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Administration**

Gravel Roads

Maintenance and Design Manual

South Dakota Local Transportation
Assistance Program (SD LTAP)

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Gravel Roads
Maintenance and Design Manual

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The need for a comprehensive manual that addresses most issues that deal with gravel road maintenance has been recognized by several entities across the states and the world.

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Definition of Terms

Articulation: As used in this manual, it refers to a machine with a jointed main frame. This assists in steering the machine, allowing it to work in an angled configuration, yet move forward in a straight line.

Ballast: Extra weight added to a machine such as iron weights mounted to the wheels or frame. Liquid material such as a water/calcium chloride solution placed in the tires can also serve as ballast.

Density: The weight of material in pounds or kilograms per unit of volume (cubic feet or meters).

Grader: Any device either self-propelled or mounted on another machine used for final shaping and maintenance of earth or aggregate surfaces. Occasionally, a simple, towed drag-type device is referred to as a grader.

Gravel: A mix of stone, sand and fine-sized particles used as sub-base, base or surfacing on a road. In some regions, it may be defined as aggregate.

Moisture Content: (in percent) That portion of the total weight of material that exists as water.

Moldboard: The part of the grader that is actually used to cut, mix, windrow and spread material.

Motor Grader: Any self-propelled machine designed primarily for the final mixing and shaping of dirt or surfacing material. Sometimes referred to as a maintainer, patrol, or simply a "blade."

Optimum Moisture: The percentage of water (by weight) in material that allows it to be compacted to achieve greatest density.

Paved Road: Any road that has a semi-permanent surface placed on it such as asphalt or concrete. Gravel surfaced roads are virtually always referred to as unpaved roads.

Pit: An area where a natural deposit of stone, sand and/or fine material is removed from the earth.

Quarry: An area where solid stone is removed from the earth generally by ripping, drilling and/or blasting. The stone is then crushed and processed into useable sizes.

Segregation: A problem that arises when the coarse and fine material separates and no longer forms a uniform blend of material.

Windrow: A ridge or long, narrow pile of material placed by grader while performing construction or maintenance operations.

List of Acronyms

AASHTO	American Association of State Highway and Transportation Officials
ADT	Average Daily Traffic
ASTM	American Society of Testing and Materials
ΔPSI	Allowable serviceability loss
DOT	Department of Transportation
E_{BS}	Elastic modulus of aggregate base layer
E_{SB}	Elastic modulus of aggregate sub-base layer
ESAL	Equivalent single axle load (18,000 lbs.)
FHWA	Federal Highway Administration
LL	Liquid Limit
LTAP	Local Transportation (Technical) Assistance Program
M_R	Resilient Modulus
MUTCD	Manual on Uniform Traffic Control Devices
PI	Plasticity Index = LL – PL
PCF	Pounds per cubic foot
PL	Plastic Limit
PSI	Pounds per square inch
RD	Allowable rutting in surface layer
ROW	Right-of-Way

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Forward

There are over 1.6 million miles of unpaved roads (53% of all roads) in the United States. In some nations, the road network is predominantly unpaved and generally consists of gravel roads. This manual was developed with a major emphasis on the maintenance of gravel roads, including some basic design elements.

Gravel roads are generally the lowest service provided to the traveling public and are usually considered greatly inferior to paved roads. Yet,in many rural regions, the volume of traffic is so low that paving and maintaining a paved road is not economically feasible. In many cases, gravel roads exist to provide a means of getting agricultural products in and out of farm fields, timber out of forests, or as access to remote areas such as campgrounds and lakes. Many gravel roads serve rural residents as well. Many of these roads will remain unpaved due to very low traffic volume and/or lack of funds to adequately improve the subgrade and base before applying pavement layer(s).In some countries, economic constraints mean gravel roads are the only type that can be provided.

The purpose of this manual is to provide clear and helpful information for doing a better job of maintaining gravel roads. It is recognized that very little technical help is available to small agencies that are responsible for managing these roads. Gravel maintenance has traditionally been "more of an art than a science" and very few formal standards exist. This leads to many arguments between grader operators, managers, and motorists over questions such as:What is enough surface crown? What is too much? What causes corrugation? This manual contains guidelines to help answer these and other questions about the maintenance of gravel roads.

This manual is designed for the benefit of elected officials, managers, and grader operators who are responsible for designing and maintaining gravel roads. The information provided in this manual is as nontechnical as possible without sacrificing clear guidelines and instructions on how to do the job right.

Introduction

Good gravel road maintenance or rehabilitation depends on two basic principles: proper use of a motorgrader (or other grading device) and use of good surface gravel. The use of the grader to properly shape the road is obvious to almost everyone, but the quality and volume of gravel needed is not as well understood. It seems that most gravel maintenance/rehabilitation problems are blamed on the grader operator when the actual problem
is often material related. This is particularly true when dealing with the problem of corrugation or "washboarding." The problem is often perceived as being caused by the grader but is primarily caused by the material itself. This manual will help provide a better understanding of what makes good surface gravel.

