Problems Associated With Gravel Roads

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Problems Associated With Gravel Roads
Foreword

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INTRODUCTION

Aggregate- or gravel-surfaced roads form a large part of local jurisdictions' highway networks. In many localities they far outnumber their paved counterparts. Maintaining gravel surfaces in good shape should be the objective of every local government. Although gravel roads are not constructed or maintained to interstate standards, they still should meet reasonable minimum expectations for structural integrity, ridability, safety, and aesthetics.

Despite the diversity in their surroundings, material compositions, and uses, gravel roads everywhere in the United States share common problems. While solutions to the problems may vary, there are universal principles and practices that should be shared, discussed, tailored as needed, and implemented to benefit all local governments and the traveling public by improving, maintaining, and safeguarding a vital part of the Nation's highway network.

This handbook looks at the overall environment of gravel roads; the materials used to surface them; the common surface defects—their causes, prevention, and correction; and the equipment and techniques used to repair and maintain gravel roads. Accompanying this handbook is a three-part videotape presentation. It was produced for use in training seminars sponsored by the Local Technical Assistance Program (LTAP) centers around the country, and individuals may borrow the videotapes and order copies of the handbook from their LTAP center.

The training is intended for a wide audience including road maintenance crew members, road supervisors, equipment operators, and local elected officials responsible for gravel roads.
Introduction
Chapter 1
GRAVEL ROADS—THE BASICS

Most motorists don’t enjoy driving on gravel roads. At best, travel is slower and rougher. Worse, they may have to steer through choking, blinding dust or sloppy, slippery mud . . . or meet another vehicle where there’s no room to pass. Worse still, their car or truck may get its paint chipped or its windshield cracked. Ultimately, motorists fear blowing out a tire, breaking an axle, or losing control on loose gravel. These are not unfounded complaints and fears considering the state of many gravel roads. Just ask local elected officials and road maintenance personnel if they don’t get angry phone calls from motorists and property owners now and again!

But like them or not, gravel roads are out there, and out there to stay—especially in rural areas of the country. Even in nonrural counties and municipalities, gravel roads can account for a significant portion of the local roads network. For motorists whose homes are located on gravel roads, driving to work, school, and shopping is a daily routine. Other motorists who don’t live on them still use gravel roads frequently to get to recreational sites for camping, hunting, fishing, boating, or skiing . . . or to reach other destinations. Yet another segment of the motoring population rarely drives on them. Still, all of us depend on gravel roads.
Chapter 1 Gravel Roads—The Basics

This chapter provides general information about gravel-surfaced roads—their prevalence and importance, what they are and aren’t, minimum serviceability requirements, and construction and maintenance decisions that relate to them.

**IMPORTANCE**

A few facts and observations about gravel roads point to their place in the Nation’s life.

**Extent**

The U.S. highway network of almost 6.5 million kilometers (4 millions miles) includes more than 2.5 million unpaved kilometers (1.6 million miles)—a full two-fifths of the network. While unpaved public roads carry less traffic than their paved counterparts, they still carry more than one-fifth of it.

**Purposes and Uses**

Many city and suburban residents tend to think of gravel roads only as driveways, or as farm, park, or forest roads. They don’t typically think of them as neighborhood streets, as school bus routes, or as sites for businesses and government facilities. In truth, just about every type of enterprise or activity that is accessed by paved roads can be reached by gravel roads. And while it’s old hat to those who live on them, some residents of the pavement-only world might be surprised at how much of everyday life also takes place in the world of gravel surfaces. Mail is delivered;
Chapter 1 Gravel Roads—The Basic

shoppers drive to and from stores; workers commute to the office or factory; crops are harvested and trucked to market; students are transported to school and home again; police, fire, and ambulance services are provided; and houses of worship and cemeteries are frequented—all along gravel roads. And, of course, they carry more than the usual share of recreational vehicles, agricultural machinery, and trucks of all types that transport both raw and processed materials.

In short, although they usually carry lower volumes of traffic for shorter trips, gravel roads are used in the same ways as paved roads.

DEFINITION

This handbook focuses on gravel roads. But just what is a gravel road? The more technical term is aggregate, which dictionaries define as "... any of various hard, inert materials, as sand, gravel, or pebbles ..." Chapter 3 presents a more detailed discussion of the materials used for surfacing gravel roads, but first, consider some basics about the composition and cross section of gravel roads.

Composition

There are paved roads and unpaved roads, but not all unpaved roads are gravel-surfaced. Some are commonly called dirt roads—roads surfaced with the native materials found on site. In some areas of the country, the prevailing native material is topsoil; in other regions it might be clay or sand. There’s no hard line separating gravel roads from dirt roads. One locality’s gravel road might be considered
a dirt road elsewhere. Although dirt roads endure distresses similar to those of gravel roads and are maintained by the same equipment and methods, they typically cannot be maintained to the same quality levels as gravel roads.

This handbook focuses primarily on roads surfaced with mineral aggregate—whether it’s available entirely on site (rare) or obtained from pits, quarries, or industrial byproducts; it’s used directly or after screening or crushing; or it’s used alone or in combination with other aggregate. Using local materials, even when they require some sort of processing, is usually a more affordable option for local governments than bringing materials from far away.

Cross Section

Gravel roads have roadway elements, dimensions, crown, slopes, and superelevation similar to paved roads—assuming that the gravel roads are properly constructed and maintained.

Roadway Elements and Dimensions

Gravel roads are built on an aggregate base on top of a roadbed within a right-of-way. Figure 1-1 shows typical section that includes a wearing surface (traveled way or travelway), shoulders, foreslopes, ditches, and backslopes. Traveled ways vary in width but should accommodate two-way traffic. Shoulder widths vary also, depending on the extent of the right-of-way. Ditch widths likewise vary according to the lateral space available.
Chapter 1 Gravel Roads—The Basic

Figure 1-1. Typical section—gravel road.

Crown, Slope Rates, and Superelevations

The traveled way should be crowned (elevated) in the middle of the road to drain water off the surface. As shown in figure 1-2, the proper crown for gravel roads has a modified A cross section. Maintaining such crowns on gravel roads eliminates flat areas in the traveled way that would allow water to remain on the surface and cause potholes or other problems.

Figure 1-2 also illustrates improper crowns, including parabolic crown, excessive crown, flat (no) crown, and inverted crown.

An excessive crown is undesirable mainly from a safety standpoint. Cross slopes that are too steep may actually cause vehicles to slide off the road when the surface is slick. In addition, excessive crowns force motorists to drive in the middle of the road rather than to the right, resulting in reduced safety and extra wear in the center of the traveled way.
Chapter 1 Gravel Roads—The Basics

A *parabolic crown* has a somewhat flat, circular contour. It drains poorly, and the gravel tends to get scraped off the center of the road. Without this gravel, water can run further along the road’s center and weaken the road in the process. Parabolic crowning may develop during blading because of motorgrader moldboards that have edges that are worn or cupped in the middle. When used correctly, moldboard edges should continue to be basically straight even as they wear down.

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*Figure 1-2. Gravel road crowns.*

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Problems Associated With Gravel Roads
A flat crown is really no crown at all. It allows for little or no drainage. Water basically drains off the road only when it builds up enough to start flowing.

An inverted crown not only doesn’t allow water to drain off the road, but it also channels water toward the middle and holds it on the traveled way—which is obviously harmful to the road and dangerous to motorists.

As for the amount of crown slope, the wearing surface should fall away from the crown at a uniform rate of about 2.75 to 4 percent between the center line and the shoulder. This amount should permit good drainage of surface water from most gravel roads without washing off the aggregate. The slope of the shoulders from road edge to ditch foreslope must equal or be slightly greater than the road surface cross slope so that drainage continues uninterrupted from the traveled way to the ditches.

Where roads curve to the left or the right, the modified A crown should gradually be eliminated as the side away from the direction of curvature is elevated until the road is banked. This superelevation of the roadway helps vehicles resist centrifugal force and stay on the road through the curve—the same principle that operates on banked racetracks.

SERVICEABILITY

Nationwide, the condition of gravel roads varies from jurisdiction to jurisdiction, and often within each jurisdiction. But, while gravel roads are not designed and constructed to the same demanding standards as interstate highways, they all should meet certain minimum requirements to provide adequate service.
Chapter 1 Gravel Roads—The Basics

Structural Integrity

Gravel roads should be constructed on stable, well-drained roadbeds. The aggregate surface layers must be strong enough to prevent overstressing the subgrade, and stable enough to resist raveling, shoving, rutting, and consolidation within themselves.

Ridability

Gravel roads should have smooth, even, tightly knit surfaces that provide a smooth ride. Drivers should not have to brake constantly or abruptly because of frequent or occasional surface defects. The cross section should be correct for the alignment and drainage requirements—and consistent enough that motorists aren't continually challenged to make abrupt steering adjustments.

Safety

Above all, gravel roads need to be built and maintained for safety. Sufficient attention and effort must be given to proper alignment, cross section, surface condition, sight distance, and signing. Loose gravel can cause skidding. Dust and encroaching vegetation reduce visibility. And, as noted above, excessive crown makes it easier for vehicles to slide off the surface and tends to make motorists drive in the middle of the road.
Aesthetic

While no one expects gravel roads to win beauty contests, basic attention should be given to ensuring that the roadway and roadside have a pleasing appearance. For the most part, about the only beautification that local residents and other regular road users want to see is the elimination of all those ugly potholes, ruts, and washboards—and getting rid of the dust that blocks their view of the country side. Beyond that, dumping and other ill use of the right-of-way should be campaigned against. Battered, illegible signs and other eyesores should be removed. Appropriate natural growth should be encouraged, even while controlling its height and extent for safety.

DECISION MAKING

Gravel roads, although low in initial construction cost, are often more expensive to maintain than paved roads. Because it’s not unusual for a county to spend twice as much on gravel road maintenance. This being the case, decisions about gravel road construction and maintenance should obviously be given great importance.\(^{(1)}\)

But while they’re very important, these decisions more often are nontechnical rather than technical, and frequently they’re made by field personnel. For example, “The best time to use a york rake for removing cobbles is right after supper when traffic is low and it’s still light enough to see.”\(^{(2)}\) Hardly space-age technology, but it is sound, practical advice at the field level.
Although such *seat-of-the-pants* determinations may appear primitive in our highly sophisticated and technical world, the results are in line with the economic constraints associated with maintaining gravel roads. Successful grass-roots methods for keeping gravel roads in good shape ought to be disseminated to benefit all local government road agencies. Although dramatic breakthroughs in maintenance techniques, materials, or equipment are not likely to occur, modest but useful advances have been made and can be expected in the future. By both encouraging innovations and refining tried-and-true methods—and then by widely sharing both—the state-of-the-practice in gravel road maintenance can be more completely developed.

**REFERENCES**


Chapter 2
ENVIRONMENTAL INFLUENCES

Gravel roads are heavily affected by their environments. This applies as much to the effects of the man-made environment—including traffic, historical events, political decisions, and economics—as to the natural environment’s effects—from topography, climate, and geology.

This chapter discusses five environmental influences:

- Historical/political/economic.
- Topographic.
- Climatic.
- Geologic.
- Traffic.

A basic geographic categorization of gravel roads follows the discussion of the above factors. This categorization describes the influences of environment on gravel roads and will help readers understand similarities among even widely separated areas of the country.

Finally, a focus on drainage and related issues addresses the effects of water on gravel roads.

HISTORICAL/POLITICAL/ECONOMIC

Historical, political, and economic factors played a significant role in the establishment and evolution of
Chapter 2 Environmental Influences

America’s roads. Today’s gravel roads are a product of those influences—showing the effects in their locations, alignments, widths, cross sections, compositions, and uses. And, of course, these same influences affect today’s gravel roads and will continue to affect them in the future.

Primarily because this Nation sprang from diverse colonies with far-flung cities and isolated settlements, road-building began as a local concern. And even with the sometime involvement of the Federal Government in building national roads and providing States with road-and canal-building funds from the sale of public lands, gravel road construction and maintenance remain a fundamentally local issue.

Major events and eras such as the great westward expansion, wars, the rise and expansion of the railroad industry, and the advent of the automobile age affected the building and improving of rural roads. The railroads’ initial effect was a decline in rural road-building and upkeep. Ultimately, however, as railroads became some of the strongest supporters of good roads, it served to promote them.

To understand how social factors such as history, politics, and economics can affect the physical characteristics of gravel roads, compare road development in the early eastern U.S with what took place farther west. Early roads in the east sometimes followed trails long traveled by American Indians. The routes tended to follow natural paths along streams, rivers, and lake shores; atop ridges; and through broad valleys and narrow defiles. Other routes were established by early European colonizers, often in similar locations. In any case, most of the inhabitants lived along roads that had been established “... through continued public use rather than by plan.”(1)
Chapter 2 Environmental Influences

Typically, these roads "... followed the boundaries between farms or occupied the lands least suited for agriculture, and thus were often winding and poorly located."

Contrast the above situation with what occurred farther west, in the prairie-and-plain regions. "The local road situation was somewhat different in the public land states, those which had been formed from the public domain. The lands in these states had been subdivided into rectangular townships and sections according to an ordinance of the Continental Congress, May 29, 1785. These land lines became the boundaries between farms, and thus were the lines of least resistance for local roads. The customary rights-of-way for these roads was one chain wide (20 m/66 ft), and each property owner donated 10 m (33 ft) on his side of the section line."\(^2\) So, in the west, farms were laid out in straight-sided parcels with wide rights-of-way.

Political events and decisions affecting gravel roads include turnovers of local elected or appointed officials, changes in fixing jurisdiction, and levying property and other taxes earmarked for roads.

More purely economic issues influencing gravel roads include economic upswings and downturns that alter road budget allocations, fluctuations in the costs of materials used to surface or treat gravel roads, equipment and fuel cost changes, and developments in local economies that affect how roads are used.

Taken together, these historical, political, and economic factors represent a constant influence on how we construct, use, and maintain our gravel roads.
Chapter 2 Environmental Influences

TOPOGRAPHIC

The effect of topography on gravel roads is seen in terms of alignment, drainage, and aggregate loss.

Alignment

Both a road's vertical alignment (grade) and its horizontal alignment are directly related to topography—the lay of the land. Because of design standards for roadway alignments, higher classification highways are constructed on alignments that smooth out the more severe irregularities in the terrain; that is, the grade is flatter and the horizontal curves are more gradual. Flatter vertical alignments and straighter horizontal alignments permit higher travel speeds without sacrificing safety.

As figure 2-1 illustrates, vertical curves can be flattened by constructing deeper fills and cuts for the roadway. The roadbed is cut down where it crests hilltops and built up where it traverses low spots to reduce the overall rise and fall of the road's grade. Likewise, meandering horizontal alignments can be straightened by aligning the roadway through rather than around certain obstructions.

Gravel roads, however, tend to follow the natural contours of the land much more closely than do higher classification paved highways. In highly contoured terrain, gravel roads are likely to be steeper and more sharply curved than their paved counterparts. The effects of topography on gravel road alignments are therefore greater. Thus, in hilly or mountainous country the effects are pronounced, in flatlands they are generally not so evident.

Problems Associated With Gravel Roads
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Actual vertical alignment of terrain

Cut

Fill

Filling and cutting to improve the vertical alignment

Improved vertical alignment for roadway

Figure 2-1. Vertical alignment of roadway.

Drainage

Topography also affects the drainage of gravel roads. In flat, low-lying areas the problem may be a water table that’s too high. Put another way, the road may be situated too low for the existing water table. Water-logged roadbeds are soft and weak. The problems that result are chronic and severe. The only solution may be to raise the grade of the road to keep it above the groundwater level.

In low-lying locations in hilly country, the problem may be water that collects at the roadside and cannot drain away. Again, the problem is a roadbed that stays boggy. Different topography, but similar problems.

Problems Associated With Gravel Roads
Flat terrain doesn’t have to be low lying to have other drainage problems. Cloudbursts can put enough water on the ground and in motion to overwhelm normally adequate drainage ditches and culverts and wash out roads. Flash flood damage can be a real threat, especially in open, barren deserts.

Steep hills and mountains also encourage water to flow rapidly. To drain it without harming gravel roads, the water must be intercepted and channeled away from the roadway. The cross slopes of roads that hug steep hillsides should normally be tilted to the inside or ditch side. Figure 2-2 shows that this reduces the possibility of washout of the fill slope, At the same time, of course, the ditch has to be properly maintained so that it will carry away the drainage.

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**Loss of Material**

Topography naturally dictates the frequency, lengths, and steepness of roadway grades. The more hilly and steep the gravel road, the more it tends to lose some of its surface material to the combined forces of runoff and gravity. Steep inclines accelerate the flow of rainwater and snow melt off the road surface, carrying with it any loose gravel.

Low-lying areas can contribute to another kind of material loss. As noted above, where water stands along the roadside and soaks into the roadbed, the foundation softens and weakens. Under these conditions surface gravel can actually sink into the roadbed and be completely lost as a surface material. As far as the local roads department is concerned, it’s as though thieves hauled away truckloads of their gravel. It’s gone.
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Figure 2-2. Hillside pitch of roadway.
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Washboarding

Finally, hills contribute to the formation of what's commonly called washboarding or corrugation in gravel roads. Both roadway grades and curves suffer more washboarding than straight, level stretches of road. The causes, prevention, and correction of washboarding are discussed at length later in this handbook. For now, it's enough to say that places in gravel surfaces where vehicles accelerate or decelerate are prime candidates for this problem.

CLIMATIC

The influence of climate on gravel roads encompasses factors such as the amounts, frequencies, and forms of precipitation, the effects of temperature and wind, and the uses to which roads are put.

Precipitation

The importance of moisture and drainage to gravel roads will become clearer throughout this handbook. It is common knowledge that climates determine amounts, frequencies, and forms of precipitation. And road managers and crews can appreciate how moisture on, in, and under gravel surfaces affects roadways.

As the precipitation amounts themselves vary, so too do the ways of assessing these amounts. They may be looked at as annual amounts, seasonal amounts, or amounts in a
Chapter 2 Environmental Influences

typical rainfall. Heaviness of precipitation is a factor as well. Moisture may be added to gravel roads gently and gradually, or it may be added forcefully and rapidly. Heavy downpours or rapid, heavy snowmelts are potentially more destructive to roads than are the more gradual and gentle forms of moisture addition.

Frequencies of precipitation are also significant and are a different issue than amounts and heaviness of precipitation. Roads whose moisture content remains somewhat constant perform differently than roads that undergo wet-and-dry cycles. Climates that produce rainy seasons and dry seasons influence gravel roads differently than do climates with evenly scattered rainfall, wet climates, or arid climates.

