easier to understand than before the catch, however, is that to be effective the rules must be followed.
Culvert Inspection and Repair
By Marisa DiBiaso, Project Assistant, UNH Technology Transfer Center

In the autumn water levels are usually low, making it a great time to inspect culverts and perform routine maintenance. This article will cover inspections to determine needed cleaning, repair or replacement, and methods to minimize erosion.

Inspections
Thorough inspection is essential to effective maintenance. Knowledge of culvert material can predict the types of problems a culvert may have. Each material has specific weaknesses.

- Steel culverts are subject to corrosion and abrasion, and have a shorter life span than other materials.
- Aluminum culverts can sustain abrasion and have less strength.
- Plastic culverts bend easily and are subject to ultraviolet degradation. They are subject to impact damage at low temperatures.
- Concrete is the most durable material, but concrete and reinforcing steel still deteriorate.

Cleaning
Inspections frequently show that culverts require cleaning. During cleaning, certain maintenance tasks should be performed:

- Remove obstructions and clean inside the pipe.
- Examine the culvert for visible cracks, changes in shape, corrosion or abrasion.
- Check upstream for trees, dead branches, and other debris that may obstruct the pipe.
- Cut vegetation that may hinder flow near inlet and outlet.
- Look for evidence of past overflow to indicate whether the culvert is the correct size.
- Remove debris and sediment, or add material to make the ditch bottom level with the culvert invert elevation.

Repairs
Bent or broken culvert ends should be repaired for smooth water flow. Repair headwall cracks, loose mortar, and displaced stones. The chart on the facing page will help to diagnose other problems and choose a repair.

Replacements
The most important reason to replace a culvert is to minimize the possibility of structural failure. Weak culverts beneath a road are especially dangerous. Replace a culvert if it cannot handle the expected water flow. Water and debris lines above the culvert indicate a larger
A culvert is needed. Area residents and town records can indicate water levels of past storms and the maximum level to expect.

Replacing a culvert with one only slightly larger significantly increases the capacity of flow. For example, an 18" culvert has about 50% more capacity than a 15" culvert. Before installing a larger culvert, check culverts downstream to ensure they can handle the increased flow.

Multiple culverts might be necessary if cover is insufficient for a larger culvert. The table below shows the number of smaller diameter culverts equal in water carrying capacity to that of one larger sized culvert. It is based on culverts laid on the same slope. For example, one 24" diameter culvert is equivalent in water carrying capacity to five 12" culverts or two 18" culverts.

<table>
<thead>
<tr>
<th>Multiple Culvert Installation</th>
<th>Plunge Pool Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diam</td>
<td>12&quot;</td>
</tr>
<tr>
<td>12&quot;</td>
<td>1</td>
</tr>
<tr>
<td>15&quot;</td>
<td>1.7</td>
</tr>
<tr>
<td>18&quot;</td>
<td>2.5</td>
</tr>
<tr>
<td>21&quot;</td>
<td>3.6</td>
</tr>
<tr>
<td>24&quot;</td>
<td>5</td>
</tr>
</tbody>
</table>

**Erosion**

Water exiting the culvert can erode the land at the outlet. Erosion increases as flow velocity increases. Erosion at the outlet of an upstream culvert will loosen sediment and debris, which can build up in ditches and inside a culvert downstream. Buildup slows the flow. Ultimately sediment is carried into streams, ponds, or lakes. A solution for low velocities is to plant vegetation. For higher velocities, crews should construct a stone splash pad or plunge pool at the outlet. Typically, for culverts with a diameter of 30 inches or less, the depth of the plunge pool should equal the diameter of the culvert.

Inspection determines whether culvert cleaning, repairs, or replacement are needed. Where necessary, obtain a wetlands permit before performing maintenance. If replacement is necessary, it is important to choose a culvert the right size for the location and water flow. Regular maintenance, such as removing sediment and debris, is essential to keep the culverts working properly.
### Common Culvert Problems and Solutions

<table>
<thead>
<tr>
<th>What you observe…</th>
<th>What may be the reason…</th>
<th>How to fix it…</th>
</tr>
</thead>
</table>
| Scouring/erosion at the inlet. | • Ditch too steeply graded.  
• Poor location / alignment.  
• Clogged pipe. | • Line the ditch with stone.  
• Properly align the ditch with the culvert.  
• Clean and flush the culvert. |
| Scouring/erosion at the outlet. | • Pipe sloped too much.  
• Pipe is too small. | • Build a stone splash pad or plunge pool  
• Check size and replace with larger pipe if necessary. |
| Ponded/puddled water. | • Invert is too high.  
• Ditch grade is too flat. | • Reset the pipe – match the invert to the channel bottom.  
• Regrade ditch to maintain correct flow. |
| Dented/crushed ends. | • Traffic / snowplows are hitting the ends. | • Fix pipe ends.  
• Install maker posts or guardrails. |
| Heavy corrosion. | • Water flowing through culvert is acidic. | • Install a PVC sleeve or replace with a non-corrosive material. |
| Piping around the culvert. | • Pipe is incorrectly installed. | • Reinstall pipe with proper bedding and compaction.  
• Install a head wall. |
| Sediment buildup. | • Not enough slope. | • Reinstall pipe with a slope of at least ¼" per foot. |

**Sources:**
- "Culvert Installation and Maintenance." A Series of Quick Guides for New Hampshire Towns. UNH Technology Transfer Center.
- Drainage, Drainage, Drainage UNH Technology Transfer Center. Durham, NH. January 1996.


5. Drainage, Robert E. O’Connor and Donald R. Esmond, Community Assistance Section, State Capitol Projects Bureau, New York State Department of Transportation, 1982.


REFERENCES CITED

17. *Handbook of Steel Drainage and Construction Products*, American Iron and Steel Institute, New York, N.Y.

18. *Design Manual – Concrete Pipe*, American Concrete Pipe Association, Vienna, VA.


BIBLIOGRAPHY

Basics of a Good Road, Vermont Local Roads Program, St. Michael’s College, Winooski, Vermont.

Concrete Culverts and Conduits, Portland Cement Association.


Design Charts for Open-Channel Flow, Federal Highway Administration – Hydraulic Design Series No. 3.

Design of Roadside Channels with Flexible Linings, FHWA-IP-87-7, April 1988.

Drainage of Asphalt Pavement Structures (MS-15), The Asphalt Institute, September 1984.


Effects of Drainage Design on Road Performance, Fact Sheet T-610, Vermont Local Roads Program, St. Michael’s College, Winooski, Vermont.


*Road Drainage*, Wisconsin Transportation Bulletin No. 4, Transportation Information Center, University of Wisconsin – Madison, Madison, Wisconsin.