Another important matter to consider is the dramatic change in the vehicles and equipment using low volume roads. Trucks and agricultural equipment are increasing in size and horsepower. The trend is toward even larger machinery. The effect of larger and heavier vehicles
on our paved roads is well understood. There is a definite need to build stronger bases and pavements. But the effect on gravel roads is just as serious and often is not recognized. For this reason, a section on the design of gravel roads is included. The strength of the subgrade and depth of the material needed to carry today's heavy loads must be considered.Proper drainage is also important.

The final section of the manual covers innovations in the gravel road maintenance/ rehabilitation industry. Change is constant in almost every aspect of this modern world and maintaining gravel roads is no exception. There are new ways of stabilizing roads, new methods of dust control, new and different kinds of equipment available for maintenance/ rehabilitation of gravel roads, and even new surface materials such as recycled asphalt being used. Not all of these innovations may be available or practical for every local government entity, but everyone is encouraged to take an objective look at each of them. Then an informed decision can be made about changing the way gravel roads are designed and maintained within a particular jurisdiction.

Section I: Routine Maintenance and Rehabilitation

Understanding Road Cross Section

Everyone involved in gravel road maintenance must understand the correct shape of the entire area within the road's right-of-way. Figure 1 shows a typical cross section of a gravel road. If states have minimum standards or policies for low-volume roads, they must be followed.

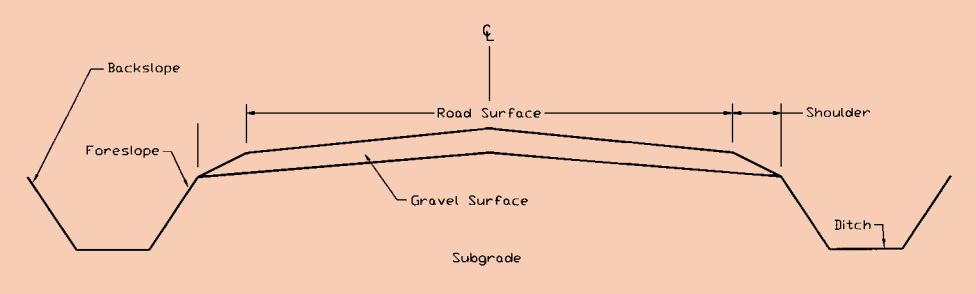


Figure 1: The components of the roadway cross section.

In order to maintain a gravel road properly, operators must clearly understand the need for three basic items: a crowned driving surface, a shoulder area that slopes directly away from the edge of the driving surface, and a ditch. The shoulder area and the ditch of many gravel roads may be minimal. This is particularly true in regions with very narrow or confined right-of-ways. Regardless of the location, the basic shape of the cross section must be correct or a gravel road will not perform well, even under very low traffic.

Paved roads are usually designed and then constructed with careful consideration given to correct shape of the cross section. Once paving is finished, the roadway keeps its shape for an indefinite period of time. Gravel roads are quite different. Unfortunately, many of them are not constructed well initially. In addition, gravel roads tend to rut more easily in wet weather. Traffic also tends to displace gravel from the surface to the shoulder area and even to the ditch during dry weather. Managers and equipment operators have the continual responsibility of keeping the roadway properly shaped. The shape of the road surface and the shoulder area is the equipment operator's responsibility and is classified as routine maintenance.

Keeping the foreslope and ditch established and shaped is often the maintenance operator's responsibility as well. Obviously, the whole idea here is to keep water drained away from the roadway. Standing water at any place within the cross section (including the ditch) is one of the major reasons for distress and failure of a gravel road. There is sometimes a need for specialized equipment to do major reshaping of the cross section,especially in very wet conditions. However, the operator of routine maintenance equipment must do everything possible to take care of



This road, located in Poland, has very poor cross section with no ditches. Consequently, water drains down the roadway itself and after many years of erosion,the roadway is several feet lower than its original elevation. (Courtesy of Mary O'Neill,Office of Remote Sensing, South Dakota State University)



This well-traveled road in Ecuador performs well in a region that receives approximately 200 inches average annual rainfall. (Courtesy of Ron Anderson, Tensar Earth Technologies, Inc.,USA)

the roadway since budgets often do not allow for the use of extra equipment and manpower on gravel roads.

The recommended shape of each part of the cross section will be discussed in detail later in this manual.When a gravel road is maintained properly, it will serve low volume traffic well. Unfortunately, most gravel roads will fail when exposed to heavy hauls even when shaped properly. This is due to weak subgrade strength and marginal gravel depths which are often problems with gravel roads. The low volume of normal traffic does not warrant reconstruction to a higher standard. However, improper maintenance can also lead to very quick deterioration of a gravel road, especially in wet weather. The maintenance equipment operators must always work at maintaining the proper crown and shape.



Example of a gravel road with good shape of cross section. Notice crown in driving surface and proper shape of shoulder and ditch.



An example of a well shaped gravel road shoulder that slopes away from the driving surface and drains water to the inslope and ditch.

Routine Shaping Principles



The distortion that was cut into this road surface is the result of operating a motorgrader too fast.The angle of the depressions which match the angle of the moldboard reveal this. This is not the same as "washboarding," which has different causes.