The amount of precipitation is sometimes secondary to the form of precipitation. Two different climates may produce the same total amount of precipitation, but if one is quite cold—and the precipitation occurs mostly as snow—then the effects of the moisture are deferred until spring thaw. Instead of well-distributed precipitation, the moisture (or its effects, at least) are concentrated at one time of the year.

Temperature and Wind

Air temperature can affect both the individual particles that form gravel road surfaces and the various layers that make up the road structure. Pieces of gravel will begin to degrade under the effects of temperature extremes and fluctuations. Some types of material will actually crack and break more than others. Wind slowly erodes the particles too, with emphasis on slowly. Yet, the more pronounced effect of weather on gravel roads is structural.
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For example, heat accelerates the drying of the surface gravel, which contributes to the creation of dust. The drying and eventual loss of the fine dust particles hastens the breaking up of the whole surface. Where dust is a problem, however, heat is by no means the only or even the chief culprit. But it does aggravate the problem.

Cold temperatures play a role too. Where pockets of moisture are found in gravel surfaces and in underlying roadbeds, subfreezing temperatures can cause frost-heaves to form. Not only do frost heaves create immediate bumps in the surface, but later—after thawing out—they leave the road with weak, unstable spots.

If one round of freezing and thawing can cause problems, imagine the effect of many freeze-thaw cycles! Some areas of the country are just plain cold; while others stay warm year-round. Still others can’t seem to make up their minds; temperatures fluctuate back and forth between below freezing and above freezing. These fluctuations are termed freeze-thaw cycles. The State of West Virginia reportedly leads the Nation in the average number of them. They tend to wreak havoc with roadbeds and gravel surfaces, not to mention pavements.

Wind tends to aggravate other problems more than cause problems by itself. Where dry, dusty roads are a local irritant, winds further dry out parched road surfaces. Plus, they stir up and blow away the accumulated dust on the road, removing it from where it’s needed and depositing it where it’s a nuisance—on cars, in ditches, on field crops, on trees, and on front porches.
Road Usage

This factor could come under topography or economics or traffic as well as under climate. It is affected by each of them, and they are all interrelated.

Different climates mean that gravel roads may be used by trucks that carry harvested pineapples, or cotton, or beef cattle, or yellow pine logs, or what . . . that is grown or raised in the fields or forests or pastures that are served by those roads. Most gravel roads, in fact, fit into the category of farm-to-market. What grows along the roads—as determined in large part by the area’s climate—determines the main use of the roads. Some products require gargantuan harvesting machines and hauling rigs; others call for more normal-sized vehicles. It just may be that gravel roads serving alfalfa-growing areas take a greater beating than those serving sheep-raising areas, based on how those enterprises affect road use.

In a similar vein, climate also influences the recreational use of lands and waterways accessed by gravel roads. The better the climate, the more the public and commercial developers will find recreational uses for areas served by the roads. On the other hand, harsh, uninviting climates—whether too hot, too cold, too wet, or too dry—often put the damper on such usage.

GEOLOGIC

Geology influences gravel roads by determining the materials available for surfacing the roads and in determining the materials prevalent in the roadbed.
Sometimes, in some places, geology also explains subsurface drainage characteristics and features.

**Surface Materials**

Because local road construction and maintenance tend to use locally available materials, the area’s geology has a marked influence on questions such as the kind of gravel used to surface; availability and cost; and its behavior under traffic and ability to withstand the effects of wetting and drying, and freezing and thawing.

Some areas have good-quality gravel available directly from local pits. Others have plentiful local rock from quarries that, to be suitable for surfacing gravel roads, must first be crushed to make it both small and angular enough. Yet other areas have abundant sand but lack a readily available larger material to combine it with. Still other areas have no suitable surfacing material whatsoever.

Any kid tumbling from a bike on a gravel road knows that the surface is hard—and it hurts! Geologically speaking, though, some surfacing materials are soft when compared to others. And soft in this case isn’t usually good. It means that traffic and weather will deteriorate the material more readily. Softer road gravel is less resilient; it will wear down quicker and break up easier than harder material. Softer material will produce more dust. But softness and hardness are only two of many characteristics of gravel. Chapter 3 contains a detailed discussion of materials.
Chapter 2 Environmental Influences

Subgrade (Roadbed)

The geologic makeup of the subgrade also influences the strength and durability of gravel roads. Strong, compactable, inert, free-draining materials produce stable, durable roadbeds.

While local agencies do their best to select and obtain good surfacing materials, they must often contend with whatever material is already in the roadbeds. Because most gravel roads were laid out long ago, just about anything and everything can be found in the subgrade. And knowledge of local geologic characteristics is probably a good predictor of what to expect.

In mountainous and other rocky areas of the country, gravel roads are often constructed directly on bedrock. It's not unusual to see rock outcroppings protruding through the gravel surface layer. The foundation is of course quite strong and stable, but drainage can be a problem at such locations. In addition, motorgrader blades can be damaged if they catch on an outcropping.

TRAFFIC

Traffic is part of the man-made environment affecting gravel roads, and the types, amounts, and speeds of vehicles traveling on gravel roads are each variables in the equation.
Types of Vehicles

A gravel road that carries mainly passenger cars and the occasional pickup truck receives much less abuse than one that carries heavy coal trucks, agricultural equipment, or log trucks. It's not uncommon nowadays for some gravel roads to endure rigs that are legally too heavy for the interstates! Some monstrous equipment may show up just once each year, but it can do so much damage that whole sections of roads have to be rebuilt.

The gross weights, number of axles, and type and number of tires all affect the wear and tear of traffic on gravel surfaces. Even tire inflation pressures seem to have an effect.\(^{(3)}\)

Heavy vehicle loads not only put wear on the surface gravel, but they also test the strength of the roadbed as well. Smaller, lighter vehicles may not strain the roadbed so much, but they still manage to gradually deteriorate the surface.

Volumes

Traffic volume refers to the number of vehicles using a road. Even though gravel roads usually carry less traffic than paved roads, actual gravel road traffic counts may range from as few as 20 vehicles per day to more than 100. For example, somewhere in the Mojave Desert there's a 32-km- (20-mi-) long road with just one house on it—at the very end. Meanwhile, on the outskirts of Sioux City, there's a short gravel road between two paved highways that serves as a shortcut for hundreds of vehicles daily. All
other factors aside, which one probably requires the more maintenance?

Now consider which weighs more, a kilogram of lead or a kilogram of feathers? A trick question with a simple answer. But here’s a nontrick question whose answer may not be so simple—which is tougher on a gravel road, five 0.9 Mg (1-T) cars or one 4.5 Mg (5-T) truck? Although engineers and scientists might be able to give an indisputably correct answer, the point is that both the loads themselves and the number of times those loads are applied stress gravel roads. And, when both the weights and numbers of vehicles are high, stress on the roads is maximized.

Speed

As if those weren’t enough variables to consider, there’s also speed to consider. A vehicle’s speed can exacerbate the stress that its load places on a gravel surface. Some of the increased stress transfers to the subgrade, but the worst stress is inflicted directly on the gravel surface.

The abrasive action of the tires coupled with the oscillating motion of both the tires and the vehicle’s suspension forms corrugations or washboarding. The higher the speed, the faster and more serious are the corrugations that develop in a surface.^(4)^

Then there’s dust. Vehicles at high speeds unravel the very top of the road. This produces dust. The more vehicles that travel the road and the faster they go, the more dust is produced, kicked up, and lost. And the problem goes well beyond this, but further discussion of dust and related developments is reserved for chapter 4.
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GEOGRAPHIC AREAS

A four-category geographical classification of gravel roads serves somewhat to combine the natural environment factors discussed above and also to interrelate different parts of the country. These geographic areas can be described as:

- Flat to rolling, temperate climate.
- Mountainous, rocky.
- Arid.
- Flat, moist delta.

Most localities in the United States fit best in one of the above areas; but the categorization is basic and by no means perfect. Many places in the Southwest, for example, might share characteristics of both the arid and mountainous, rocky areas. Seeing localities in terms of these categories is perhaps a useful analytical exercise that helps road managers and crews better understand the problems of gravel roads by noting the environmental effects upon them.

Perhaps the best way to see where a specific locality fits in is not to immediately select an area based on the name alone, rather, read the descriptions until a match is found.

Flat to Rolling, Temperate Climate

This category is extensive—no doubt encompassing more area than any of the other three. Included would be much of the eastern and southern interior regions of the U.S. as well as most of the Midwest. Even portions of the West
would have to be included. After all, most of the U.S. does have a temperate climate; and flat to rolling pretty well describes much of the countryside. Central Iowa is often given as the archetypical locale representing this type of geography. But much of Illinois, Indiana, Georgia, Missouri, Kentucky, New Jersey, Kansas, and Minnesota also can be included.

The terrain is flat to rolling, not mountainous or otherwise rocky. Large numbers of straight section roads are typical (sometimes called grid roads). These roads may be bordered by open pasture or crop lands, forests, or mixed forests and fields.

Dust is common in the summer. Rutting and corrugation are typical problems. Roadway widths are greater in the more open prairie/plains regions than in partial or full woodlands.

Mountainous, Rocky

Mountainous, rocky areas are regions where rocky, granular aggregates are typical. Grades are frequent and are often long and steep. Numerous freeze-thaw cycles lead to frost-heave distress.

Arid

The most common characteristic of these areas is of course their prevailing dry condition. Dust is generally a problem, perhaps all year long. Fine-grain aggregates are typical. The terrain may be flat or rolling. Some locales have characteristics of both mountainous, rocky and arid areas.
Chapter 2 Environmental Influences

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Flat, Moist Delta

This category includes coastal areas where rocky, mountainous, or arid conditions do not predominate. Basically, this means the Gulf Coast and the Atlantic Coast south of New England. The terrain is flat and, of course, low in elevation. Roadways are usually narrow with lots of trees bordering them.

Some areas within this category have good available aggregate, but others have none. Shell is one local material that is plentiful in some areas. However, there may be restrictions on its use in some localities. Sandy bases are typical. Substantial precipitation is normal, and rutting is a common problem.

WATER

The final—and most important—environmental influence on gravel roads that will be discussed here is water. That includes rainwater, snow-melt, stream or lake water, underground water, and even the moisture in the air. Most of the time, it seems, water is viewed as an enemy of gravel roads. But it has its beneficial effects too.

Positive and Negative Effects

Unlike paved roads, gravel-surfaced roads actually benefit from moisture because it can make gravel more workable. (Indeed, without moisture, gravel surfaces should not be worked or else there may be more harm than good done.)
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Water aids in the consolidation, or compaction, of the surface course. It helps hold the gravel particles together. It contributes to the forming of a surface crust or skin that provides a stable, smooth riding course and prevents the intrusion of unwanted water. And it prevents or reduces the generation of dust.

Yet, when water strikes gravel surfaces, flows along or across them, or penetrates them and their foundations, it can be destructive. It can erode the surface, wash away fine aggregate particles, get into the subgrade and cause pumping and rutting, and promote the development of potholes. A little moisture helps gravel to consolidate and form a strong, stable mass. But too much moisture, especially when combined with liquified clay, over-lubricates the particles. Then, under pressure from traffic loads, the gravel pieces will slide past each other. In this way the gravel layer loses strength and stability.

The ideal balance is when roads retain the beneficial effects of moisture while warding off the destructive effects. Protecting gravel roads from water is accomplished by drainage. It’s difficult to overstate the importance of proper drainage to gravel roads. In fact, more than one expert has described the three main problems of maintaining any road as “drainage, drainage, and drainage.” It’s been said that good drainage requires three actions:

1. Get water off the road.
2. Get it out of the road.
3. Get it away from the road.

Accomplish all three, and agencies can maintain any road.
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Principles of Proper Drainage

The actions of getting water off, out of, and away from a road can be called principles of proper drainage. Each deserves comment.

Off

Water that gets on gravel road surfaces needs to be removed and kept off. Water allowed to remain on the surface creates problems. The immediate ones are safety related—puddles or channels of water are a driving hazard that can cause drivers to lose control. But in the long run, water that stays on the surface begins to damage the road by weakening the gravel layer and causing potholes to form. Eventually water will work its way deeper into the roadbed and cause other problems.

Out Of

To prevent those other problems, remove water that can penetrate the road’s surface and get past the gravel layer into the subgrade. Even when a good job is done of keeping water off the road, some still manages to get into the subgrade. It may get there not only from above, but also from below, or by entering the roadbed laterally. If water in the road is not removed, it weakens the foundation to the point where serious rutting and pumping can develop at the surface, and gravel can be pulled into the subgrade.

Away From

Water that remains on and around a gravel road is bound to get into it and cause problems. Even when water is cleared off the road and out of the road, it must be channeled away from the road. Water that stands in
roadside ditches or other close-by locations will seep back into the roadbed and weaken it. The objective should be to drain water completely away from the right-of-way.

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**Keys to Proper Drainage**

The keys to proper drainage of gravel roads are crown and slopes; eliminating depressions and obstructions; surface crust; surface and roadbed materials; and ditches and culverts. Together they help accomplish the objectives of getting water off, out of, and away from the road.

**Crown and Slopes**

Gravity is a wonderful natural ally that aids roadway drainage. Water will flow readily off a road surface if given a proper path, and then stay out of its way. A proper path is provided by sloping (inclinling) the surface in the best direction for the water to drain.

A proper modified A crown, as discussed in chapter 1, is the desired cross section. It elevates the road along its center so that water flows down and away from the crown, across the traveled way, over the shoulders, and into the ditches. Otherwise, if the crown is:

- Flat (no crown). Water will not drain away from the road’s center, but it will form in a sheet covering the surface. If there’s a grade, the water will flow downhill, but even then it will tend to flow on the road rather than off it.

- Insufficient. Water will flow off the road too slowly. While that’s better than no crown at all, it’s not much better. Heavy rain can build up so much
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water on the road that the effect of the slight crown is nullified.

• Inverted. The road itself becomes a drainage ditch. Water channels right down the middle, having no escape from the surface.

• Excessive. The draining water can wash fine aggregate off the surface and into the ditches. Erosion might occur as well.

The term cross slope is also used in discussions of crown. The recommended amount of crown or cross slope for the traveled way is about 4 percent of width as measured from the center of the road to the outside edge or shoulder. However, slopes of 3 percent are not uncommon. Varying local conditions account for the range in cross slopes rates. The frequency and severity of rain, the drainage quality of the surface gravel, and the steepness of the road are factors that should be considered in determining the actual cross slope. Where conditions are severe and the road is steep, a steeper cross slope is needed. Level roads require a flatter cross slope. Shoulders should have cross slopes the same or slightly steeper than the traveled way.

In summary, effective drainage depends on proper roadway crown and traveled way, and shoulder cross slopes help get water off the road. Maintaining them is probably the most important step in ensuring proper roadway drainage.

Depressions and Obstructions

A roadway may have a proper crown and cross slopes, but still have depressions or obstructions that catch and hold water on the surface. And, of course, when water stands
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on the surface, it soon finds its way into the road. Both depressions and obstructions must be eliminated. Depressions, for example, may start when wheel tracks develop and become slight ruts in which rainwater collects and forms channels. Or, settlement of the roadbed may cause other surface depressions in the form of *bird baths*.

Obstructions block the drainage of water by projecting above the surface. The four most common types are:

- Motorgrader operators sometimes leave a windrow, or ridge, of bladed gravel at the edge of the traveled way. Even though this is often results from routine surface smoothing, the maintenance windrow blocks the flow of water from the road.

- High shoulders result from plant growth combined with road gravel, dirt, and other debris that accumulate there. To keep shoulders from building up, keep the vegetation mowed, and reclaim any built-up gravel during routine blading.

- Winter sanding operations may leave behind ridges of sand that effectively block drainage from the traveled way.

- Aggregate loosened from the surface may be kicked toward the edges of the road and accumulate in ridges that interfere with proper drainage.

Eliminating depressions and obstructions helps both to get water off the road and to keep it out.
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**Surface Crust**

Another key to draining gravel roads is the surface crust. When the top of the gravel layer can be formed into a hard, closed, tightly knitted surface, it acts like a skin that sheds water until it is broken by the effects of traffic and weather. Such a crust keeps water from penetrating into the surface course, base course, and subgrade, and also speeds the flow of water off the surface because of its hard, smooth texture. In the absence of a crust, drainage is slower and penetration is much greater. Chapter 3 presents more information about surface crusts.

**Surface and Roadbed Materials**

The nature of the materials that form gravel road surface courses, base courses, and subgrades also influence drainage. Some gravels and base and roadbed materials naturally shed water, others absorb and retain it, and others swell when moistened. Some materials stand firm against the flow of water, while others erode easily. These characteristics affect how water drains over the road surface and through the structural layers.

Poor-draining materials—such as clays—resist penetration of water but don’t function satisfactorily in surface courses for other reasons. When materials occur farther down in the road structure, they tend to entrap water and create wet pockets in the roadbed. And that increases the likelihood of subgrade pumping and surface rutting. Free-draining materials, on the other hand, more readily shed water at the surface and allow it to pass through them with little retention or entrapment. Water flows off the road and out of the road better, and it does so without eroding the structural layers.
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Ditches and Culverts

The preceding keys of drainage contribute exclusively to getting water off the road and out of the road, but it’s up to ditches and culverts to move water away from it.

As crucial as ditches are to roadway drainage, it’s amazing how many gravel roads in the U.S. have either no ditches or something that barely passes for them. Differences in their environments allow some roads to survive without ditches while others have a life-and-death dependency on them. The purpose of roadside ditches is to collect the water that drains off the traveled way, shoulders, and foreshores, and then channel it away from the roadway.

Ditches should be built as extensions of the shoulders. Not only does a smooth transition look better, but it also drains the road better and is easier to maintain.\(^5\) Ditches must be ample enough in width and depth to collect and carry the volumes of drainage typical in their locale. The effective capacity of roadside ditches, however, is often reduced by gravel and dust deposited in them by traffic or washed into them by runoff. Vegetation too can reduce the amount of drainage ditches can handle. So, to get water away from roads, ditches need proper maintenance—including cleaning, shaping, and mowing.

Shape is an important factor in a ditch’s ability to function as intended. Figure 2-3 depicts common ditch shapes. The following points explain their pluses and minuses.

- Flat-bottom ditches have the best drainage capacity, but because of their greater width, they require more space than is often available. They also can be difficult to maintain. In addition, they slow drainage so much that water may tend to seep into the soil.
Figure 2-3. Common ditch shapes.

- U-shaped ditches actually have up to 30 percent less drainage capacity than the other shapes. They also tend to look messy. Their steep sides make mowing, cleaning, and shaping difficult. (Only a backhoe or Gradall can be used to work these ditches; graders can’t do it.) Furthermore, the steep sides are likely to cave in. Finally, vehicles that drive into this type of ditch can easily get stuck.
V-shaped ditches are an improvement in some ways. They have more drainage capacity, are safer, can be cleaned with a grader, are easier to mow, and blend into the roadside. But the narrow bottom is a problem because of its tendency to erode.

Modified V-shaped ditches—with slightly rounded or flat bottoms—are the recommended ditch shape. The slightly rounded or flat bottom reduces erosion, while the other advantages of the basic V shape apply.

Ditch maintenance is further discussed in chapter 5.

To carry away water drained from the roadway, ditches run alongside the road until they can flow into streams, other natural bodies of water, drainage basins, or other ditches that channel the drainage off the right-of-way. It never makes sense to ditch water to a roadside depression from which there is no outlet—it will weaken the road. Ditches also must drain water away from property that might be damaged by it. Ditch depths should be enough to keep water from draining into agricultural areas.\(^6\)

Culverts carry the drainage under intersecting roads and driveways, and cross under the main road itself. In hilly terrain, these cross culverts typically catch the water from the ditch on the uphill side of the road, carry it beneath the road, and discharge it on the downhill side. On steep grades, there must be enough cross culverts to handle the drainage from heavy rains.

Like ditches, culverts have to be cleaned periodically to maintain their full capacity. Clogged culverts can cause road washouts from water flowing over or along the road. Maintaining vegetation on the roadside and in the ditches helps catch sediments that otherwise would enter and clog culverts.
Figure 2-4 depicts some of the points discussed above relative to gravel road drainage.

*Figure 2-4. Gravel road drainage.*
REFERENCES


2. Ibid.


Chapter 3
SURFACE AGGREGATE

Part of understanding any structure, and the problems that it may have, is being familiar with the material or the material's components. The same is especially true of gravel roads. It's incumbent to know a lot about surface aggregate itself to deal with the problems of gravel roads. That knowledge should include awareness of the basic characteristics of aggregates; the types of aggregates and their descriptions and sources; and the principles and practices of their quality control.

BASIC CHARACTERISTICS

Even a material as straightforward and uncomplicated as surface aggregate has characteristics that must be understood before one can deal effectively with its use on the road. These characteristics include particle sizes, aggregate gradation, particle shapes, and binding ability of the aggregate.

But first, a word about the terms aggregate and gravel, as used in this handbook. Aggregate is the more technical term, but the everyday term for roads surfaced with mineral aggregate is gravel. It's the term most used in the rest of the manual. However, gravel has another, more technical, use: to identify specific kinds of aggregate—in contrast with sand, crushed stone, slag, etc. So, to distinguish between the two, the rest of this chapter uses aggregate to indicate the general material and gravel to mean one kind of aggregate.
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Size

Pick up a handful of aggregate from a road surface and see that, size-wise, there’s everything from tiny specks of material on up to pebble-size pieces. Good surface aggregate includes particles as fine as flour and as large as 20 mm (3/4 in) in approximate diameter. The biggest particles in a particular surface aggregate are referred to as the top size of coarse aggregate. The smallest particles, having the consistency of flour, are called fines. Between the two extremes are coarse and fine aggregate particles that are larger than the fines but smaller than the top-size material (figure 3-1).

From specks as fine as flour . . .

... to particles as large as 20 mm (3/4 in) in diameter

Figure 3-1. Aggregate particle sizes.
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Top size

In general, 20-mm (3/4-in) aggregate is recommended as the top-size aggregate to use in road surfacing. Keep in mind that 20 mm (3/4 in) is not all that large. In fact, it's slightly smaller than a nickel. Even though there are different opinions as to which size is best for the largest stone, 20 mm (3/4 in) is widely accepted as a standard. Still, there are roads with much larger top-size aggregate—as large as 40 mm (1.5 in); while some agencies use smaller top sizes—13 to 16 mm (0.5 to 0.6 in), for example.

Overall, more aggregate of a smaller top size is being used now than in past years. The following are some observations about the issue of smaller top-size stone versus larger top-size stone:\(^1\)

- Surface aggregate with a smaller top size tends to stay down better on the surface, especially in prolonged dry periods.

- Aggregate with a larger top size tends to come loose from the surface quicker and pile up between the wheel tracks and along the shoulders. (This makes for a rougher ride and a surface that's much more difficult for the motorgrader operator to maintain.)

- Smaller top-size material seems to cause fewer washboard problems.

- Smaller top-size material apparently is strong enough to hold up well in wet weather (especially if the road has been regraveled several times).

- While it costs more to screen or crush aggregate down to a smaller size, that cost can be recovered in easier and better road maintenance.
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Fines

As for the fines, they are indeed small—small enough to pass through the mesh of a sieve having 75-µm (0.075-mm/No. 200) openings. To give that size a scale, realize that a fingernail is about 0.5 mm (0.02 in) thick!

Fines consist mainly of clay and silt. Both are very low in permeability. That is, they are difficult for water to penetrate or saturate. Clay particles are hard when dry and soft when wet. They swell when moistened and shrink when dried. When wet, they feel greasy. Silt particles are slightly larger and more bulky than clay. Silt particles erode easily. Unlike clay, silt particles don’t change volume (swell/shrink) when their water content changes.

Although very small in particle size, fines play a big role in the effectiveness of surface aggregate. First, they fill the voids among the coarser particles and act as a binder to hold the total aggregate mixture together in a dense, tight mass. Second, they enable the surface aggregate to form a hard, tight crust that sheds water and bears traffic loads. This crust has been discussed somewhat already. It can only be formed when the aggregate surface is first moistened and then compacted to produce a dense, smooth, interlocked mass.

Coarse and Fine Aggregates

Between the top-size stone and the fines, the remaining particles of surface material consist of coarse and fine aggregates. The top-size stone itself is a coarse aggregate, which by definition is the aggregate retained on the 4.75-mm (No. 4) sieve. Fine aggregate is the aggregate that entirely passes a 9.5-mm (3/8-in) sieve, almost entirely passes the 4.75-mm (No. 4) sieve, and is predominantly retained on
the 75μm (No. 200) sieve. So the particle sizes in surface aggregate can be diagrammed this way:

\[ \text{Top Size} \rightarrow \text{Other Coarse Aggregate} \rightarrow \text{Fine Aggregate} \rightarrow \text{Fines} \]

(≤19 mm/3/4 in) \hspace{1cm} (19 mm to 4.75 mm/3/4 in to No.4) \hspace{1cm} (4.75 mm to 75 μm/ (>75 μm/No.200) \hspace{1cm} No.4 to No.200)

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**Gradation**

The above diagram indicates the extent or range of the aggregate particle sizes. Add to this the amounts of different-sized particles, and it describes the relative distribution of aggregate particles. Taken together, the range and relative distribution define the gradation of the aggregate.

Gradation is not a characteristic of individual aggregate particles, but rather of the combined particles. Think of gradation as the blend of different particle sizes. Wire-mesh sieves are used to separate aggregate particles by size to determine the gradation of the whole. In sieving, a representative sample of aggregate is placed in the top of a stack of sieves (figure 3-2) and shaken until all particles no longer pass through the openings. Each sieve’s contents are then weighed. Next, calculations are made to determine the percentage of aggregate, by weight, passing each required sieve. The calculated percentages passing are then compared to the gradation requirements for the material in question.

In the specified gradation, upper and lower limits are shown for the required percentages passing each sieve. For example, figure 3-3 shows two good gradations for surface aggregate—crushed gravel on the one hand and crushed stone on the other. Note, in both cases, that as
little as 50 percent or as much as 90 percent of the aggregate may pass the 9.5-mm (3/8-in) sieve to satisfy the gradation requirements. A note about the two

Aggregate sample placed in stack of sieves.

Portion of sample retained on each sieve (or pan).

Figure 3-2. Sieving to determine gradation.
categories of aggregate in figure 3-3: The difference between the crushed gravel and the crushed stone is the source of the material. If the aggregate is from a glacial deposit of gravel, the crushed gravel gradation is used. If the source is a quarry, the crushed stone gradation is used.

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Crushed Gravel</th>
<th>Crushed Stone</th>
</tr>
</thead>
<tbody>
<tr>
<td>37.5 mm (1-1/2 in)</td>
<td>100 %</td>
<td>100 %</td>
</tr>
<tr>
<td>25.0 mm (1 in)</td>
<td>95—100%</td>
<td>95—100%</td>
</tr>
<tr>
<td>19.0 mm (3/4 in)</td>
<td>50—90%</td>
<td>50—90%</td>
</tr>
<tr>
<td>9.5 mm (3/8 in)</td>
<td>35—70%</td>
<td>35—70%</td>
</tr>
<tr>
<td>4.75 mm (No. 4)</td>
<td>20—55%</td>
<td>15—55%</td>
</tr>
<tr>
<td>2.0 mm (No. 10)</td>
<td>10—35%</td>
<td>—</td>
</tr>
<tr>
<td>0.425 μm (No. 40)</td>
<td></td>
<td>—</td>
</tr>
</tbody>
</table>

**Figure 3-3. Good gradations for surface aggregate.**

The difference between good base course aggregate and good surface aggregate is the presence of fines in the latter. Because of it, the surface aggregate is sometimes said to be dirty. This dirtiness is desirable in surface aggregate but not in base aggregate. While fines contribute to the cohesion and stability of a mass of aggregate, they diminish the mass strength, ability to drain, and resistance to frost-heave damage. Instead of fines percentages of 8 to 15 or 5 to 15 as in Gradation No. 3 (figure 3-3), the percentage specified for base materials is more often on the order of 0 to 8.
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**Shapes**

Aggregate particle shapes affect their ability to interlock and, thus, the strength and stability of the mass. The desired shape for surface aggregate particles is *angular*, as opposed to *rounded* (figure 3-4). Angular aggregate has edges and faces that permit the individual pieces to fit closely together when mixed and compacted. The close-fitting particles produce another benefit: They reduce the voids, air pockets, that would weaken the aggregate course and entrap water.

Angular aggregate occurs naturally in some areas of the country. Angularity is also *manufactured into* aggregate through the crushing of stone and gravel. It may also be a byproduct of manufacturing, such as slag.

In many parts of the country, natural deposits of stone and gravel consist of rounded material. Much of this rounded aggregate comes from glacial deposits or water courses. Rounded shapes don’t allow aggregate to

![Diagram](image)

*Figure 3-4. Aggregate shapes.*
consolidate and interlock. They are interspersed with numerous voids. As the particles are worked and compacted, they tend to shift around and remain unstable without eliminating many of the voids. Even when the gradation is good—and there are adequate fines—rounded material fails to settle down and firm up. In effect, it's like trying to consolidate marbles or ball bearings: The mass shifts under pressure, acting more like a liquid than a solid, and fails to become a firm, stable structure.

**Binding Ability**

The ability of surface aggregate to bind together in a dense, stable course is obviously very desirable. Contributing to this, on the one hand, is a property called natural cementation. Although not fully researched, this property apparently stems from the "colloidal products of rock decay and increases in a general way proportionately with these products, reaching a maximum in rocks free of quartz."(4)

Natural cementation is probably but one of several such properties relating to aggregate binding. A more commonly recognized and verifiable property is plasticity index, or PI. It's usually found in the fines discussed above—the particles finer than the 0.075-mm (No. 200) sieve. As explained, most fines consist of clay and silt particles. These are plastic, or flexible, which enables them to compress and bind larger aggregate particles together. The higher the PI value, the better the fines will bind the total aggregate together. And the drier the climate, the higher the PI should be.
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Other Characteristics

Other properties of aggregate used for road surfacing should be noted: permeability, compressibility, and strength. Figure 3-5 rates gravel, sand, silt, and clay in terms of these three properties.\(^{(5)}\) Aggregates for road surfacing should be:

- Strong enough to bear traffic loads without degrading easily.
- Relatively incompressible so that future settlement is not significant.
- Stable against volume change as water content varies over time.
- Sufficiently permeable—that is, pervious to water.

<table>
<thead>
<tr>
<th>Aggregate Type</th>
<th>Permeability</th>
<th>Compressibility</th>
<th>Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravel</td>
<td>Pervious</td>
<td>Negligible</td>
<td>Good—excellent</td>
</tr>
<tr>
<td>Sand</td>
<td>Pervious</td>
<td>Negligible</td>
<td>Good</td>
</tr>
<tr>
<td>Silt</td>
<td>Semi-pervious to Impervious</td>
<td>Low—medium</td>
<td>Fair</td>
</tr>
<tr>
<td>Clay</td>
<td>Impervious</td>
<td>High</td>
<td>Poor</td>
</tr>
</tbody>
</table>

*Figure 3-5. Aggregate properties.*

The qualities of high strength, low compressibility, and stability are normally associated with good compaction (high density). Proper permeability means that changes
in moisture content do not cause aggregate materials to shrink or swell. Proper compactibility and stable volume are very important properties of surface aggregate.

**Types**

Aggregate is granular material of mineral composition. It may be a material available directly from nature (such as pit-run gravel), a natural material requiring some processing before use (such as crushed sea shells), or a man-made material that is the byproduct of manufacturing (such as slag). It may be a single material or a combination (such as sand and clay, or slag and crushed limestone).

**General Available Materials**

Some aggregate materials are widely available and commonly used to surface roads all over the country. These include crushed stone, gravel, crushed gravel, slag, certain lightweight aggregates, and sand.\(^6\)

**Crushed Stone**

Crushed stone is a material that results from the mechanical crushing of blasted ledge rock. Substantially all the faces of crushed stone result from the crushing operation, making it very angular. These faces are referred to as fractured. Crushed stone is therefore good for surface material in terms of its shape and texture. Crushed stone is usually limestone, which is available in many parts of the country. Other common kinds of rock are granite, quartzite, and sandstone.
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Gravel
Gravel is a coarse aggregate that originates from the natural disintegration of rock caused by the forces of nature. It's usually found in river beds or as natural deposits along former watercourses. Gravel usually consists of rounded particles because of its association with water.

Crushed Gravel
Crushed gravel is produced by mechanically crushing large particles of gravel—cobbles or boulders—to create more angularity of shape. Specifications may require that at least one face of each particle result from fracture. Often the requirement is for more than one fractured face. The source of this material is, again, current or former stream beds.

Slag
Slag is a nonmetallic material produced in a molten condition as a byproduct during the manufacture of iron, steel, or other products. There are basically two kinds. Air-cooled slag is solidified from molten condition by allowing it to cool in air, sometimes speeding up the process by subsequently applying water to the solidified surface. Granulated slag is formed by rapidly chilling the molten material, usually by immersing it in water directly. This produces glassy, granular particles. Some local agencies use recycled slag; for example, after its use as a sandblasting medium.

Lightweight Aggregates
These are expanded cellular materials produced by special controlled processes from clay, shale, or molten slag. They are referred to by terms such as burnt clay and
expanded shale. They are either a byproduct of heavy industry or a commercially produced aggregate material.

**Sand**

Sand is a fine aggregate that results from the natural disintegration of rock caused by natural forces. It is usually found in river beds or as natural deposits in old stream beds. Sand is also manufactured through the crushing of rock or gravel.

**Local Materials**

Other mineral materials, while not widely available, are found locally and make good aggregates for road surfaces. These include crushed sea shells, natural soil, crushed basalt, and chert.

**Crushed Sea Shells**

Sea shells are found in natural deposits in certain areas along the Gulf Coast and close to the oceans. The material may be plentiful in many localities of those areas, but in some places its use is restricted by environmental regulations. Where use is permitted, sea shells typically must first be crushed to produce a desirable gradation for road surfacing.

**Natural Soil**

Although a distinction is drawn between dirt roads and aggregate roads, the natural soil of some areas of the country may be suitable for road surfaces—especially when nothing better is available or affordable. This is especially true in some parts of the Midwest, such as Kansas. Sometimes local soils may be treated with other materials to make them suitable as road surfaces. For
example, where clayey soils predominate, sand may be added as a stabilizer. The resulting mixture may perform satisfactorily.

**Crushed Basalt**

Basalt is a dark, dense, fine-grained igneous rock of volcanic origin. It occurs in lava flows or minor intrusions. Its columnar structure lends itself to crushing.

**Chert**

Chert is a compact rock consisting essentially of microcrystalline quartz.

**Choosing the Best Material**

Crushed stone or gravel normally performs better than sand, slag, natural soils, or sea shells. Crushed materials having a good percentage of broken, angular-shaped particles almost always perform better than materials that are only screened. It’s because of their ability to consolidate and interlock better.

Harder materials generally perform better than softer ones. Local agencies need to beware of soft aggregate. Even some limestone is too soft to hold up under traffic. In roads surfaced with such material, vehicle tires break the rock down to progressively smaller sizes (degradation). This particle size reduction typically contributes to excessive dusting as well. Both problems reduce stability.

In addition to the angularity and hardness of a material, road agencies need to pay close attention to the gradation. A good aggregate will have a good distribution of particle
sizes. In particular it will have sufficient fines. Often, it pays to haul a good-quality, well-graded gravel from far away rather than use a cheaper, poor-quality local material that does not perform well, requires more frequent blading, and wears away more quickly.

In the end, choose material that rates high in terms of the above-mentioned qualities—and that produces a durable, stable crust.

Locating Aggregate

Locating sources of suitable, affordable road surface aggregate is difficult for many local agencies; but by obtaining good materials, local officials can reduce the problems of their aggregate roads.

QUALITY CONTROL

Surface aggregate must be properly obtained, processed, stored, and handled to ensure its good quality. Understanding a few principles and practices for safeguarding aggregate quality can make a difference in the material that goes into roads . . . and in the soundness of the roads themselves. Proper work methods and techniques should be followed at the gravel pit, crusher, stockpile, and roadway.
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Gravel Pits

At the very source of most aggregates—the gravel pit from which they're obtained—quality can be affected by the removal method. Typically, front-end loaders are used to remove buckets of aggregate from the pit walls. The loader operator should be sure to remove material from the full face of the pit wall (figure 3-6), not from only a narrow band. Removing material from the full face ensures that a complete and uniform blend of the pit's available aggregate is obtained. Taking aggregate from a narrow band usually prevents the material from being as complete and uniform.

Figure 3-6. Full face of gravel pit wall.
Crushing and Screening Plants

Conditions at crushing and screening plants also affect aggregate quality, in at least two ways: the levelness of the plant equipment, and the condition of the plant's screens.

Plant Levelness

First, there's the basic setup of equipment: It must be level to avoid segregating the aggregate. Segregation is the undesirable separation of the different aggregate particles by size. That is, instead of remaining well-blended, the coarser particles tend to separate from the finer portions of the aggregate. All it takes is for the crushing or screening plant (figure 3-7) to be out of level. Then, normal plant vibrations plus gravity combine to separate the aggregate particles. The problem usually shows up on a conveyor belt as two different swaths of material moving side by side.