Grader operator cleaning a ditch and restoring shape to the foreslope and backslope.



The primary focus of this section will be the use of the motorgrader for gravel road maintenance. However, there are other devices used for the job that can work well. Front or rear mounted grading attachments for tractors, road rakes, and other devices of various designs are used in some areas of the country. The principles of shaping are the same no matter what machine is used.

Operating Speed

Operating speed in blading operations must not be excessive. This has caused problems on many roads. It is virtually impossible to do good work above a top speed of 3 to 5 mph.When the machine begins to "lope" or bounce, it will cut depressions and leave ridges in the road surface. Conditions including moisture, material, and subgrade stability vary; therefore, the maximum speed for good maintenance can vary.

However, in virtually any condition, it is difficult to exceed 5 mph and still do a good job.

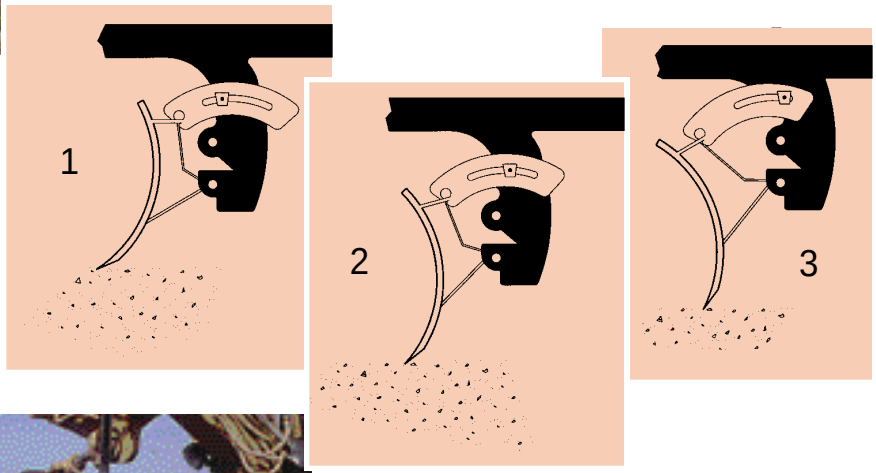
Moldboard Angle

The angle of the moldboard is also critical to good maintenance. This angle is fixed on some grading devices, but on motorgraders it can be easily adjusted. It is important to keep the angle somewhere between 30 and 45 degrees. It is a challenge to recover loose aggregate



This is an example of poor use of the grader. The moldboard is pitched back too far and is not angled enough.Notice the gravel builds up and does not fall forward to give a good mixing action.Also, the loss of material from the toe of the moldboard will create a high shoulder, which destroys good drainage across the shoulder to the ditch.

Moldboard pitch or “tilt” refers to how much the moldboard is tipped forward or backward.The right pitch ranges from aggressive cutting (1), to spreading (2),to light blading or dragging action (3) for maintenance of gravel roads.





This is the other extreme of pitching the moldboard too far forward.The material will not roll across the face of the moldboard and does not mix.In addition to this, the cutting edge will not easily penetrate a hard surface, making it hard to trim out even light depressions in the road surface. It simply tends to skip along the surface with no real benefit.





Notice these examples of good pitch and angle. The gravel falls forward and moves across the moldboard very well. The cutting edge is close to vertical from the road surface, which makes a nice light trimming action for routine maintenance, and the angle is good,not allowing material to spill from the toe of the moldboard.

from the shoulder of the roadway without spilling material around the leading edge (toe) of the moldboard. Operating without enough angle is a primary cause of this spilling.

Moldboard Pitch

Along with correct angle, it is important to understand proper pitch or "tilt" of a moldboard. If the moldboard is pitched back too far, the material will tend to build up in front of the moldboard and will not fall forward and move along to the discharge end of the blade. This also causes excess material loss from the toe of the moldboard.It also reduces the mixing action that is desirable when recovering material from the shoulder and moving it across the roadway, leveling and smoothing it in the process. This mixing action is part of routine maintenance. Traffic tends to loosen material from the road surface and displace it to the shoulder area as well as between the wheel tracks. The stone will tend to separate from the sand and the fine-sized material.At the same time, small potholes and an uneven surface will develop. It is the job of the maintenance operator to recover the material, mix it again as it rolls along the face of the moldboard and restore good surface shape.