Figure 3-7. Screening/crushing plants should be level.
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**Screen Condition**

Another plant problem is poor screen condition. Screens can gradually wear thin and eventually break (if not inspected and replaced in time). Worn screens end up with holes that are of course larger than the nominal screen openings—and which allow larger pieces of aggregate to pass through and combine with smaller size material. See figure 3-8.

Typical screen wear . . .

. . . leads to holes that allow larger pieces of aggregate to pass through

*Figure 3-8. Poor screen condition.*
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Screens also get clogged often, creating somewhat the opposite problem that holes cause. Instead of aggregate particles passing through sieves that they shouldn’t, they may not even pass through the sieves that they should. Some particles simply carry over the sieves that they should fall through. The same carry-over effect occurs also when screens are overloaded—too much aggregate placed on them at one time. The outcome is that finer particles don’t all pass through the appropriate screens and instead are combined with coarser material.

All of these problems of faulty sieving result in faulty gradations of aggregate. Out on the road poorly graded material will fail to properly compact or form a good surface crust.

Stockpiles

Aggregate stockpiling principles and practices also play a definite role in quality control. Two aspects of stockpiling enter the picture—preparing the area and building the stockpiles.

Area Preparation

The site for stockpiles needs to be properly prepared and in good condition to avoid problems of excessive moisture, contamination, and intermingling of different aggregates. In selecting and preparing the site, note the drainage of the area. The location should be reasonably level and well-drained (figure 3-9). That is, the site should not collect and hold water; and water should be able to flow freely away from the stockpile. Stockpiles in locations where runoff flows into them will not only be too wet much of the time, but they also will be contaminated by mud and debris that wash into them.
Stockpile site should drain well.

Figure 3-9. Stockpile sites.

Contamination occurs when foreign matter gets into the aggregate—such as the mud and debris just mentioned. Foreign doesn’t mean that the contaminant has to come from far away or be something exotic, of course. Typically it’s the soil or vegetation from the ground around or beneath the stockpile. So stockpile locations should be cleared and grubbed beforehand. All vegetation as well as other unwanted objects or materials should be entirely
removed from the site. If they're not removed, they'll end up in the stockpile. Then the ground should be smoothed and compacted, if necessary.

Another consideration for site selection and preparation is space. Whether just one stockpile or several stockpiles of different aggregates are to be built and maintained, there should be enough room. Even with only one stockpile, there needs to be enough space for trucks and loader to add to and take from the pile. With piles of different aggregates, either there should be enough room to adequately space them apart—to prevent intermixing the different materials—or partitions of some sort should be installed to separate them (figure 3-10).

Stockpiles separated by space . . .

. . . or by bulkheads

Figure 3-10. Stockpile separation.
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Stockpile Building

The main concern with the actual building of stockpiles is to avoid segregating the aggregate. Because of their density, larger aggregate particles tend to roll away from the body of aggregate as it falls and rolls. The longer and farther the material falls and rolls, the worse the segregation. Dropping aggregate at one point and allowing it to tumble and flow down the outside of a large pile should be avoided (figure 3-11). Otherwise, the finer aggregate particles stop flowing sooner while the larger particles continue rolling down and out to accumulate at the stockpile base.

Figure 3-11. Aggregate flow down the outside of a stockpile.
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Building cone-shaped piles is especially bad (figure 3-12). From one point the coarse aggregate fans out as it flows down all the outside surfaces to form a skirt of segregated coarse material all around the bottom. It's a sure-fire way of undoing the good gradation that comes from the pit, screening plant, crusher, or commercial supplier.

![Cone-shaped stockpile](image)

*Figure 3-12. Cone-shaped stockpile.*

To the extent possible, stockpiles should be built in layers (figure 3-13). Successive layers, each less than a meter deep and set in a little from the underlying layer, minimize segregation by limiting the falling-rolling-sliding movements of the aggregate. Alternatively, individual truckloads may be dumped in a single layer of closely spaced adjoining piles.

**Removing Aggregate**

Having quality aggregate in well-formed stockpiles is a good start, but there are still potential pitfalls to handling materials improperly.
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Layered stockpile

Bottom 300 mm (12 in) or so of stockpile to remain undisturbed as flooring. Segregation is minimized.

Closely spaced individual truckloads in a single layer

Figure 3-13. Proper stockpile building.

When removing aggregate from stockpiles, the loader operator should certainly avoid digging the bucket into the ground and scooping up clay, roots, boulders, or other foreign material. The bottom 300 mm (12 in) or so of the stockpile should be considered as flooring not to be disturbed by the loader. The flooring of aggregate serves as a barrier to keep soil, debris, and excessive moisture out of the rest of the stockpile (figure 3-13). By keeping the bucket a little above the ground when the loader moves into the stockpile, the operator ensures that only good aggregate will be removed. Avoiding the dirty, segregated material that always lies around the base of stockpiles is a good idea in itself. Maintaining the flooring aggregate intact also allows for the stockpile to be replenished with new aggregate without having to rebuild it from the ground up.
Chaper 3 Surface Aggregate

Besides avoiding the aggregate at the very bottom of stockpiles, there are other good practices in removing stockpiled material. When a stockpile hasn’t been formed in the best manner—and looks something like the one shown in figure 3-14—the loader should remove aggregate from the ends rather than the sides. Why? Because the sides contain more segregated coarse aggregate, loading the bucket at the end of the stockpile provides a better cross section of aggregate. The gradation will be correct, or at least better than loading from the sides will provide.

![Diagram of stockpile with arrows indicating concentration of coarse aggregate caused by segregation and a loader removing material from the end rather than the sides.]

*Figure 3-14. Removing aggregate from Roadway*

Finally, aggregate quality can be affected by the equipment and techniques used to haul, dump, and handle it on the road. Trucks and graders in good condition and properly operated help maintain good aggregate quality, but poor
Chapter 3 Surface Aggregate

condition or operation leads to contamination, segregation, or other problems.

Segregation, for example, is common when surfacing aggregate is hauled by trucks with poor suspensions, or when it is improperly dumped on the roadbed. Grader operators need to be alert so that, when equalizing the windrows of dumped material, they can eliminate or at least reduce the segregation.

In terms of contamination, grader operators who cut too deeply into the road surface will bring up subgrade materials that are undesirable for the wearing course. Pulling ditches and clipping shoulders may put plant matter and other unwanted materials on the traveled way. Operators need to keep from mixing such contaminants into the aggregate or else they’ll create weak spots in the road surface.

The curve of grader moldboards enables operators to do different things when working the aggregate. Proper forward tilt of the moldboard creates a tumbling/mixing action in the aggregate ahead of the blade. This helps maintain the desired blend of material and avoid segregation. Carrying the right amount of aggregate on the blade further prevents segregation. Pushing too much material too far and too long only allows finer particles to be carried forward.
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From source to destination, aggregate is susceptible to loss of quality mainly through contamination and segregation. Knowing the basic types and characteristics of aggregate, the key principles of quality control, the points at which quality is likely to be jeopardized, and the right and wrong ways of handling and working with aggregate, can all help local roads officials, managers, and equipment operators avoid problems with the material. And problems with the material relate directly to problems with aggregate surfaces.

REFERENCES


3. Based on Wisconsin DOT’s “Gradation No. 3,” as shown in Subsection 304.2.7 of the Standard Specifications for Road and Bridge Construction, 1989 Edition.
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Chapter 4

PROBLEMS—
CAUSES AND SOLUTIONS

In discussing general information, environmental influences, and surfacing aggregate so far in this handbook, references have been made to some of the problems of gravel roads. This chapter focuses directly on the three most common distresses that gravel surfaces suffer:

- Corrugation.
- Loss of [aggregate] material.
- Rutting and potholes.

This last problem is actually two different distresses put together in one problem category. That's appropriate because the two distresses have similarities; but then, so do all of the surface problems. Each of them interrelates with the others to some degree. Chapter 2 examined the environmental influences on gravel roads and considered factors that directly affect the specific distresses of corrugation, loss of material, ruts, and potholes. Likewise, chapter 3 considered aggregate characteristics—factors that directly affect those same specific distresses. Focusing closely on the distresses, this chapter includes some of the same ground at times, but also imparts some new understanding of the problems—as well as their causes and solutions.
Chapter 4 Problems — Causes and Solutions

Before creating too much hope for the total eradication of these distresses, be advised that there are no cure-alls, quick-fixes, sure-fire remedies, miracle drugs, or magic potions. But there is a wealth of experience, some sound advice, a lot of common sense, and a few new ideas and products on the subject. This chapter tries to bring all that together to help road managers and crews comprehend and combat these problems associated with gravel roads.

CORRUPTION

First up is corrugation, or the more familiar washboard. There are a few other names for the problem out there including corduroy, ridges, and ripples. Regardless of the name, it's the same irritating, pervasive distress whether in Maine or the Mojave.

Description

Corrugations are rhythmic undulations that normally extend across the full width of the traveled way and run perpendicular to the direction of traffic (figures 4-1 and 4-2). They extend over enormous lengths of gravel roads in many parts of the world. Probably their closest likeness is their namesake, the old-fashioned laundry washboard. In fact, long after the day when only antique dealers will know what a real washboard is (or was), crews probably still be contending with the gravel road versions.
Chapter 4 Problems—Causes and Solutions

Figure 4-1. Typical corrugation—longitudinal view.

Figure 4-2. Typical corrugation—viewed from roadside.
Chapter 4 Problems — Causes and Solutions

Classifications of the severity levels of most of the gravel road problems discussed here are described in Rating Unsurfaced Roads, a field manual developed by the Cold Regions Research & Engineering Laboratory of the U.S. Army Corps of Engineers (USACRREL), see reference.

Of course it’s not just the appearance of the washboard that makes the comparison valid. It’s also the feel of the washboard. The bone-rattling ride over gravel road corrugations is very like the feeling of running one’s fingers over the ridges of a washboard.

Other common objects and materials bear a resemblance too, for example, corrugated pipe and paper. The similarities are in the regular undulations that form alternating ridges and valleys. In wave terminology, the height of a ridge—from its crest to the bottom of the adjacent valleys—is the amplitude. The length of a corrugation is measured from crest to crest and is termed the pitch (figure 4-3). Amplitudes—heights—may be as much as 80 mm (3 in), with less severe corrugations measuring less. Pitches—the lengths of corrugations or distances from crest to crest—typically measure 150 to 200 mm (7 to 8 in).

While corrugations no doubt contribute to wear-and-tear on vehicles, and to more than a few headaches, they are also harmful because they seriously impair drivers’ control of steering and braking. So the rough ride contributes to three problems of personal discomfort, vehicle damage, and loss of driving control.
Chapter 4 Problems—Causes and Solutions

Figure 4-3. Corrugation dimensions.

Causes

The causes of corrugation have been debated for decades. Among the theories is one that attributes their existence to vehicles pushing mounds of gravel in front of their wheels and then riding over the mounds when they have attained a crucial size. Another theory argues that "... corrugations are caused in the manner of waves on windblown sand by the clouds of dust produced by high-speed vehicles." Most investigators, though, now agree that corrugations are associated with two key factors—the effects of traffic and the character of the road surface. (1)

Effects of Traffic

Research shows that gravel road corrugations are formed by the complex interaction of two vehicle-produced actions. One is vehicle oscillation produced by suspension systems and tires. Oscillations are pendulum-like, to-and-fro movements—vibratory-type motions. The springs and dampers of suspension systems, as well as the tires, do the oscillating; the tires transmit the action to the road surface.
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The other action is abrasion, the friction between tires and road that wears down the gravel surface. Abrasion is modified by tire hardness and speed, and by acceleration, deceleration, and turning forces.

Research has shown that hard tires tend to cause corrugation more than soft tires. The hardness versus softness is mainly a function of inflation pressures. The lesser tendency of soft tires to corrugate gravel surfaces may stem from their greater contact area with the surface, or from their greater internal damping effect (which softens their impact on the road).

As for speed, it’s noteworthy that India has no problem with washboarding on its 560,000 km (901,000 mi) of unsurfaced roads. Why? It seems that roads in India carry mostly slow-moving animal-drawn vehicles that prevent the relatively small number of mechanically powered vehicles from traveling at higher speeds. Vehicle speed definitely plays an important role in the creation and severity of corrugations. Higher speeds hasten the forming of corrugations and also enlarge their size. In driving on corrugated roads, drivers notice that by adjusting their travel speed they can partially smooth the ride and lessen the violent vibrations. In fact, slower speeds on corrugations typically cause a rougher ride. Normal speeds usually reduce the effect of the vibrations because the body motions are not excited by the high rate at which the corrugations are covered.

Vehicle acceleration, deceleration, and turning increase the abrasive effects of tires and their tendency to corrugate the road surface. Accelerating quickly from a dead stop, decelerating suddenly to 0, or turning sharply at high speed all heighten the effects even more. No wonder it’s easy to predict where corrugations will occur on gravel roads. First, there are intersections (figure 4-4),
especially those where traffic comes to a complete stop—
sudden deceleration, followed by rapid acceleration, and
often including sharp turning.

Figure 4-4. Corrugation at intersections.

Next are driveways (figure 4-5). Vehicles slow down
quickly to turn in, and speed up quickly to turn out—
often from a dead stop.

Curves too are likely locations for corrugations (figure 4-6).
Vehicles slow upon entering a curve and speed up when
exiting it. The sharper the curve, the more rapid the
deceleration and acceleration—and the more severe the
washboarding.
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Figure 4-5. Corrugation at driveways.

Figure 4-6. Corrugation on curves.
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The slopes of hills are also prime candidates (figure 4-7). Vehicles accelerate on the upgrade, and decelerate on the downgrade.

Figure 4-7. Corrugation on hills.

Character of Road Surface

While it takes vehicle oscillation and tire abrasion to produce corrugation, the character of the road surface also has a lot to do with their formation. For one thing, investigations reveal that for corrugations to form, the surface must be friable—crumbly. Then, as vehicles oscillate, the tires’ contact area with the road surface alters. This creates lateral and longitudinal shear stresses that displace gravel particles from the loose surface and form corrugations.
Another contributing factor is the lack of sufficient fines to bind the gravel particles together. Whether there weren’t enough fines in the gravel originally placed, or they have dusted or washed away, surfaces lacking them are going to readily corrugate. Dry conditions can cause or worsen the problem. On the other hand, steep terrain and excessive crowns may allow fines to wash away during heavy rainfalls.

Soft roadbeds and pot-holed surfaces encourage washboarding too. Research shows that the composition of the surface material plays a role in terms of the clay/sand ratio. A mixture of 20 percent clay to sand has the greatest tendency to corrugate. However, while lower and higher clay contents may decrease the tendency to corrugate, they may promote other problems, including washouts and potholing. And, once potholes are present, they themselves encourage washboarding (as noted above).

**Improper Grader Operation**

While it’s not a widespread cause of corrugation, improper operation of motor graders will produce the problem too. It stems from oscillation of the machine when it’s operated too fast. The washboarding is typically diagonal because the angled blade makes the ridges as it oscillates with the rest of the grader. They’re probably produced by inexperienced operators, or operators in too much of a hurry.

**Prevention**

As with most problems, preventing corrugations is much preferred to correcting them. For example, grader-caused corrugations can be avoided by blading at a speed of
about 5 to 8 km/h (3 to 5 mi/h), preferably using the proper gear, setting the correct blade angle and pitch, and inflating the tires properly.

Preventing regular washboarding is more difficult. Because corrugations are caused by traffic, it might be tempting to ban vehicles from using gravel roads. While that is impractical to say the least, some local agencies do try to educate the public to drive in ways that reduce the tendency for washboarding to form. For one thing, getting drivers to slow down helps a lot. Agencies should ensure that proper speed limits are set, adequately posted, and—to the degree possible—enforced. Speed limit signs alone may not be enough, but use of the airways and any other means of spreading the word may help change driving habits enough to make a difference. Efforts should not only try to change drivers' tendencies to go too fast, but also their inclination for jack-rabbit starts and sudden stops.

Realistically speaking, however, gentle driving habits can only lessen the severity of corrugations or slow their development. It's the road's materials and surface characteristics that really determine whether or not washboarding will be a problem. From this standpoint, preventing corrugations means ensuring that gravel roads are:

- Constructed on subgrades of stable materials that drain well and are sufficiently compacted to provide a firm roadbed.

- Constructed of well-graded gravel that has enough binder in it to hold the surface material together and resist the forces of traffic oscillation and abrasion.

- Maintained with as unblemished a surface as possible—free of potholes and loose gravel.
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As discussed earlier, not all locally available gravel has adequate natural binder to provide the needed cohesion. One solution for this is to bring in material from more distant sources. Of course, the cost of transporting gravel from several counties away, or farther, may be prohibitive.

Another solution may be the use of commercially available binders. Some agencies add them to their local gravel to provide the binding ability that their material lacks. There are as many as two dozen such commercial products in use for this and other purposes. Many of them also serve as stabilizers or dust palliatives. These products are liquids, and may be based on petroleum, lignin sulfonate, or enzymes—or be of other chemical composition. For product use and availability in an area, contact the State’s Technology Transfer (T²) Center.

Briefly, though, just a few words about binders. Petroleum-derived products are emulsions—that is, the petroleum component is carried in a water solution as tiny globules. After mixing with gravel, the water evaporates and leaves the petroleum to act as a binding agent. Lignin sulfonate is a product obtained from pulp mills—basically tree resin. Having sap-like qualities gives it staying power to function as a binder within the gravel. It’s supplied as a liquid to facilitate applying and mixing it with the gravel.

Enzyme-based commercial binders are also available in liquid form. For the enzymes to work properly as a binder, the gravel must have a significant amount of organic material with which the enzymes can react.
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Correction

Even with the best gravel, road surfaces tend to corrugate. So most local agencies must contend with correcting the problem as part of their normal gravel road maintenance.

For light washboarding—where the corrugations are less than 25 mm (1 in) high—routine blading or dragging will remove the problem. Motorgraders are commonly used to do this smoothing; but drags, rakes, and underbody [truck] blades may be used instead.

With moderate-to-severe washboarding, the correction has to be more than simply eliminating the ridges. Eliminating the ridges is actually the easy part. The hard part is getting rid of the corrugations in a way that averts their early reappearance. It seems that severe corrugations are like bad teeth: it’s necessary to go to the root to get rid of the problem.