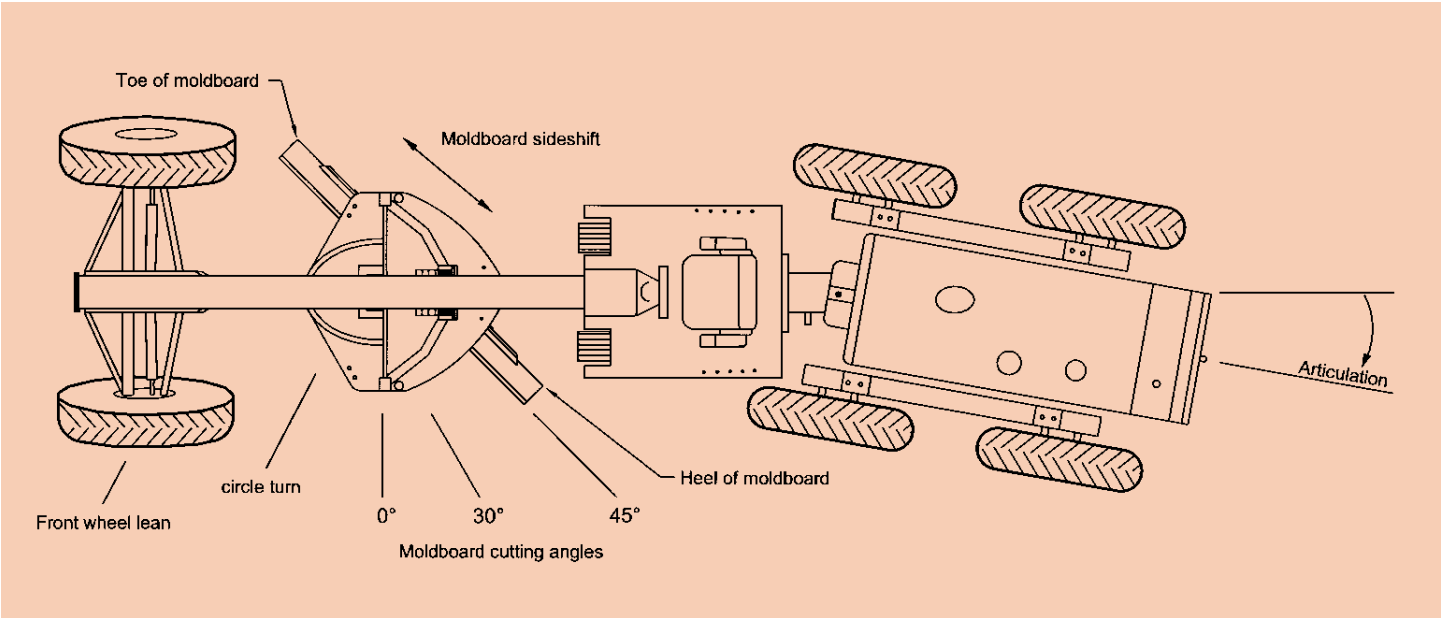


Figure 2:Illustration of an articulated motorgrader. (An illustration showing additional components of a motorgrader and recommended walk-around checks is shown in Appendix E.)

Motorgrader Stability

It can sometimes be hard to keep a machine stable, especially while carrying a light load of material. Counteracting machine bounce or "loping" requires experience in knowing the cause and then finding a solution.If a motorgrader begins to rock from side to side — often called "duck walking" in the field — it is usually caused by blade angle that closely matches the angle from corner to corner of the tires on the rear tandems. The solution is generally to stop, change angle slightly on the moldboard and slowly resume blading. Simply reducing speed will often eliminate the loping effect of a machine. Experimenting with different tire inflation pressures can also help stabilize a machine as well as leaning the front wheels in the direction that material is being moved. Filling tires with liquid ballast to about 70% capacity is sometimes done to increase traction, weight and stability of the grader. The ballast often used is a solution of calcium chloride and water. Stability problems that are constant and severe should be brought to the attention of your equipment dealer and/or tire supplier.

Articulation

Virtually all modern motorgraders are equipped with frame articulation. It can be an advantage to slightly articulate the machine to stabilize it even in a common maintenance operation.

Windrows

In some areas of the country, particularly arid or semiarid regions, it is common to leave a small maintenance windrow, sometimes referred to as an inventory windrow. This leaves a small amount of material to be picked up next time and worked back across the road for filling small depressions. This is a commonly accepted practice in some regions. In others, it is disapproved of and departments may even have policies forbidding windrows. This is often true in regions with narrow right-of-ways and narrow driving surfaces. Operators should follow department policy at all times. For those who allow the use of windrows, it is very important to keep them to a minimum. It can be very difficult to define what is acceptable and what is an excessive windrow. The windrow should also be placed near the edge of the roadway to allow as great a width for travel as possible. In the absence of a policy on this matter, be aware of the commonly accepted practices in your region and try to deviate as little as possible.





If a maintenance windrow is allowed by policy and used, try to keep it as light as possible. These examples show a light windrow being placed at the edge of the roadway and an obviously excessive windrow being left at the roadside. In the latter case, multiple passes should have been made to work out the vegetation and spread more of the material on the roadway, or perhaps some mechanical means of breaking up the lumps of sod such as a disk should have been used to allow more of the material to be spread on the roadway.

Crown

Establishing proper crown in the gravel surface probably generates more controversy than any other aspect of good maintenance. How much crown is enough? Can one get too much? What is a recommended crown? These are frequently asked questions by local officials, the traveling public, and equipment operators.

First of all,problems develop quickly when a gravel road has no crown. Water will quickly collect on the road surface during a rain and will soften the crust. This will lead to rutting which can become severe if the subgrade also begins to soften. Even if the subgrade remains firm, traffic will quickly pound out smaller depressions in the road where water collects and the road will develop potholes. A properly drained gravel road should have crown.



A road that lacks good crown.There is also centerline corrugation (washboarding),a problem that will grow worse when there is inadequate crown.

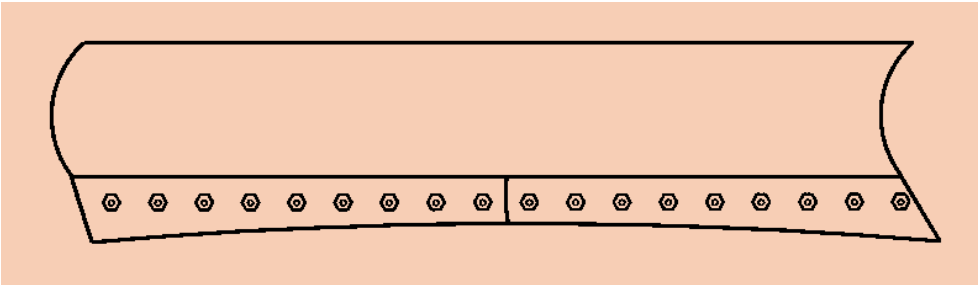
Yet an operator can also build too much crown into the road surface. This can lead to an unsafe condition in which the driving public does not feel comfortable staying “in their lane”or simply staying on the right side of the road. Because of the excessive crown,drivers begin to feel a slight loss of control of the vehicle as it wants to slide towards the shoulder. There is additional risk driving on gravel roads with excessive crown in regions that experience snow and ice cover. For these reasons drivers will tend to drive right down the middle of the road regardless of how wide it is.



A gravel road with a 26-foot driving surface, yet everyone drives in the middle. The primary reason is excessive crown.



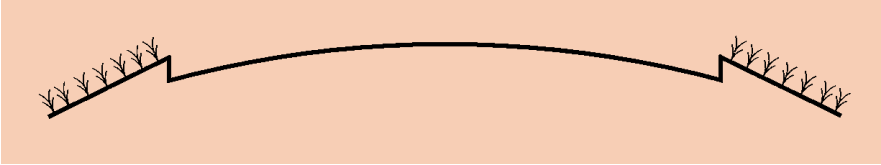
This road located in New Zealand does not have adequate crown to drain water to the roadside. Consequently, potholes form. (Courtesy of Ken Skorseth,SD LTAP)



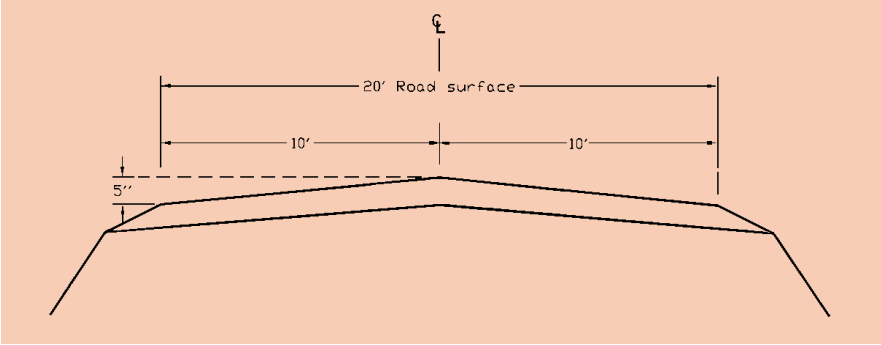
Problems from center wear in cutting edge.

What then is recommended crown? Recommendations from supervisors and skilled operators across the country indicate that at least 1/2 inch of crown per foot (approximately 4%) on the cross slope is ideal. It is also recognized that it is virtually impossible for any operator to maintain an absolutely uniform crown. However, try to deviate as little as possible. There are crown gauges available which can be used to determine existing crown. There are also very sophisticated electronic slope controls available for graders. These are found more often in construction operations than in maintenance, but certainly can be used for maintenance.

There is one further problem with crown that needs to be discussed. The ideal shape is a straight line from the shoulder up to the centerline of the road. This gives the road the same shape as the roof of a house, often referred to as a flat "A" shape. However, this shape can sometimes become rounded. The engineering term for this is "parabolic crown." This is virtually always a problem. The middle portion of the road will have considerably less crown than the outer edges. Water will not drain from the middle and potholes and ruts will form. The greatest cause of parabolic crown is excess wear at the center of the cutting edge. This is normal wear and will vary with types of gravel, width of road, wheel path location and other factors. A good operator will make an effort to avoid the parabolic shape on a roadway by keeping the cutting edge straight.



Roadway with parabolic crown.The outer edge of the road slopes too much. Gouging causes high shoulder, and center 1/3 of the road tends to be flat.





This road in New Zealand performs remarkably well because of good crown and good gravel quality in a region that receives nearly 150 inches of moisture a year! (Courtesy of Ken Skorseth, SD LTAP)

A simple method is to use a cutting torch and straighten the cutting edge whenever 1/2 to 3/4 inch or more of center wear exists. Another method is to use a thicker, harder section of cutting edge in the middle of the moldboard to resist wear. This will retard excess center wear, but generally will not eliminate it.