So, moderate-to-severe corrugations—25 mm (1 in) and higher—are not only more pronounced, they are also more difficult to correct. It’s not enough to clip the high spots and fill in the low spots. Experience shows that corrugations tend to begin re-forming at the same locations in a matter of days, perhaps hours. Reason: The relatively loose and uncompacted clipped material left lying between the former ridges is kicked out by traffic and piled back up on the former ridge bases. In this manner the corrugations are rebuilt. The process is depicted in figure 4-8.
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Figure 4-8. Re-forming of corrugations.

Instead of the clipping-and-filling cycle, follow these 5 steps to correct moderate-to-severe washboarding:

1. Scarify the corrugated surface.
2. Cut down 80 to 100 mm (3 to 4 in).
3. Add sufficient natural or commercial binder.
4. Add more gravel if needed.
5. Mix the materials in place and reshape the surface.

By undercutting the corrugations—roots and all—the problem is completely removed and will not readily re-form, especially if binding material is mixed in and the whole gravel layer is reshaped. Obviously, merely
smoothing the surface is not enough to correct moderate-to-severe washboarding. Also required is an improvement of the gravel’s quality to resist the forces that form corrugations.

The same corrective steps listed above can be applied to isolated occurrences of corrugation as well as to extensive areas. As noted, the problem is often concentrated at intersections, driveways, curves, and hills. When the spot corrections require scarifying, adding materials, and reshaping, the motorgrader operator needs to blend the corrected area into the adjacent surface.

Whether the correction of corrugations is extensive or limited to certain locations, the roadway crown or any superelevation must be maintained everywhere.

In addition, special attention needs to be given to smooth transitions at bridges and intersections.

An important goal when repairing gravel surfaces is to reestablish the surface crust. A tight, dense crust helps ward off washboarding as well as other distresses. Correcting corrugations after rains is always good practice because the moisture is needed to compact the reshaped surface and form a good crust.

**LOSS OF [AGGREGATE] MATERIAL**

Because mineral aggregate is the main component of gravel roads, its loss should be a major concern. For a road to function properly, it must have a surface layer of sufficient depth and proper composition and cross section. Loss of material from a surface leaves it weaker,
less smooth, and more susceptible to the development of
distresses. In addition, the loss costs local agencies for
replacement material, equipment, and labor. The loss also
threatens motorists’ safety and even poses some health and
other environmental problems.

Description

Despite the frustrating notion of some local officials—that
someone out there is stealing their gravel from the roads—
most lost aggregate material is not attributable to theft. Nor
is its disappearance related to mysterious, supernatural
forces. For definition here, material is lost either by being
removed from roadways or displaced within them. In other
words, gravel doesn’t actually have to disappear to be lost
as usable surface material. For example, everyone has
driven on gravel roads that have bare wheel tracks
bordered by parallel mounds of loose stone running down
the road between the tracks or next to the shoulder lines.
This loose gravel is still on the road, but it’s been
displaced—it’s out of position. Therefore, its effectiveness
as part of the road structure has been lost.

Surface aggregate is lost in three ways: by dusting, by
raveling, and by a process called sinking.

Dusting

Although it may seem that removing the dust from the
living room furniture settles right back down on the surface
again, it’s not so with the dust from gravel roads. Because
of wind and the drafts from vehicles, most road dust ends
up elsewhere—lost. This dust consists of the finest particles
of the aggregate, particles small and light enough to be
picked up by the swirling breezes of passing traffic or the
winds of Mother Nature (figure 4-9).
Figure 4-9. Gravel road dust.

The wafting aloft of dust particles results in several problems for gravel roads. First is the loss of material from the wearing surface. When looking at thick dust clouds, it may be hard to imagine all that great a quantity of material actually being lost. Yet, studies have shown that as much as 25 mm (1 in) of surface gravel is lost each year from dusty roads. Researchers calculate this loss to be about 70 Mg/km (125 T/mi)! It takes a lot of fines from the gravel surface to add up to that much loss, every bit of which should be replaced if the road is to be maintained properly.

Another problem posed by dust is its effect on motorist safety. Both as billowing cloud and clinging film, dust hampers drivers’ vision. Whether following another vehicle’s dusty wake or passing another vehicle, visibility ranges from slightly restricted to 0—depending upon conditions.

Whether it’s airborne or earthbound, road dust is an environmental nuisance. Breathing it is unhealthful—for humans, pets, livestock, or wildlife. It’s not the best thing
for vehicles to breathe either. Crops, trees, shrubs, and other vegetation along the right-of-way can be choked by thick dust. In the extreme, it’s a form of air pollution.

Finally, besides the cost of replacement, and the threat to health and safety, dusting poses one more serious problem—it removes from the surface gravel the binder that’s needed to hold all the aggregate together. Remember, not just a little binder, but in some cases as much as 70 Mg/km (125 T/mi)! Without the fines, the surface is susceptible to washboarding, and the rest of the layer is subject to further disintegration and loss of material.

**Raveling**

The further disintegration and material loss just mentioned above refers to raveling. The term is actually borrowed from the distress common to bituminous pavements. But it pretty well describes what happens to gravel surfaces too. The surface crust breaks down, binder is lost through dusting, and the larger particles become unstable. The loosened gravel separates from the surface and is displaced. Traffic either kicks it off the road entirely (primarily into the ditches) or accumulates it in longitudinal *berms*—ridges that run in the direction of traffic (figure 4-10). These berms run between wheel paths and along the roadway edges or shoulders. Loose stones also collect on the low sides of curves, and where vehicles stop or turn. One way or the other, the raveled gravel is either lost from the road or displaced on it.

Raveling means that the road’s crust has broken down and the surface material has come apart. The surface stops performing its intended functions well, or at all. It doesn’t seal out water; it doesn’t provide firm support; and it
doesn’t allow a smooth ride. The raveled material creates poor traction and steering. Windshields are frequently broken or chipped by loose gravel kicked back or chipped by other vehicles’ tires.

**Sinking**

This term may be unfamiliar (relative to gravel roads, that is) but the problem is very real. While dusting and raveling result in material loss *up and away from* the surface, *sinking* results in material loss *down and into* the surface. The gravel is pushed downward and is replaced by materials that are displaced upward from the subgrade. Stated another way: Surface gravel merges with the underlying subgrade material. The problem may be extensive—occurring over an entire road—or may be limited to small sections.

The problems created by gravel sinking into the roadbed are twofold. First there’s the loss of material itself.
Excavations at sites of severe sinking have shown surface gravel as far down as a meter (several feet) into the subgrade. Again, the gravel hasn’t been lost from the roadway, but drastically displaced from the surface.

Second, sinking gravel means an unstable road—one that will not hold its shape or support traffic without deforming. This instability leads to rutting, which is discussed later in this chapter.

Causes

Although the descriptions above convey why aggregate material is lost, further explanation is necessary.

Dusting

Road dust is related to dryness, and correctly so. Fines absorb moisture that increases their weight substantially and holds them down. When the moisture evaporates—because of an arid climate, a dry season, or simply a rainless spell—the fines become lighter and are prone to be stirred up and blown away. It’s impossible for fines to be an effective binder when they’ve dried completely because they lose their binding ability.

The process of dust generation begins as the surface crust dries out and starts breaking up. Raveling begins; and as gravel loosens and separates, more of the surface material is exposed to the drying effects. Tire abrasion separates coarse from fine particles and soon lifts up the accumulated dried fines as dust.
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Raveling

The drying out of the wearing surface, the breaking down of the road’s crust, and the separating of coarse particles from the binder—all lead to raveling. Although dryness is a key instigator of raveling, rainfall can actually speed it once it’s started. Rain further erodes the separated fines and washes them off the road. Excessive crowns also may aggravate the problem, allowing greater wash-off of fines.

Other contributors to raveling stem from the surface gravel’s composition: particle shape, size, and gradation. Recall that rounded gravel doesn’t bind together well to begin with. So when the fines dry and lose their binding ability entirely, raveling gets into full swing. Larger top sizes of gravel lend themselves to earlier raveling as well. It’s more difficult for denser particles to remain interlocked, especially once the binding material dries and loses its cohesive quality—and traffic action begins working the heavier stones free. Finally, poor gradation—especially a lack of fines—will usually doom a gravel surface to premature raveling. No need to wait for the fines to dry up and dust away; there weren’t enough of them to begin with.

Sinking

The problem of gravel that sinks into the surface results from poor-quality roadbed materials, usually in combination with wet conditions. Subgrade materials that are soft and compressible—especially those containing a lot of clay or silt—allow denser gravel particles to be pushed into them under certain conditions. Poorly drained roads where boggy conditions prevail are the most likely candidates for this problem. In clayey roadbeds, moisture forms a clay paste that is pulled to the surface by the suction created by tires passing over the
road surface. This paste coats and lubricates the gravel particles, allowing them to slide past each other and work their way down into the roadbed. When dry, these gravel particles are basically stable; the dry friction between particles prevents them from sliding past each other. But the lubricating effects of the clay paste welling up from below enable the gravel to move. With tires pushing the surface gravel downward, while at the same time pulling the clay paste upward, an exchange is effected: clay paste to the surface; coarser gravel particles to the bottom. In this fashion the surface gravel sinks. Through time, the worst offending roads seem to have a limitless capacity to absorb whatever amounts of gravel are placed on them. The gravel is down there, but in functional terms, it’s lost.

Prevention

Preventing the loss of aggregate material means more than merely postponing the day when a road will have to be regraveled. It means maintaining the integrity of the surface layer so that safer, more comfortable driving can be ensured, the roadside environment can be protected, and the life of the road itself can be prolonged.

Dusting and Raveling

Both of these problems can be prevented—or at least delayed—by making sure that new gravel surfaces have enough binder in them. Agencies that customarily use surfacing material deficient in natural binder, should investigate the possible use of commercial binders like the ones discussed above. While ensuring that gravel to be added contains enough fines, also be sure that the:
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- Overall gradation is good.
- Top-size gravel is no larger than about 20 mm (3/4 in).
- Gravel has enough fractured faces for proper interlocking.

Attention needs to be paid to material quality, but good construction practice can also help. When a surface is regraded, it should be rolled with a roller, usually after adding water. Rolling doesn’t compact the individual gravel particles, rather it consolidates them in the layer—making the surface more dense and firm. Moisture is needed to maximize this densification, as well as to form a tightly knit crust.

In fact, maintaining a good crust is another way of warding off dusting and raveling. Routine smoothing of gravel surfaces with a motorgrader—when the surface has a little moisture in it—will restore the crust. As long as the crust remains intact, dusting and raveling will not become serious problems.

The use of dust palliatives is one more means of keeping dust down and has proven effective and beneficial to the road in other respects. These are products that include calcium chloride, magnesium chloride, resins (such as lignin sulfonate and emulsified asphalts), enzymes, salt, cements, and other agents. They bind particles together and hold down the dust by making dust particles:

- Heavier by attracting and holding water.
- Heavier by adding oils to them.
- Hold together with cementing action.
- Hold together by ion attraction.

Calcium chloride and magnesium chloride, for example, fit into the first category above. They not only retain the moisture that’s already in the gravel, but they also actually pull more of it from the surrounding air (provided the air
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is humid enough to provide any). The ingredients in these products can absorb more than their own weight in water. When mixed with surface gravel prior to regraveling, the chlorides will effectively prevent the new surface from drying out. And as the product gradually leaches out of the surface, periodic reapplications at reduced rates can replenish the palliative content and continue the dust-suppressing effects. Figures 4-11 through 4-13 is a close up of three different chloride-treated roads. Figure 4-11 shows a smooth, closed-texture surface. Figure 4-12 shows minimal dusting during an extremely dry spell in South Dakota. Figure 4-13 shows no dusting at all on a desert road in Arizona.

Figure 4-11. Surface of chloride-treated road.

Dust palliatives may be incorporated with the surfacing gravel for new construction, mixed with the gravel before regraveling, or applied to existing gravel surfaces. Local agencies should consult their T^2 Centers and investigate the effectiveness of the various palliatives before using one or the other.
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Figure 4-12. Minimal dusting—treated road in South Dakota.

Figure 4-13. No dusting evident—treated road in Arizona.
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Sinking

Preventing the sinking of gravel ideally would be taken care of by ensuring that subgrade soils are always of good quality in terms of strength, stability, and drainage. Typically, though, local budgets for gravel roads don’t allow for extensive replacement of poor subgrade soils with more select materials. So where the general soil characteristics of a region are poor, the local roads department may have to do the best it can under existing conditions. Most local budgets are no doubt better equipped for replacement of limited, smaller scale occurrences of poor roadbed soils.

All agencies, however, can do the best possible job with roadway drainage to head off problems of this sort by paying close attention to proper roadway crown, ditches, and culverts. Keeping water off, out of, and away from the roads will at least lessen the severity of gravel sinking into the subgrade.

A bright spot in combating this problem is the apparent effectiveness of geotextile products. Briefly, the installation of a geotextile fabric or grid on top of a troublesome subgrade can keep clay paste from pumping up into the gravel wearing surface. Chapter 6 contains more information on geotextiles.

Correction

Dusting and Raveling

Corrective measures for dusty or raveled roads must begin with replacing the lost portion(s) of the aggregate material. Motorgraders can often be used to reclaim fines
from the shoulder edge, remix them with the existing gravel, and then blade the material to restore the surface. This operation should be part of routine maintenance along with restoring the road’s crown. Additional fines—either natural material or commercial product—will likely be needed because of dust that has blown away. They can be brought in and mixed with the existing gravel in the same manner. In all cases, to prevent future dusting and raveling, binder will have to be reincorporated into the gravel surface.

For raveled surfaces, the coarser material will likewise need to be restored. Again, graders can collect the loose, displaced gravel from where it’s accumulated between tire tracks and on the outer edges and shoulders of the road; then remix it with the rest of the surface material and blade it to restore the surface shape and crust.

A dust palliative may also be needed. Again, palliatives may be mixed with the gravel before the roadway is final-bladed and shaped, or they may be applied to the finished surface. Always consult manufacturers’ recommendations for proper usage.

Sinking

The recommended correction for sinking gravel may depend on the extent of the problem. For long sections of road, installing a geotextile material may be the best solution. With the fabric or grid between the problem layer and the gravel surface, water may pass through, but the clay paste is barred from moving up to the surface. The shielded gravel is no longer prone to sink. So even when the volume of poor roadbed material is too great to remove and replace, the gravel surface layer can be separated from it—and protected from its negative effects—by means of geotextiles.
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The smaller scale problem areas may be corrected by geotextile installation; or it may be advisable instead to undercut the offending soil layer and backfill it with good-quality subgrade material. Habitually wet and unstable sites may be correctable only through a combination of both methods.

RUTTING

The roadway conditions that lead to material loss by sinking cause another serious problem: the distress known as rutting. And similar to ruts in some respects is the distress called potholing.

Description

Ruts

Ruts are longitudinal depressions that form in wheel paths because of a permanent deformation in any road layer or the subgrade (figure 4-14). The deformations make gravel surfaces rough, producing an uncomfortable ride.

Worse, however, is when ruts are deep enough to cause drivers to lose control of their vehicles. And, naturally, as long as the road remains soft and wet, there’s the chance that tires will get stuck and the vehicle will get bogged down.

Beyond the annoyance and the danger posed by ruts, there’s the further deterioration that they expose the road to—they cause severe breakup of the road surface,
prevent proper drainage from the traveled way, and allow the water they collect to penetrate the subgrade and cause further damage.

Aside from the surface ruts that result from deformation of an underlying road layer, there is the slight surface rutting caused by normal traffic wear. These are similar to the wheel channel ruts in bituminous pavements. Another type of gravel road rutting occurs where some of the surface gravel is dislodged. These ruts, however, do not produce the serious consequences of the ruts under discussion in this handbook.

**Potholes**

Potholes are bowl-shaped depressions in gravel road surfaces. They may develop singly or in clusters. A group of potholes often ends up interconnecting as each expands. Potholes may also develop in conjunction with other surface distresses, especially washboarding.
Potholes vary in depth and are usually less than a meter (3 ft) in diameter. Some classifications consider potholes as having low severity if they are less than 50 mm (2 in) deep, of medium severity if they’re between 50 and 100 mm (2 and 4 in) deep, and of high severity if they’re more than 100 mm (4 in) deep. Potholes that contain water grow faster than ones that stay more or less dry (figure 4-15).

![Pothole with water](image)

**Figure 4-15. Pothole with water.**

Like ruts, potholes are both uncomfortable to drive on and potentially dangerous to vehicles and motorists. The hazards stem both from potholes’ physical effect on steering and their psychological effect on drivers who often react to them by swerving or suddenly braking. In addition to the discomfort and danger posed by potholes, there’s the expense of vehicle repairs for damaged alignments, suspensions, tires, and rims. Potholes typically produce more wear-and-tear on vehicles than do ruts because of the normally greater shock that potholes
produce. But, like ruts, potholes contribute to other gravel road distress. In particular, they encourage washboarding to form. They also hold water and allow it to enter the road layers and do further damage.

Causes

Ruts

The serious ruts referred to above are related to the problem of sinking gravel. Recall the conditions that lead to their development: soft, weak subgrade soils, usually excessively wet. The excessive wetness may stem from low-lying location or from poor drainage conditions. As tires press down on the gravel in their paths, the gravel is forced downward (figure 4-16). In reaction, the material outside the wheel tracks is forced upward. No matter what the quality of the surface gravel, the underlying softness in the road permits severe deformation at the surface.

Naturally, the heavier the vehicle, the greater the force it exerts on the road—and the more severe the rutting that occurs. Indeed, overweight vehicles should be considered a cause of rutting. Even stronger subgrade soils without excessive moisture have trouble resisting the tremendous loads sometimes driven over them. Because such overweight vehicles are recognized for damaging paved roads, it only makes sense that they be acknowledged as causing damage to unpaved roads as well.

Helping the surface gravel to be displaced is the clay paste brought to the surface by the suction created when tires pass over the road. As discussed above, the clay paste lubricates the pieces of gravel, enabling them to overcome friction and slide past each other.
In addition, excessive fines in a surface layer cause rutting. Just how severe depends on the preponderance of fines in the material. Sandy roads, for example, usually rut easily—especially when wet.

**Potholes**

Potholes are caused primarily by traffic wearing away small pieces of the road surface. Minor causes of
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Potholes include the dislodging of oversize stones at or near the road surface. The cavities left by their removal form immediate, small potholes that may grow larger. The presence of any foreign objects or material at or near the surface may likewise lead to potholes. The removal of such leaves openings that may develop into potholes simply because the crust has been broken and traffic and water can now team up to enlarge the problem.

A major contributor to pothole formation is a wet roadbed. As stated, potholes containing water grow faster than dry potholes. Of course, the amount and type of traffic affect pothole size and growth rate too.