Another option is to use the modern carbide-tipped bits on the cutting edge. These are extremely wear-resistant and dramatically reduce center wear. There are also carbide insert or carbide-faced cutting edges that are very wear-resistant.

In summary, the recommended crown is a straight line from the shoulder to the centerline that rises approximately 1/2 inch per foot (or approximately 4%).

Road Shoulder

The road shoulder serves several essential functions. It is there to support the edge of the traveled portion of the roadway. But another important function is to provide a safety area for drivers to regain control of vehicles if forced to leave the road surface. Yet another important function is to carry water further away from the road surface to the foreslope and ditch.

In order for the shoulder to perform all of these functions, its shape is critical. First of all, the shoulder should meet the edge of the roadway at the same elevation. In other words, the shoulder should be no higher or no lower than the edge of the roadway. By maintaining this shape, the low shoulder or drop-off is eliminated which is a safety hazard and also reduces roadway edge support. But the other extreme, which is a high shoulder, should also be avoided. This will be discussed later.

It is also recognized that gravel roads in some regions, particularly those with very narrow right-of-ways, have very little shoulder area. In some cases, the edge of roadway is actually the beginning of the foreslope down to the ditch. But here again, it is important that there is not a steep drop-off or a ridge of soil to block drainage. Maintaining shoulders is a critical part of gravel road maintenance.



The photos above and below show good examples of gravel shoulders that match the edge of the roadway very well and drain water to the ditch.





A common condition along the edge of many gravel roads:the secondary ditch.

High Shoulders (Secondary Ditches)

This problem can be seen along gravel roads almost anywhere people travel. There are many slang terms used in the field such as “berms” or “curbs.” The engineering term for this condition is “secondary ditch” and it is a good description of the condition. When a gravel road develops a high shoulder, it destroys the drainage of water directly from the surface to the real ditch. This causes several problems. In relatively level terrain,the water collects here and seeps into the sub-grade, often causing the whole roadway to soften. In rolling and rugged terrain, the water quickly flows downhill along the secondary ditch,often eroding away a large amount of gravel and even eroding into the subgrade. This also creates a serious safety hazard. There are many reasons to work hard to eliminate secondary ditches.



Secondary ditch over six inches deep.

Causes of High Shoulders

What causes secondary ditches to form? There are several causes. They can develop from improper maintenance such as losing material from the toe of a grader's moldboard,which builds up a high shoulder, or from cutting too deep at the shoulder line with the toe of the moldboard. This is a particular problem when the cutting edge is not kept reasonably straight. But there are other causes, such as excessive "whip-off" of loose material from fast traffic,which tends to build up along the shoulder line. Also, heavy loads on gravel roads with weak subgrades can cause this. When heavy vehicles have to travel near the shoulder while meeting other vehicles, the roadway can rut while the shoulder area shoves upward. Yet another cause is the buildup of sand in northern regions where winter ice/snow control requires some winter sanding operations on gravel roads. An expert in the field once made this statement: "It is difficult to completely eliminate secondary ditches, but it pays to work hard to keep them to an absolute minimum." This is excellent advice. The time spent in dealing with a high shoulder (secondary ditch) will result in a road that is easier to maintain afterwards. But the real challenge is getting the job done.



Here, water has run down a secondary ditch or high shoulder and then eroded through the shoulder material at the bottom of a hill. This creates a hazardous condition.

Recovering and Spreading on Roadway

If a motorgrader is the only piece of equipment used on the job, generally more than one pass will be required to recover material from high shoulders. It is wise to place standard MUTCD warning signs such as "Road Work Ahead" since this is more than routine maintenance. If there is little or no vegetation on the shoulder, simply extend the moldboard out into the shoulder material and begin to pull it onto the roadway. If the amount of material is light, you may be able to do this in one pass. The material recovered is often good gravel that needs to be returned to the roadway surface.



Using grader to recover material from a high shoulder and restore correct shape to the shoulder.

Breaking up Sod and Vegetation in Recovered Material

Quite often, the material pulled out onto the roadway from the shoulder is very hard to spread because of the vegetative material in it. It will require multiple passes with the grader to get the job done. Many agencies are turning to other mechanical means of breaking up the material to make the road safe for traffic. This can range from something as simple as a disk or drag to sophisticated pulverizing equipment.



Windrow pulverizer fabricated by the Hyde County Highway Department of Highmore, South Dakota.



A commercially manufactured pulverizer.



A small rear-mounted tandem disk on a mower tractor.



A commercially manufactured rock rake, normally used in farming operations.

Pulling Shoulders and Covering

The material from a high shoulder is not always suitable to be reused on the roadway. It may be best to cut the material loose, pull it onto the roadway and then load and remove it. However, this can be very expensive. It is sometimes acceptable to pull the material and cover it. In several areas of the country, a method called "sweeping it under the carpet" is used. The following photo sequence shows how "sweeping it under the carpet" is done.

Make sure that the soils are suitable to be used as base material under the edge of roadway and shoulder before doing this. If you're not absolutely sure, try this on a test section of 1000 ft. or less to see how it performs. This method works best when there is a lot of sandy soil both in the subgrade of the roadway and also in the material recovered from the high shoulder. The sand will be unsuitable to recover and spread onto the roadway, but will be reasonably easy to cut and place under the gravel that will be placed back over it. If the road is scheduled to be regraveled, it is an excellent time to do shoulder work to get the roadway back into good shape.

Again, this is much more than routine maintenance and signs should be placed to warn motorists of roadwork being done. A better option would be to close the section of road being worked on if possible.

The existing surface gravel is cut loose and windrowed to the opposite side of the road.





The existing secondary ditch is then cut slightly deeper and the material is placed in the roadway.



The material from the high shoulder is then pulled into the cut that has just been made. Generally, this material will have to be worked several times with the grader to break it up enough to spread evenly.



The windrowed gravel is then brought back over the recovered material and the roadway is restored to proper crown and shape. The high shoulder has been eliminated.

Benefit of Mowing

Any of the procedures discussed for dealing with high shoulders are much easier to accomplish if a good job of mowing is done in advance. This is true even in routine maintenance operations. When grass or other vegetation grows high along the edge of the roadway, it becomes difficult to maintain a clean, uniform shoulder line. In a survey of operators in the state of Iowa, mowing the shoulders on gravel roads ranked as one of four primary functions needed to maintain a good gravel road! (Keeping proper shape, drainage, and straight cutting edges were the other three.)

The frequency of mowing depends on the region of the country and the climate. However, the cost of mowing is often offset by reduced costs of other maintenance as well as safer roads. In northern plains regions, there is yet another great benefit to mowing. By removing the standing vegetation, drifting snow will not be trapped on the roadway and snow removal costs can be drastically reduced. The best equipment for this is rotary or flail mowers, which do a good job of shredding the vegetation and are not as easily damaged or plugged by roadside trash.



Notice the dramatic difference in the road shoulders shown above and below. It becomes so much easier to recover gravel that has drifted to the edge of the roadway when the vegetation has been cut cleanly. It is particularly important to get rid of the vegetation prior to a shoulder-pulling operation.



Gravel Road Rehabilitation

Gravel roads are generally maintained by routine blading and adding gravel as needed either by "spot graveling"or regraveling entire sections. However, almost any gravel road will gradually begin to show distress that requires more than routine maintenance to correct. The most common problems that develop are "berms" or secondary ditches that build up along the shoulder line and the shifting of material from the surface to the shoulder area and even onto the inslope of the grade. This comes from gravel being displaced by traffic, winter plowing operations, erosion of material during heavy rain and sometimes from poor routine blading techniques. This often causes major problems with drainage. At certain intervals, virtually every gravel road requires some major rehabilitation. (35, 36)



This gravel road shows severe distress after being subjected to a heavy haul from trucks hauling wheat to a grain elevator. The problem was made worse by an unusually wet season.

Reshaping Surface and Shoulder

These can usually be corrected with the motorgrader alone. Spring is the best time for this as there is minimal vegetative growth and moisture is present. The reshaping of the driving surface and the road shoulder can be done by cutting material with the motorgrader and relaying it to the proper shape and crown.If possible, the use of a roller for compaction will greatly improve the finished surface. This will leave a denser, stronger, smoother surface that will be easier to maintain.

Reshaping Entire Cross Section

Severe rutting,loss of crown, gravel loss and deep secondary ditches — a combination of any two or more of these calls for a major reshaping. This requires a much greater effort.It often occurs after a gravel road has been subjected to an unusually heavy haul. This will be worse if a heavy haul occurs during wet weather.

Major reshaping often has to be done on the entire cross section and it may have to be done immediately regardless of the vegetative growth. Motorgraders, disks, pulverizers/mixers and rollers are often needed. These are not always available, but certainly make the job easier. The field supervisor's knowledge and the operator's skill in knowing how to rebuild the cross section becomes very important. These projects seldom have the benefit of much planning or technical assistance. There is seldom any surveying or staking done. But it is very important to rebuild a uniform cross section and pay attention to restoring good drainage. Only after this is done — and done correctly — should good surface gravel be replaced.



The same road as shown on the previous page approximately three months after the heavy haul was finished.The road was restored to remarkably good shape simply with the use of motor-graders doing a complete reshaping of the inslope, shoulder and surface with a small amount of surface gravel added.

Erosion Control

Having discussed the importance of reshaping a gravel road, there is another issue that must be addressed. When major reshaping is done outside of the traveled way, vegetation and ground cover will obviously be disturbed. This can lead to erosion of soil. The problem will vary depending on the region. In arid and semi-arid areas, the problem is small or non-existent.Areas which receive frequent rains, have rolling or rugged terrain, and have highly erodible soils, are particularly vulnerable. When vegetative cover is disturbed,there are problems that can arise. While trying to eliminate problems, new ones can be created such as clogged culverts and blocked ditches, pollution of streams and lakes, and eroded slopes which can shorten the life of improvements. You may be found in violation of state and federal regulations. Damage claims and lawsuits may be filed.