**Prevention**

The prevention of both rutting and potholing in gravel roads yet to be built starts with the roadbed. Strong, stable subgrade soils that drain well should be used in new construction. For existing gravel roads, prevention comes down to maintenance of adequate drainage. The road’s crown must be correct. The shoulders and foreslopes must slope properly, with no blockages of drainage. The ditches must be deep enough and shaped properly to carry away runoff.

Materials added to gravel roads as stabilizers or dust suppressants help ward off the formation of ruts and potholes by strengthening the surface layer and increasing the tight, impervious character of the crust.

Keeping overweight vehicles off gravel roads also will help prevent rutting and potholing. Local governments should do what they can to establish and enforce load limits to curtail travel by giant rigs that almost single-handedly destroy unpaved roads.
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Correction

Slight Rutting

The basic corrective measure for slight rutting—where rut depth is less than 25 mm (1 in)—is for a motorgrader to blade the surface to restore the crown. In other words, remove the ruts and shape the surface so that it drains properly. Remember, some slight rutting may simply be traffic wear.

Severe Rutting

Ruts between approximately 25 and, say, 75 mm (1 and 3 in) are in the moderate range; while ruts deeper than that are considered severe. The following measures are warranted in correcting these more serious distresses.

- Improve drainage. To begin, the rutted surface first has to be put back into good shape. A good starting point is for the grader to blade out the ruts and restore the crown. But since moderately to severely rutted roads usually got that way because of more serious drainage problems, merely blading the surface and restoring the crown may not fix things for long unless these more serious problems are first corrected. So investigate for drainage obstructions on the shoulders and foreslopes—and use the grader to remove any blockages. Then check the ditches and culverts.

Clean up the ditches by removing stray gravel, vegetation, and debris to restore a proper flow line (figure 4-17). As necessary, deepen the ditches to increase drainage capacity. Are there enough culverts, and are they correctly positioned—in terms of both grade and horizontal alignment? Are they free of built-up debris and able to handle the quantity of drainage from the ditches? Some culverts may have to be
cleaned; others may need to be replaced; still others may have to be added to handle the drainage. The severe rutting cannot be eliminated without taking care of these drainage needs.

Figure 4-17. “Pulling” (cleaning) a ditch.

- Add gravel. A certain amount of gravel displacement takes place with all severe rutting. Gravel is pressed into the deformed, softened surface and underlying layer. Much of it goes down too deep to practicably recover for surfacing. So new gravel may well be needed to replace the lost material and to rebuild the surface layer. Of course, this new gravel should be good material—of proper gradation, particle shape, and durability. Where the cause of the rutting is excessive fines, new gravel should consist of coarser material to provide stability when mixed and shaped with the existing fine material.
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- Stabilize gravel. It may be advisable to provide greater strength, durability, and imperviousness to the corrected surface by adding materials such as dust palliatives. The benefits of these products—beyond dust control—were described earlier in the chapter. The incorporation of chloride, salt, cement, resin, or enzyme products will enable the corrected surface to resist traffic wear, water penetration, and surface deformation much better.

**Isolated Potholes**

To correct isolated potholes, follow these procedures:

1. First clean the depression (and the surrounding surface). This involves sweeping away loose stones and dust and removing any foreign objects or materials from the site. Get rid of any accumulated water from the pothole. It may be advisable to dig into the bottom of the depression to see the condition of the underlying layer. Removing and replacing wet, unstable material may be warranted. Be sure the pothole isn’t the result of an underground spring or other cause that may require special corrective action.

2. Fill the cleaned depression with *clean granular material* that is properly graded and mixed. A 50-50 mixture of crushed gravel and calcium chloride (CaCl₂) is recommended. The calcium chloride will help bind the gravel particles together, strengthen the *patch*, and provide a tight surface crust. Follow the placing of the patching material with a sprinkling of water. The added moisture will enhance the consolidation of the gravel, which is the final step.
3. In referring to consolidation, the term *compaction*, is actually incorrect. The material is not actually *compressed* (which is what *compaction* would indicate). Instead, the process eliminates the air pockets and makes the whole mass more dense. Consolidation makes the particles reorient themselves, fit together, and interlock to form a stronger, more stable patch. The consolidation is accomplished by *tamping*. Mechanized tampers are ideal but are not all that common in gravel road maintenance. Manual tampers can do a good job; so can rolling the patch with truck tires. The important thing is the consolidating effort—a step too often omitted from gravel road maintenance.

*Extensive Potholes*

When there’s a whole flock of potholes, treating them as individual patch jobs would be impractical. Instead, try these suggested steps:

1. Begin by scarifying the area—that is, break up the surface slightly deeper than the depths of the potholes. Typically, a motorgrader equipped with a scarifying attachment is used to scarify the area to the desired depth.

2. Next, add clean granular material—crushed gravel—that is properly graded and mixed. If called for, and affordable, calcium chloride may be mixed first with the gravel. Place enough gravel on the scarified surface to restore the area to the proper grade and cross section after rolling (*compaction*). The gravel may be dumped from trucks and spread by grader. With the gravel placed over the area, add enough water to thoroughly moisten the surface.
3. Now mix the gravel in place. The calcium chloride may be added to the spread gravel at this point rather than mixing it in before gravel placement. In any case, thoroughly mix the material and then spread it evenly to reshape the surface. Remember to restore the proper crown or superelevation in the process.

4. Roll the surface. Again, this should be done thoroughly by at least the truck tires. Better is the use of both a rubber-tired roller and a steel-wheeled roller. Rubber-tired rollers (or truck tires) produce a kneading action that consolidates the gravel effectively. Smooth-drum, steel-wheeled rollers provide additional consolidation and seal the surface to form a tight, dense crust.

Steel-wheeled rollers may be vibratory. A precaution, though, is to verify that they do not crush the gravel and change its properties. Generally, vibration can improve consolidation, but only if the correct frequency and amplitude of vibration are used. The wrong frequency or amplitude can instead decrease density, and even lead to segregation of coarse and fine particles. Even with correct frequency and amplitude, some segregation may occur if the gravel surface is overrolled. Normally, make no more than two or three passes in the vibrating mode. Make any additional finishing passes in the static (nonvibrating) mode.
Despite advances in gravel road maintenance, there will continue to be plenty of opportunities for both preventive and corrective work to combat the problems of corrugation, material loss, rutting, and potholes. However, a promising development would be an increase in prevention efforts and a corresponding reduction in correction efforts—indicating that road agencies might be starting to get ahead of the problem. Information such as that provided here, and available from local Technology Transfer programs, should help movement toward that goal.

REFERENCES


3. Based on Wisconsin DOT’s “Gradation No. 3,” as shown in Subsection 304.2.7 of the Standard Specifications for Road and Bridge Construction, 1989 Edition.
Chapter 4 Problems — Causes and Solutions


Chapter 5

EQUIPMENT AND TECHNIQUES

This chapter focuses on equipment and techniques employed in combating the problems associated with gravel roads. The first topic is motorgraders. Next, it’s other equipment. Then, it’s techniques.

MOTORGRADERS

The motorgrader has traditionally been the workhorse of gravel road construction, maintenance, and repair. Its versatility in cutting, removing, placing, spreading, cleaning, shaping, and smoothing is undeniable. While the basic configuration of graders has remained the same through the years, improvements have gradually been made in safety, control, and maneuverability.

Types and Features

Many different makes and models of motorgraders are used by local governments. All of them need to be maintained and operated properly to use their full capabilities in maintaining gravel roads. While grader operators often have strong preferences for one type of machine over the others, all graders can accomplish the same basic operations: smoothing, reshaping, regraveling, and ditch cleaning.
While today’s graders may look about the same as their ancestors, they’ve evolved in significant ways. The following are brief descriptions of basic types of graders.\(^1\) Unfamiliar terms will be explained later in this section. One term, however, that should be clear from the outset is *moldboard* (figure 5-1). The moldboard, or blade, is the *business end* of all graders. It’s the tool that does most of the work—the cutting, shaping, mixing, spreading, and so on. Later in the chapter the discussion will focus on moldboards.

*Figure 5-1. Motorgrader moldboard.*
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**Rigid Frame**

Traditionally, motorgraders have had rigid, straight frames (figure 5-2), which:

- Require space for turning and maximum side-shift for cleaning ditches (unless grader can get into the ditch).
- Are best kept on a stable work platform.
- Should use caution near road edges.
- Make a good #2 or #3 machine when multiple graders are used in reshaping work.
- Are good for smoothing surfaces.

**Articulated Frame**

More recently, graders have been developed with articulated, or jointed, frames (figure 5-2) that:

- Can be turned and maneuvered in tighter spaces than rigid-frame graders.
- Allow the drive wheels to be offset away from edges and ditches. Offsetting puts the most machine power and mass directly behind the load on the moldboard while keeping side-shift to a minimum to reduce strain on the circle gear.
- Is a good choice for the heaviest work and work near road edges.

It’s been observed that some experienced operators of articulated graders don’t always employ the articulation when called for. Apparently, they don’t use the feature
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either because they naturally resist change or because they don’t as yet know how to use it. If such operators don’t take advantage of articulation, their machines become just higher priced rigid-frame graders.

**Single Rear-Axle, Four-Wheel Drive**

This type of motorgrader (figure 5-2):

- Is used for tighter areas or road alignments.
- Tends to be too light for heavy mixing work.
- Is limited in its finish grading capabilities to low speeds even with tire circumferences matched.
- Has good control in slick conditions due to its all-wheel drive.

**Tandem Rear-Drive**

The characteristics of this type of grader (figure 5-2) are its:

- Good traction because all the engine weight being placed on the tandem drivers.
- Handling of medium-to-heavy moldboard loadings in doing reprocessing work.
- Good production capability for quality finish grading when all the tires’ circumferences are matched (otherwise, it may jump and leave chatter marks).
Figure 5-2. Types of graders.

**Tandem Rear, On-Demand Front-Wheel Drive**

Finally, these motor graders (figure 5-2):

- Can handle heavier loads—when using all-wheel drive—than tandem rear-drive graders.
- Have good control in slick conditions.
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- Usually do finish-quality grading without the front-wheel drive, so the same quality and constraints apply.

**Features, Attachments**

An important grader feature is *wheel lean*. The front wheels are tilted to the left or the right to provide more control over heavy blade loads, keep the front end in place, and make steering easier. The wheels are leaned in the direction the gravel is rolling across the blade, normally 10 to 15 degrees from the vertical position (figure 5-3). This helps the grader resist the pull in the other direction—the *side thrust*—caused by the material being pushed. The resistance to side thrust holds the grader on a straight, steady course. In effect, it’s like a person digging in his heels to pull a heavy object. He does it to apply force and keep his feet under him.

*Figure 5-3. Grader wheel lean.*
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Grader attachments include snow-moving implements and scarifiers (figure 5-4). Scarifiers play an important role in correcting the problems discussed in this handbook. They may be front-, middle-, or rear-mounted on the grader. The farther back, the heavier the scarification they can perform. Rear-mounted units are usually on tool bars, allowing either scarification or ripping work by interchanging the teeth.

Before delving into any more details about motorgrader parts or features, the following pages present an overview of basic grader operations.

Figure 5-4. Scarifier attachment.
Basic Operations

Motorgraders perform four basic, routine operations in maintaining gravel roads: smoothing, reshaping, regraveling, and ditch cleaning. All the work steps and grader techniques cannot be covered in full detail here, but the local Technology Transfer Center can provide ample detail. Three good references (from which much of the information included here is drawn) are shown under in the References section of this chapter.\(^{(2)}\) One more excellent source is the pocket-size training guide, *Blading Aggregate Surfaces*, of NACE.\(^{(3)}\)

Smoothing

*Smoothing*—also called *blading* or *dragging*—is performed to smooth and level the road surface when it becomes rough and uneven. It’s the most common gravel road maintenance operation and is intended to restore a smooth surface and good ridability without disturbing the existing crust. To accomplish this, the grader must apply light downward pressure with the moldboard to produce a dragging, rolling action that compacts the surface without cutting into it.

Keep in mind that smoothing provides only temporary improvements in surface condition and ridability. It’s done with the idea that it will need to be routinely redone—whether that means every week or every months, depending on traffic and local resources.

Reshaping

The purposes of *reshaping*, also referred to as *grading*, are to get rid of surface irregularities, restore surface drainage, and reprocess segregated materials to improve
surface stability. The operation should include the entire traveled way and shoulders. Unlike smoothing, reshaping usually requires some cutting into the surface. This of course breaks the crust, which will have to be restored at the end of reshaping.

The *Maintenance of Aggregate and Earth Roads* manual (see References) includes four distinct phases in its description of the complete reshaping operation: *cutting and moving*, *reprocessing* (mixing), *spreading* (redistributing), and *compacting*.

The initial cutting passes are very important because they control the final shape of the road. A sufficient cutting depth is needed to ensure cutting out all irregularities. In locations with deeper corrugations or potholes, the road surface may have to be scarified first. Other passes are made on the shoulders and in the ditches to recover gravel that has whipped off and washed from the traveled way.

Moisture is crucial to reshaping because it's needed during all four phases just mentioned. Even if the road is adequately moist at the beginning, manipulation of the gravel during subsequent phases will aerate and dry it. So water trucks often are needed along with one or more graders. And a roller should be used for the compacting phase. Use of a roller rather than merely relying on traffic compaction usually extends the life of the reshaped surface—more than paying for the rolling costs.

**Regraveling**

Even with regular smoothing and reshaping, the effects of weather and traffic will batter the surface crust and contribute to other problems. One serious problem is aggregate loss, as discussed in chapter 4. When too much gravel and fines have been lost—through dusting, raveling, and sinking—roads can no longer be maintained and the
subgrade will be damaged. The lost aggregate needs to be replaced—the surface must be regraveled. So, unlike smoothing and reshaping, which normally just reuse the materials already on the road, regraveling always involves bringing in new aggregate.

The five basic steps of regraveling are:

1. Place traffic control devices. Set out advance warning signs far enough ahead of the work zone and space them properly. It also may include posting flaggers when there is a lane closure, a sight obstruction, or enough traffic flow to require them.

2. Reshape and compact the subgrade. The existing surface irregularities need to be cut out and the remaining surface gravel must be bladed into windrows . . . then spread evenly back over the surface to the proper cross slope. In effect, the old surface is turned into the new subgrade, to serve as a platform for the new gravel to be placed.

3. Load, haul, and place the new gravel. Trucks bring the new material and dump it in well-spaced piles according to the thickness desired for the surface course.

4. Spread the gravel. The motorgrader usually forms the separate piles of gravel into a windrow first to control the even spreading of the material. Several grader passes are made to blend and spread the gravel. One important rule is that the layer of gravel should be at least twice the thickness of the largest stone size in the new gravel. Water is added as needed to keep the moisture content correct for proper mixing and to suppress dusting. Maintaining the proper moisture content now will also aid in getting good compaction later.
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5. Compact the gravel surface. Follow the same procedure as used to compact the subgrade. More water should be added if the surface becomes too dry. Make eight to ten complete roller passes to ensure complete compaction and create a smooth surface and tight crust.

Ditch Cleaning

Cleaning or pulling ditches typically involves using a motorgrader unless the slopes are too soft to support the grader, the slopes are too steep for easy access, or the ditch is frequently interrupted by drain pipes or culverts. Another problem in some areas of the country is limited right-of-way. Boom-mounted articulated buckets, such as Gradalls, are more appropriate in these exceptional cases.

The grader’s moldboard is positioned to remove collected road gravel and fines, vegetation, and debris from the ditch as it reshapes the ditch’s cross section to the correct slopes and depth. Where vegetation is heavy, an initial pass by the grader may first be needed to clear it. Or, indeed, mowing or other vegetation removal operations may be called for first. While moist gravel and fines should be recovered from ditches and moved back onto the traveled way to be incorporated in the surface course, mud or other undesirable material should never be placed on the traveled way.

It’s important to create a smooth flow line for water to move unimpeded through the ditch. In the process, the ditch’s full capacity to carry drainage is restored.

One hazard for which grader operators must be alert is large solid objects in ditches—boulders, rock outcrops, stumps, and other just-under-the-surface objects that can severely damage the moldboard, the grader itself, and its operator.
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Ditch cleaning combines with smoothing and reshaping operations to provide for uninterrupted drainage across the roadway crown and shoulders, and into the ditches. Tied in with ditch cleaning is the cleaning out of culverts and drains, although the grader is of little use in these activities.

Gears and Speeds

The proper gear/speed combinations for traveling and working depend on the type of motorgrader, the road’s condition, the blade’s settings, and the work to be done. Too much speed tends to make the moldboard bounce, which can leave corrugations in the road surface. The grader action caused by this improper operation is sometimes called chattering. The recommended working speed of motorgraders is between 5 and 8 km/h (3 and 5 mi/h). Traveling speeds—to and from work sites—should be in accordance with posted speed limits and actual road conditions.

Safety

View motorgrader safety from two perspectives: the public’s and the operator’s.

Public

In protecting the public from graders that travel and work on our local roads, the first issue is visibility. Just being big enough to be seen often isn’t enough. And yellow or orange paint may still not be bright enough to guarantee visibility at dusk or dawn... or in fog or dust, or on gray,
rainy days. To catch motorists' attention, all graders should have a flashing warning light atop the cab. Graders should have working headlights and taillights. In back there should be a triangular warning sign (slow-moving vehicle). Finally, the ends of the moldboard should be marked with orange flags to make them more noticeable.

*Audible* warnings should supplement the visual ones. Graders should have working horns and backup alarms.

The way that motorgraders are operated affects public safety too. Proper speed has been mentioned as good operational practice, but it's also a key to safe operation. The *direction* of operation generally should be *with* the traffic rather than against it. When operation must be against traffic, the headlights should be turned on. The operator must keep an eye on the rearview mirror to be aware of traffic overtaking the grader and wanting to pass. Often, such drivers need to be signaled by the operator when it's okay to proceed. In general, motorgrader operators need to be sensitive to motorists, even on roads where there is little traffic.

Other equipment and operational safety measures include:

- Putting transmission in low range for greater braking power when blading downhill.

- Placing proper signs (and flaggers when required) where needed to warn of work in progress or of unattended grader.

- Ensuring that a properly charged and visible fire extinguisher is on the grader.
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- Keeping a hand shovel in good condition on the grader.

- Shifting moldboard to the center of the grader, grounding it, and locking it when parking and leaving the grader.

- Taking the ignition key when leaving the grader unattended.

Operator

Of course, ensuring the above safety measures protects not only the public, but also the operator. Other safe practices should be followed as well. First, motorgrader operators should be properly attired and equipped. Hardhats may not seem necessary while the operator remains in the cab, but some agencies require their use just the same. Safety shoes are always a good idea, and likewise are sometimes required. Safety glasses make sense, as do gloves—at least when the operator dismounts to work around the unit, checking things out, making adjustments, etc.

Operators sometimes want to stand up to get a better view of things during operation. They are encouraged, however, to stay seated and safety-belted while the grader is in motion. Operators have tumbled from cabs and been killed because they weren’t seated and belted. Caution should be shown especially when working along road edges and steep slopes.

Moldboards

A few pages ago, moldboards were identified as the business end of motorgraders. A grader is useless without one, and not fully effective or efficient if the one it has is incorrectly adjusted, worn out, or improperly used.
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Parts and Dimensions

Moldboards (figure 5-5) are curved metal implements typically 3.66 m or 4.26 m (10 ft or 15 ft) long, with preference usually given to the longer length because of its capacity to move more material. The term blade is sometimes used to refer to the whole moldboard, or to indicate only the bottom cutting edge or cutter blade. Cutting edges—or blades, tips, or bits—are replaceable metal sections that do the cutting and shaping of gravel surfaces. They suffer the bulk of the wear and tear on moldboards. Each moldboard is fitted with a pair of these cutting edges—equal in length—that are bolted securely in place. They are manufactured in four combinations of thicknesses and widths. Standard thicknesses are 16 mm or 19 mm (3/5 in or 3/4 in), and widths are 152 mm or 203 mm (6 in or 8 in). The bottom surface of cutting edges is beveled about 60 degrees to provide a sharp cutting edge.

![Diagram of Moldboard Parts and Dimensions]

Figure 5-5. Moldboard parts and dimensions.
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Settings

The ways that moldboards are set or adjusted determine their ability to cut, shape, move, smooth, and mix gravel road materials.

Angle. The moldboard’s angle is its position—in degrees—relative to a line perpendicular to the roadway centerline (figure 5-6). It’s not as complicated as that sounds. With the moldboard at a right angle to the road’s centerline, it’s considered to be angled 0 degrees—no angle. Moving one end of the moldboard forward 20° produces a 20-degree angle; moving it forward 45° produces a 45-degree angle; and so on. The closer the moldboard gets to parallel with the centerline, the greater becomes the angle. The greater the angle, the faster the gravel will come off the back end of the moldboard. Lesser angles keep the gravel in front of the moldboard longer, thus mixing it more.

Figure 5-6. Moldboard angles.
Now, to keep things straight, the ends of the moldboard usually are not referred to as front, back, lead, or trailing—or even left and right. Instead, the terms used are toe and heel—just as in referring to feet. And it’s just that easy to know which is which. The leading end of the moldboard is always the toe, and the trailing end is the heel. Either end can be the toe, and either end can be the heel—depending on their relative positions.

**Pitch.** Moldboards can be pitched—tilted—forward or back, according to what the operator wants to accomplish with the cutting edge (figure 5-7). On most motor graders, pitch is controlled hydraulically. A full forward pitch causes the cutting edge to drag the gravel surface. A full backward pitch causes the cutting edge to cut into the surface. Pitch the moldboard gradually back from full forward and it will provide increasingly less dragging and more cutting action. Push it forward from the full back setting and it will provide increasingly less cutting and more dragging action.

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**Figure 5-7. Moldboard pitch (tilt).**
The cutting pitch of moldboards puts the beveled point of the cutting edge in position to slice into the surface—much like a chisel—with the bevel flat against the bottom of the surface material being removed. This produces the best cutting action with the least effort, and it keeps the bevel point from wearing down prematurely. Too much forward pitch makes the edge try to dive deeper. Too little forward pitch makes the edge climb back out.

For smoothing or scraping with sharp, new cutting edges, the moldboard is pitched forward so that it drags across the surface. In this position, removing surface material depends on putting enough force on the cutting edge to scrape off the high points. The grader’s downpressure plus its forward motion provide the necessary force.

Between the cutting and smoothing pitches there are a number of different moldboard positions. The right pitch for mixing depends on the grader’s speed. Generally, the correct mixing pitch is slightly back of vertical, but variations are needed to accommodate different materials and get the best mixing action. Besides moldboard pitch, mixing is affected by the moldboard’s angle and the grader’s speed.

**Pressure.** The operator controls the downward pressure that the moldboard applies to the road surface. Increased pressure means deeper cutting action or harder dragging/smoothing/compacting action, depending on the moldboard’s pitch. The pressure is also varied to produce different mixing and spreading results. Of course, greater pressure also means more wear on the cutting edge.
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**Height.** The ends of the moldboard can be raised or lowered independently. These settings allow the grader to properly shape the road surface, slope the shoulder, and pull the ditch. Improperly setting the moldboard height can result in extra grader passes, ruin a crown, or clip off the edge of the traveled way and actually narrow a road’s width.

**Sideshifting and Banking.** These two settings really show the flexibility and versatility of graders. Sideshift is the ability of most motor graders to extend the moldboard to the left or right for increased reach of 2 m (6.6 ft) and more. This is especially useful in shoulder work. The moldboard doesn’t actually lengthen, of course, but is shifted (usually hydraulically) to one side or the other, as needed.

Banking is a setting in which the moldboard is moved clear out from under the grader and placed in a vertical or near-vertical position. This setting allows the grader to work steep backslopes while driving on the shoulder/foreslope.

**Blade Wear**

Most of the wear on moldboards is concentrated on the blades (cutting edges). Because of the abrasive nature of gravel road materials and the long hours of heavy work that graders put in, new blades can wear down quickly. Improper grader operation will accelerate this wear. Blades wear down mainly in two ways.

One way is a pattern in which the blade edges in the middle of the moldboard wear down faster, although one side of the edge may wear faster than the other (figure 5-8). This effect is called *cupping* or *crowning*. Cutting edges worn in this manner may produce parabolic crown in the road surface. (See chapter 1.) If the blade wear is less than 10 mm (0.4 in), the sections can be switched so that the
deepest ends are now in the center of the moldboard. In other words, the left section can be moved to the right side of the moldboard and the right section to the left side, as shown in figure 5-8. This extends the life of slightly worn edges. However, cutting edges worn more than 10 mm (0.4 in) should be replaced with new, straight sections. Never allow cutting edges wear within 13 mm (0.5 in) of the moldboard mount before they are replaced.

Figure 5-8. Blade wear.
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One solution to the problem of cupping or crowning is to use three cutting edges instead of two. The center section should be thicker so that it wears more slowly than the two outer sections.

The other type of cutting edge wear is in the bevel of the blades. The 60° bevel helps the blade slice cleanly into gravel surfaces. For cutting, the moldboard should be pitched to the proper position, with the bottom of the bevel riding parallel to the road surface (figure 5-8). A moldboard not properly pitched for cutting exposes the tip of the beveled edge to direct abrasion, dulling it and wearing it down very quickly. Bevels wear down differently depending on the grader operation—smoothing and spreading versus cutting, as shown in figure 5-8.

**Scarifying Blades**

The cutting edges or blades discussed here so far are the conventional smooth, even-edged replaceable sections. When the blades are sufficiently worn down, they must be detached from the moldboard and replaced with new cutting edges. In recent years, scarifying-blade systems have been developed as an alternative to the conventional moldboard cutting edges. Rather than smooth, even-edged blades, these systems use teeth-like bits (figure 5-9) to cut into the surface and to process and spread the surface materials. The bits are either fixed or rotating, depending on the specific system. In winter they are used effectively to break up hard-packed snow and ice. They also show great potential for outperforming conventional blades in penetrating, screening, and smoothing gravel roads.
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Figure 5-9. Scarifying blade bits (Caterpillar GraderBit™ System).

The bits of these scarifying-blade systems are easily replaced (figure 5-10) and are made of carbide steel for greater resistance to abrasion and, therefore, longer wear. Either through different bit widths or variable bit spacings (figure 5-11) these systems are able to leave the fines with the gravel instead of separating them.

Figure 5-10. Replacing bits (GraderBit™ System).
Figure 5-11. Different bit widths/variable spacings (GraderBit™).

Some local agencies are able to use less-expensive pit-run material in place of more costly processed aggregate because the bits screen out the oversize rock and waste it on the shoulder. In effect, these systems provide an inplace processing capability.

Scarifying blades perform better where there is embedded shelf rock because they avoid snagging, especially the rotating bits. Even when there is damage to one or more bits, they are far easier and cheaper to replace than is an entire cutting edge.

Because of their penetrating action, scarifying blades also can remove large embedded rocks from the surface, a task that smooth-edged cutting blades cannot do. Of course, where the surface has a good crust and only minor smoothing of the surface is called for, scarifying blades are undesirable because they certainly will disturb the existing crust.
OTHER EQUIPMENT

Despite the preeminence of the motorgrader in repairing and maintaining gravel roads, other equipment is used effectively by local agencies. This other equipment consists both of traditional machines and some machines of more recent development.

Traditional

Traditional equipment and implements include drags, underbody truck blades, rakes, rollers, and water trucks.(4) The first three of these perform some of the functions of motorgraders and may, for limited use, work as substitutes. The last two are supplemental to graders of course.

Drags

Drags are simple framed machines designed to be pulled behind a tractor. They sometimes are called maintainers (which is also a nickname for motorgraders in some regions). Few of them are manufactured commercially. They consist of a metal frame supporting small blades. Drags are intended for smoothing gravel roads by redistributing loose surface materials. They also pull loose material from the sides toward the center of the road. Additionally, they can spread windrowed gravel to fill surface irregularities. Except for one type of drag produced with a 3-point hitch mount, drags depend on their own weight—plus the weight of any materials they carry—for their downpressure. They do little cutting when the cross slopes are uniform. One word of caution though: They tend to flatten the peaks of A crowns.
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Underbody Truck Blades

Some agencies equip trucks with underbody blades, also called underbody scrapers. These consist of a moldboard and ring mounted about midway between the cab and rear wheels and controlled by the driver. The driver can see the ends of the moldboard through the rear-view mirrors. The main use of underbody blades is in removing light snow accumulations and sweeping loose gravel off the road. Some agencies also report success in using them for surface smoothing. A caution: Work by underbody blades must be limited to areas accessible to trucks. Another note: Adding an underbody blade to a truck reduces its legal hauling capacity by the combined weight of the ring and moldboard assembly.

Rakes

Rakes may be towed or vehicle-mounted. In general, they all have long metal tines that are pulled along the surface by tractor or light truck. Rakes serve a couple of purposes in maintaining gravel roads. They smooth surfaces by rearranging loose gravel to distribute it more evenly. Some rakes can eliminate slight to moderate washboards as well. Rakes also pull oversize rocks and debris from the surface and leave it windrowed for later removal from the roadway. This usage explains why you often hear these machines called rock rakes. York rake is another term used in some regions.

Towed rakes, like drags, depend on their own weight for their primary downpressure. Most such units have manually adjustable angling, although some older, nonadjustable rakes are still in use. To reset an adjustable rake, the operator has to stop the vehicle to manually change the angle.
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Vehicle-mounted rakes typically have cab controls that the driver can operate to change the angle and downpressure while raking. But reversing angles is not possible. Downpressure is always limited by the tine strengths. Enough pressure can be applied to make the rake cut into washboard ridges.

Cab-controlled, driver-adjustable power rakes—both towed and vehicle-mounted—are also available. These more top-of-the-line machines may be too costly for local road maintenance budgets. They are designed primarily for landscaping, construction site preparation, and beach maintenance.

Rollers

Compaction rollers are of course common pieces of road construction and maintenance equipment. However, they are probably not used as much as they should be in repairing and maintaining gravel roads. In compacting a gravel surface, the aggregate particles are worked closer together, reducing the air pockets and producing a denser, stronger mass of material.

Pneumatic-tired, steel-wheeled, and (sometimes) vibratory steel-wheeled rollers are appropriate for compacting gravel roads. All should be self-propelled. Towed rollers are not recommended because they normally exceed the braking power of the towing vehicle and are also very tough on the towing vehicle's final drive.

The rubber tire inflations of pneumatic-tired rollers can be varied from high pressure for greater compaction to lower pressure for reduced compaction. Ballast is sometimes added to increase the effective ground pressure for different conditions. Pneumatic-tired rollers work well on most gravel surfaces. They fracture gravel particles less than steel roller wheels do.
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Steel-wheeled rollers have limited traction and braking on gravel surfaces and are not recommended for use on steep grades. They may fracture the gravel particles, depending on the hardness of the material and other factors. Serious fracturing of gravel can alter the effective gradation of the surfacing material. Vibratory steel-wheeled rollers may improve compaction when the correct frequency and amplitude of vibration are used. The wrong frequency and amplitude, however, can actually decrease compaction. Rollers with rubber-tired drive wheels have improved traction over those with dual steel drums.

For spot corrections on gravel roads, small compactors—including nonself-propelled ones—will greatly improve the quality and durability of the repair. A variety of power tampers and vibratory plate compactors are available.

Water Trucks

Water is a vital element in the proper maintenance of gravel roads, so the use of water trucks is encouraged. Four different water-application systems are in use: gravity splash plates and spraybars, pressurized closed-end spraybars, pressurized full-circulating spraybars, and pressurized sprayheads.

Gravity splash plates and spraybars are the cheapest systems in terms of initial cost, but they are the least controllable in terms of application rates. The pressure depends on the depth of water in the tank and on whether the truck is going uphill or down. Of the two applicators—splash plate or spraybar—the spraybar applies water more uniformly. Rear-mounted, front-mounted, or tag-along-trailer-mounted spraybars are available.
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Pressurized closed-end spraybar systems can control the application width and rate, but there is some rate variation between the middle and ends of the bar. These systems are often used with spray nozzles on the bars, but they are also used without nozzles when watering. Front, rear, and trailer mounts are available.

Pressurized full-circulating spraybar systems provide the best control of application rates over the full bar width. Spray widths can be varied. Front and rear mounts are available.

Pressurized sprayheads have been front side and rearmounted for some applications. An advantage of front mounts is that they spray forward within the operator’s line of vision for tighter shutoff control. A potential disadvantage, however, is that a forward mount adds truck velocity to the nozzle pressure and the added force may scatter gravel particles and actually erode the surface. A simple solution to the problem, though, is to reduce the pump pressure so that the resulting application force does not damage the surface.

New

While perhaps not totally new, these next items of equipment are not as well-known or as widespread in use as the traditional equipment discussed above. In no way do these machines propose replacing motorgraders—or for that matter any of the equipment already mentioned. Rather, they are attempts at greater specialization, designed to do specific operations very well. Some agencies and localities may need such machines more than other agencies and localities. Part Three of the video presentation briefly shows four of them.
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Gravel Processor

The Harley Gravel Recovery System manufactured by Glenmac might be considered an advanced rock picker. It processes surface material that has been windrowed by a motorgrader by continuously picking it up and running it through a revolving tumbler equipped with a screen. Oversize rocks and unwanted debris are screened out of the material and conveyed by side elevator to a truck. The collected rock can be reused as riprap. Meanwhile, the processed gravel drops through the screen and back onto the road to be respread. Different sizes of interchangeable screens can be used in the tumbler to regulate the size of gravel retained for the road. The unit processes several megagrams (tons) of rock per minute. Areas of the country having a problem with oversize rocks working their way to the road surface may find such a recovery system cost-effective.

Shoulder Disk

Equipment such as The Retriever, manufactured by AVF Rail-Tie Limited, addresses the problem of gravel road shoulder maintenance. As a disk attachment for tractors or graders, this equipment mulches shoulder vegetation, reduces roadside berms, and retrieves gravel from the shoulders back to the roadway. It also improves drainage by leveling shoulder berms that typically prevent water from flowing off the road; increases safety by eliminating sod clumps accumulated on the shoulder; and reduces mowing needs by mulching vegetation below the surface.

Windrow Pulverizer

Motorgraders are traditionally used to pull high shoulders—to get rid of the berms and keep shoulder vegetation from encroaching on the roadway. This process, however, creates so-called maintenance windrows
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that consist of sod clumps, vegetation, and gravel from the roadway. Windrow pulverizing equipment—such as Triple “S” Industries’ *Ridge Mulcher*—is designed to break up the clumped material so that it can be spread across the roadway. The spreading of reclaimed gravel from the shoulders can sometimes eliminate the need for some or all new gravel that would be applied in regraveling operations. In addition, the elimination of the maintenance windrow gets rid of a nuisance and safety hazard on the traveled way.

*Grader/Dozer Combination*

The *Qwik-Tach Road Leveler*, manufactured in South Dakota by Borgen Sales, turns a motorgrader into a grader/dozer unit. This implement has a specialized moldboard with fixed teeth similar to the scarifying blade bits discussed above. It mounts on the grader’s front snowplow lift and can be used to cut out washboards and potholes or to equalize newly spread gravel. In the winter it also is effective in chipping away ice and hard-packed snow.

Whether new or traditional, a local agency’s objective should be to acquire and use the equipment best suited for cost-effective repair and maintenance of its gravel roads.

**TECHNIQUES**

The following section is something of a catchall containing tips, dos and don’ts, cautions, clarifications and expansions of previous information, reiteration of key points, and so on.
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Traffic Control and General Work Zone Safety

General work zone safety on unpaved roads, and traffic control in particular, are not typically given enough importance. Traffic control has the objective of increasing the safety of both the motoring public and the road workers. It also should aim at lessening the inconvenience to motorists as well as avoiding disruption of the work. Consider the following eight points in planning for safety and accomplishing the work safely:\(^5\)

- Give the public adequate advance notice of delays and detours.

- Equipment should be checked for oil, fuel, hydraulics, filters, and coolants before going to the work site. Safety devices—strobos, flashers, headlights, etc.—should be checked to see that they operate properly.

- Be sure that workers are properly equipped for the specific work activity and location.

- Arrange for the deliveries of materials and small tools in a way that keeps work areas uncluttered, but has them there when needed.

- Sign work areas according to the national Manual on Uniform Traffic Control Devices (MUTCD), Part IV, and any local agency guidelines.

- Have enough equipment, personnel, and materials onhand to complete the work.

- Operate safety devices—strobos, flashers, headlights, etc.—during the work.
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- Stay within the time limits for stopping traffic set by the Engineer.

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**Moisture Content**

Except for routine, light blading, work on gravel roads should cease during prolonged dry weather—especially all cutting and reshaping activities. Without moisture in the surface, there is no advantage to grading a gravel road. As explained earlier, moisture helps bond the aggregate particles, aiding their consolidation into a dense mass. There is actually a *setting up* of the material as it dries—that is, if it’s compacted with adequate moisture content. This is similar to what occurs with cement concrete. The result in gravel roads is a thick crust that acts like a watertight skin to repel water. The crust also helps support traffic loads and resists the abrasive effects of vehicle tires. A tight skin also delays the disintegrative effects of dry periods. A good crust is so valuable that an important goal of routine smoothing operations is to avoid cutting into it. But anytime the crust *has* to be disturbed—as when reshaping is needed—moisture should be present in the surface (whether by rainfall or by water truck application) so that a new crust can be formed.

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**Smooth Surfaces**

Building and maintaining gravel roads with smooth, evenly sloped surfaces isn’t desirable from the standpoint of ridability and esthetics. The key reason for smoothly sloping surfaces from centerline to ditch line is *drainage*. A little moisture benefits the gravel surface. All other water in excess of what’s needed to help the gravel bond

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*Problems Associated With Gravel Roads*
properly is unwanted and potentially harmful to the road. Whether it’s standing in potholes or running longitudinally along the road edge because of a high shoulder, it’s an enemy. The best tactic to defeat this enemy is to get rid of it by providing as direct and rapid a retreat from the roadway as possible. Roads having a crown of the proper height and smooth, uninterrupted slopes all the way to the ditch flow lines provide just such a retreat. *Uninterrupted* is a key adjective here. All it takes to slow or stop the water’s departure from the roadway is a flat or inverted crown, a depression here and there, or a high shoulder. A well-drained road is one where the runoff flows directly to the ditches. And even then it should keep on flowing *in* the ditch and eventually *away from* the road entirely. A particularly pervasive problem is *double ditches* (also called *secondary* ditches), where long ruts, maintenance windrows, or shoulder berms act as dams that hold water on the roadway. Grader operators need to be especially careful how they blade along road edges, so that they prevent rather than create double ditches (figure 5-12).

![Incorrect windrow acts as a dam. Correct shoulder allows drainage.](image)

When blading toward the shoulder, ensure that the windrow does not form a dam at the edge of the road.

*Figure 5-12. Blading along road edge.*
In chapter 1 of this handbook, there was some discussion of correct crown height and cross-slope rates. Keep in mind that, for water to drain properly from the roadway, the shoulder slope should be equal to or preferably greater than the traveled way's cross slope. And the foreslope steepness should exceed the shoulders' slope rates. This way, runoff is enhanced rather than hampered by the slopes it traverses—from middle of road to the shoulders, to the foreslopes, and down to the ditch bottoms.

**Maintenance Windrows**

Maintenance windrows are a common sight on gravel roads in some parts of the country, especially in the Upper Midwest. They result mainly from shoulder maintenance. When motorgraders pull shoulders they clip off some of the vegetation, sod, and other debris along with gravel that's been kicked off the road by traffic. All this material comes off the heel of the moldboard and forms a windrow on the traveled way. *Making* such windrows does not create problems, but *leaving* them on the road does. The reason they are left in place for up to many days at a time is to allow the vegetation to rot and decompose before the gravel is spread back across the surface. At that point the plant matter is more easily separated from the gravel and disposed of. But until then, the windrows are a driving hazard on the one hand and a drainage dam on the other (figure 5-13). The use of specialized equipment, such as the *Ridge Mulcher* described above, can help local agencies avoid the practice of leaving maintenance windrows on the road for lengthy periods.
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Figure 5-13. Maintenance windrow/drainage dam.

Ditch Cleaning and Shaping

Roadside ditches play a substantial role in roadway drainage. Usually they are constructed parallel to the grade of the road. Sometimes, though, ditch grades are designed separately to ensure that water will flow to the desired point. Always, the ditch bottom must be below the subgrade elevation. A 2 percent grade is the minimum grade for water to flow well.\(^6\)

Ditches must periodically be cleaned out and re-cut to recover gravel lost from the roadway and to restore drainage. Motorgraders typically pull ditches as a routine maintenance activity. However, on some roads the right-of-way is too limited or the ditch slopes are too steep (more than 3:1) to permit graders to work. In certain cases the right-of-way is sufficient and the ditch slopes are flat enough, but the ground is not firm and stable enough to
support a grader. Where a grader is not appropriate, an articulated boom-mounted bucket (such as a Gradall) is recommended. Graders and Gradalls also may be used to clean material away from culvert openings. But sediment collected inside culverts cannot be removed by machine. Operators should use a shovel as necessary to clean out blockages.

The force of draining water and the weakening of soils by saturation are the most serious concerns in maintaining roadside ditches. The force of flowing water results from its volume and its speed. When the water’s force exceeds the stability of the soils, erosion occurs. Ditch soil is eroded and ends up in culverts or below the roadway. Unless controlled, severe erosive force will undermine the backslope (cutbank support) and foreslope (shoulder support).

To prevent erosion, soils should be made more stable and/or the water’s force should be reduced by:

- Compacting the ditch bottom and slopes.
- Armoring the ditch with rock (perhaps first placing a geotextile material under the armoring).
- Letting grass grow in the ditch bottom.
- Building ditch dams on steep grades.
- Making the water more shallow.

Some comments on the above—the last point first. To make ditch water shallow, widen or flatten the ditch bottom. Of the three basic ditch shapes—V (or vee), U, and flat bottom—the V concentrates water the most. (Refer to the discussion in chapter 2, figure 2-3.) In other
words, V-ditches make water run the deepest, increasing the likelihood of erosion. Nevertheless, they are the most common ditch shape. Flat-bottom ditches concentrate water the least, but they require more space than is often available and can be difficult to maintain. Also, water can sometimes be slowed too much—so that it seeps into the soil. U-ditches spread the water out more than V-ditches do—but have less capacity than the other ditches, look messy, may cave in, and can cause vehicles to get stuck. They are also harder to maintain since only Gradalls, backhoes, or other boom-mounted articulated buckets can maintain the U shape.

For erosion prevention and other reasons, the best ditch shape is the basic V, but with rounded or slightly flattened bottoms. These ditches can be maintained by motor graders, have a high drainage capacity, allow water to flow rapidly, and resist erosion—and they have the other advantages described in chapter 2.

Now, turning to the other points listed above, compacting ditch bottoms and slopes makes the soils more dense and erosion resistant. The problem is that each time they are disturbed by maintenance activity they will have to be compacted again, or else this approach will not succeed.

Armoring ditch sides and bottom with rock can be very effective. Geotextile placed underneath the armoring can further increase erosion prevention, but when geotextile is placed, it must be protected from disturbance by subsequent maintenance activity.

Letting grass grow in ditch bottoms is an easy solution in many parts of the country. Mowing operations will have to include such ditches to be sure that growth doesn’t take over and clog the drainage. In arid regions, blading ditches may be curtailed to prevent removal of sparse
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vegetation. Some agencies in dry areas find it necessary to plant native grasses in ditches—to both control erosion and prevent the growth of weeds that are harmful to livestock.

Finally, ditchdams are effective not only at slowing water flow, but also on sustained grades over about 4 percent they may be needed to force the flow into cross culverts. Culverts may largely be bypassed by the drainage when the flow is heavy and fast, especially when the culverts are at right angles to the roadway centerline. More information on ditchdams and the other erosion-prevention measures can be found in the reference cited in reference 6 above.

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**Gravel Layer Thickness**

Different thicknesses of gravel surface course may be spread, but one rule should always be followed: The applied layer of material should be at least twice as thick as the top size of stone. For example, in an 80-mm (3-in) gravel course, the top size should be 40 mm (1.5 in). Of course, chapter 3 recommended that the top size for gravel surface courses be 20 mm (3/4 in), so that's better still. The point is, in a gravel course, no individual aggregate particle's size should be close to the course thickness. A gravel layer with stones as thick or nearly as thick as the course itself lacks stability—the particles are too big to interlock. The result would be immediate raveling and displacement.
Superelevation

When crown was discussed in the beginning of the handbook, *superelevation* was briefly described. It bears further explanation.

Normal crown should be maintained in *tangent* (straight) sections of gravel roads. However, in curved sections the modified A crown should be replaced by superelevation to counteract centrifugal force by sloping the road in the direction of curvature, thereby helping vehicles maintain their speed and stay on the road as they move through curves. This is accomplished by banking the entire road surface toward the inside of the curve, with the same slope rate from edge to edge. The sharper the curve, the greater the degree of slope to compensate for centrifugal changed to full superelevation, and vice versa. For a smooth-riding surface, such changes have to be made gradually. In approaching a curve, the tangent section of road maintains a normal crown (step 1 of figure 5-14) until about 15 to 30 m (50 to 100 ft) before the curve. There, a transition begins. The right side of the road (the side on the outside of the upcoming curve) gradually rises by pivoting at centerline (step 2, figure 5-14). Meanwhile, the left side (the side on the inside of the upcoming curve) does not change. This transition section is termed the *lead-in*. The lead-in continues until the crown is completely eliminated and the road has one uniform slope across its full width—at the beginning of the curved section (step 3). This is superelevation.

When curves are sharp, the degree of superelevation may be increased by pivoting the slope at the centerline (step a, figure 5-15), at the inside edge of the road (step b, figure 5-15), or at the outside edge (step c, figure 5-15).
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1) Normal crown

2) Direction of curve
   Pivot-point
   Transition to curved section (starts 15 to 30 m/50 to 100 ft before curve begins)
   Lead-in

3) Pivot-point
   Superelevation

Figure 5-14. Superelevation sequence—steps 1, 2, and 3.

a) Pivot-point
   Full superelevation
   or

b) Pivot-point
   Full superelevation
   or

c) Pivot-point
   Full superelevation

Figure 5-15. Superelevation sequence—steps a, b, and c.
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The maximum superelevation, in any case, is termed *full* superelevation.

Once the curve ends, the return to normal crown may begin. First, if increased superelevation is used, it is returned to normal superelevation (step 5, figure 5-16). Then, the slope of the outside of the road (relative to the curve) begins pivoting at centerline until it returns to normal crown (step 6, figure 5-16). This transition section is termed the *run-out*, and should not be completed until 15 to 30 m (50 to 100 ft) after the curve ends (step 7, figure 5-16).

![Diagram](image)

*Figure 5-16. Superelevation sequence—steps 5, 6, and 7.*
An important maintenance point about superelevations is that a small shoulder area should be maintained along the top of superelevated sections (figure 5-17).

![Superelevation with maintained small shoulder area](image)

**Figure 5-17. Superelevation shoulder.**

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**Special Roadway Locations**

Certain roadway locations demand special attention including intersections, driveways, bridge approaches, and railroad crossings. One problem is the rough transition between gravel roads and intersecting roads, driveways, bridge decks, and railroad tracks. Another problem is the gravel that is left deposited on tracks, bridges, and intersecting paved roads. This stray gravel at the very least is a nuisance—causing rough driving and minor vehicle damage. At worst, it's a very real hazard—threatening life and limb.

**Intersections**

Crown can continue on one road across an intersection, but not on both roads. Or, crown can be eliminated on both roads at an intersection. The fact that one road maintains its crown through an intersection indicates that it is the more important of the two roads. The fact that neither road maintains its crown through an intersection indicates that the two roads are of equal importance.
Where gravel roads intersect paved roads, the gravel road’s crown should always be flattened in advance of the pavement. The paved road, of course, is considered the more important of the two. Flattening the crown is one part of making a good transition at a paved road. Another aspect is eliminating the bumps and dips at paved intersections. Because of continuous blading with the flow of traffic, a bump forms where the gravel road meets the pavement . . . and a dip forms where the gravel road begins again at the other edge of the pavement. The same thing, in reverse, comes back the other direction. To get rid of the bumps and dips and then prevent them from blading; against traffic this time; with traffic the next time. Here are the steps in this procedure (figure 5-18):

- The grader gradually eliminates the gravel road’s crown, starting about 15 to 30 m (50 to 100 ft) before the intersection. The grade should be the same at the point where the two roads meet.

![Figure 5-18. Intersection of gravel road with paved road.](image)
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- The operator changes the blade angle (to 0°) to meet the paved road, raises the blade, pulls onto the pavement, lowers the blade, reverses the grader, and backdrags the gravel off the pavement.

- The operator next checks to see if an extra pass or two is needed to completely eliminate the crown and to ensure that the shoulders slope away from the intersection.

- The operator then positions the grader at a bump—facing against the flow of traffic—and cuts the bump off starting at the edge of the paved road. The cutoff gravel is moved to the other side of the road, the grader is turned around to once more face against traffic, and the cutoff gravel is bladed into the dip.

- The operator repeats the procedure on the other side of the intersection.

Where gravel roads intersect each other, the crown should be eliminated gradually on each road, starting about 15 to 30 m (50 to 100 ft) before the intersection. Then the operator should see if an extra blading pass is needed to eliminate crown and ensure that the shoulders are sloped properly.

**Driveways**

Maintaining their roads in the best possible shape keeps the public happy, but messing up their driveway entrances may keep them from appreciating all the other good work. Motorgrader operators should try to leave roadway areas around private and commercial entrances as firm and smooth as possible—maintaining proper cross sections without leaving dips or bumps to irritate.
driveway users (figure 5-19). Although this may be an added demand on grader operators and their work schedules, ensuring good driveway transitions is part of proper maintenance of gravel roads—and also part of maintaining good public relations.

**Bridge Approaches**

The problems of transitions at bridges (figure 5-20) are similar to those at intersections with paved roads. In the first place, continuous blading with the flow of traffic may create a bump where gravel road meets bridge slab and a dip at the other end of the bridge. Here again, the preceding intersection blading steps apply.

Another problem is gravel that ends up on bridge decks, creating a rough ride and often kicking up to nick vehicle paint and crack windshields. Allow enough gravel and other debris to collect on bridge decks may also lead to blocked drainage. Ponded water on bridges—especially when it freezes—makes very hazardous conditions.
**Figure 5-20. Bridge approach.**

**Railroad Crossings**

Rough transitions are common at railroad crossings—chiefly the bumps and dips that are also a problem at intersections with paved roads and the ends of bridge decks. Grader operators need to take the necessary time to blade carefully up to and away from railroad tracks. And here again, gravel bladed onto the tracks or kicked there by traffic is a hazard. Too much gravel left surrounding the rails can actually cause derailment of railroad cars. Normal track maintenance by the railroad company should take care of gradual buildup of gravel caused by traffic crossing over the tracks. The main danger is posed by grader operators who blade gravel onto the tracks rather than lift their moldboards as they reach the crossing and then backdrag to leave a smooth transition.

Working with a motorgrader at the above locations is very difficult and requires a skilled operator. Nevertheless, skill does not negate the fact that gravel that is bladed into the small areas abutting pavements, bridge approaches, and railroad tracks tends to be segregated because of the
inability of the moldboard to blade through. Because segregated material seldom stays in place very long, the problem soon reappears at the same location. Truth is, not all work at these locations can be done by machine. Grader operators should know that some manual shovel work can improve the operation. A few shovelfuls of well-graded gravel placed manually and then compacted will normally produce a much longer lasting repair.

In a similar vein, although a skillful grader operator can clean a ditch right up to a culvert, the moldboard can’t reach inside the pipe to remove debris collected there. Again, a little manual shovel work by the operator can clean out the openings and prevent the culvert from filling up with trapped sediment.

Of course there may be other locations and situations where special attention must be directed. Adequate roadway maintenance from right-of-way line to right-of-way line is the objective. Using the proper equipment, operating it correctly, and following proven techniques will help ensure that gravel roads are well-maintained.

REFERENCES


2. Ibid., pp. 22-30.

"HERPICC"—Purdue University School of Civil Engineering in cooperation with Indiana Department of Transportation, Federal Highway Administration, and other Agencies, 1987 (?), pp. 9-23, 31-34.

International Road Federation, Guide to Common Road and Equipment Maintenance Procedures ( compilation of written supplements to IRF videotapes), Louisiana State University/Louisiana Department of Transportation and Development/Federal Highway Administration, 1989, pp. 9-1 through 9-4, 10-1 through 10-3, and 11-1 through 11-3.


7. T² Trumpet, University of Nevada, April, 1994 (originally appearing as The Bridge Fact Sheet, Michigan T² Center, Spring 1993).
Chapter 6 Geotextiles

Chapter 6
GEOTEXTILES

The use of geotextiles in preventing and repairing certain problems associated with gravel roads was briefly touched on in earlier chapters. Geotextiles is probably the most common name given to these materials, but other names by which they are called include filter cloth, engineering fabric, plastic filter, geotechnical fabric, and geofabric. And of course manufacturers use tradenames as well. Despite what they are called, geotextiles can all be classified as nonwoven, woven, or knitted. These different types of materials have advantages and disadvantages for specific uses.

Geotextiles already are an established material with well-documented success in stabilizing and strengthening soils, reducing erosion and lessening its effects on the environment, and in improving asphalt pavement overlays. Increasingly, they are demonstrating their ability to eliminate or at least significantly reduce the detrimental effects of the following on gravel roads:

- Underground springs.
- Extreme boggy conditions due to poor soils.
- Severe drainage problems due to the local topography.

These problems produce weak spots that become next to impassable at certain times of the year without almost weekly applications of gravel or other surface material, accompanied by reshaping. The impassability stems from severe surface deformation—rutting—typically caused by sinking aggregate (as discussed in chapter 4). Sinking
aggregate and surface rutting occur because of the presence of both poor-quality roadbed soils and excessive water.

As illustrated in figure 6-1, organic material (such as clay, silt, and peat) in a saturated roadbed forms a mud slurry (paste). Traffic passing over the softened roadbed causes this slurry to pump upward. As it pumps into the gravel surface course, the slurry coats the individual aggregate particles. Dry gravel particles have a lot of surface friction when they rub together, and they tend to be very stable. But when coated with a mud paste, gravel particles act as though motor oil has been poured on them. They become lubricated, losing their surface friction and sliding past each other to sink and disappear into the roadbed underneath.

Install the proper geotextile fabric on the roadbed, however, and the fines in the mud slurry cannot rise through the fabric to coat the gravel in the surface course. The geotextile’s openings let water through (providing a form of drainage) but are small enough to block the fines. Indeed, the one crucial function of the geotextile beneath the surface course of gravel is separation.

The use of a geotextile to remedy any gravel road problem generally involves 5 steps:

- Identify and classify the type of problem at the site.
- Select and match the geotextile to the problem type.
- Roll out and install the fabric properly.
- Place or dump the gravel on the fabric according to field conditions and the particular equipment used.
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Figure 6-1. Geotextile stopping the pumping of mud slurry.
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- Spread the gravel on the fabric without damaging or displacing it, according to field conditions and the particular equipment used.

Available through all Technology Transfer Centers is the *Geotextile Selection and Installation Manual for Rural Unpaved Roads.*\(^{(1)}\) It contains ample details about problem identification, geotextile selection, fabric installation, gravel selection and placement, gravel spreading, and finish blading.

Geotextiles show great promise in helping local highway agencies tackle the problems associated with gravel roads.

**REFERENCE**