The solution to this issue is not to cancel plans for gravel road improvement,but to plan your work carefully and use methods of reducing or eliminating erosion. Here are some things to consider:

- Some regions have certain times in the year when frequent and heavy rainfall can be expected. Try to avoid major reshape work during those periods of time.
- Keep disturbed areas small. The more earth you disturb, the greater will be the risk of soil erosion. Set work boundaries and don't let work crews get outside of them.
- Consider stabilization of disturbed areas. Silt fences, mulching, erosion control blankets and other means should be considered.
- Keep water velocity low. Removing vegetative cover and topsoil generally increases the amount and speed of runoff. Keep slopes as shallow or gentle as possible. Keep ditch slope as gentle as possible. Shorten drainage runs and work to get vegetative cover reestablished as soon as possible after work is finished.
- Keep sediment within work boundaries. Sediment can be retained by filtering water as it flows (as through a silt fence), and ditch checks will retain dirty runoff water for a period of time until the soil particles settle out.
- Inspect recent work. This is vital to make sure channels haven't formed in ditch bottoms or on slopes, or around and under controls that were used. Be particularly vigilant after heavy rains.

Areas of Concern



This type of corrugation,"washboarding," is caused by lack of moisture, hard acceleration, aggressive braking, and poor quality gravel.

It is impossible to deal effectively with this problem if you do not understand the causes. Motorgraders are often blamed, but in reality, they seldom cause the problem.

There are three primary causes: the driving habits of people, lack of moisture, and poor quality of gravel. Driving habits are clearly evident when you observe washboarding at intersections, going up or down steep hills, leading into or out of sharp curves and sometimes even near driveways. These are all places where drivers tend to accelerate hard or brake aggressively. This is a major cause of washboarding. (24,33, 35, 36)

Lack of moisture will encourage washboard formation and prolonged dry weather can really aggravate the problem. This is because the crust that

There are special situations in gravel road maintenance that should be addressed. These are common to nearly all gravel roads and it is important to understand how to deal with them. These concerns are unique to gravel roads and practical solutions are recommended for each of these.

Dealing with Corrugation

The technical term is corrugation, but virtually everyone in the field refers to the problem as washboarding. This problem can bring more complaints than any other. It is very annoying to the driver and, when it becomes severe, can lead to loss of vehicle control.



This type of washboarding appears at an angle across the roadway with ridges and depressions two to three feet apart.It is caused by excess grader speed.



It is a good practice to loosen,mix, reshape gravel in a washboard-prone area while it is moist.



Another washboard-prone area is at the transition from paved to gravel sections as shown in this photo.



An effective tool for dealing with washboard areas is the front dozer equipped with carbide bits.

forms on the surface of a good gravel road will tend to loosen in dry weather. This allows the stone and sand-sized particles of gravel to "float" and the material can easily align itself into the washboard pattern under traffic.

The two causes just mentioned are completely out of the control of gravel maintenance operators and managers. The third primary cause — the quality of the gravel — is the cause we need to concentrate on. Good quality surface gravel is thoroughly discussed in Section II of this manual. Simply put, good gravel must have the right blend of stone, sand, and fines. The stone should be fractured and the fine-sized particles should have a binding characteristic, technically called "plasticity." This type of gravel resists washboarding. However, the maintenance operators also must do their part.

Virtually any gravel will develop some washboard areas under traffic. The key for the maintenance operator is to strive to keep the material blended. In dry conditions, the operator can only smooth the road temporarily. When moisture is present, it pays to quickly get out and rework these areas. The material should be cut to a depth of one inch or more below the depressions, mixed and relayed to the proper shape. If time allows, using the machine to apply wheel compaction to material will help reform the crust. If possible, use of a roller will improve the compaction.

With the best of maintenance, washboarding can never be completely eliminated.However, the key to reducing it is

to work hard at obtaining quality gravel with a good binding characteristic. The operator can then reshape trouble spots when moisture is present and most roads will perform quite well.

If a motorgrader causes washboarding, it is almost always the result of running at too great a speed. The ridges and depressions will be spaced further apart.

The solution to the problem is simple — reduce grading speed! Another problem can be improper tire inflation pressure or defective tires. This will cause a motorgrader to bounce or otherwise operate in an unstable manner.

Intersections

There is one important thing to understand in knowing how to shape a gravel intersection: is it a controlled or uncontrolled intersection? This means: does traffic have to stop or yield from side roads? If so, it is a controlled intersection as shown in Figure 3. The primary road on which traffic passes through should retain its crown and the intersecting roads should have crown gradually eliminated beginning approximately 100 feet before the intersection.At the point of intersection, the side roads are virtually flat to match the primary road. When the intersection is uncontrolled as shown in Figure 4,the roads should all have the crown gradually eliminated beginning approximately 100 feet from the intersection. The intersection itself becomes virtually flat, allowing vehicles to pass through without feeling a noticeable hump or dip from any direction. Be careful not to make the intersection lower so that water collects there.

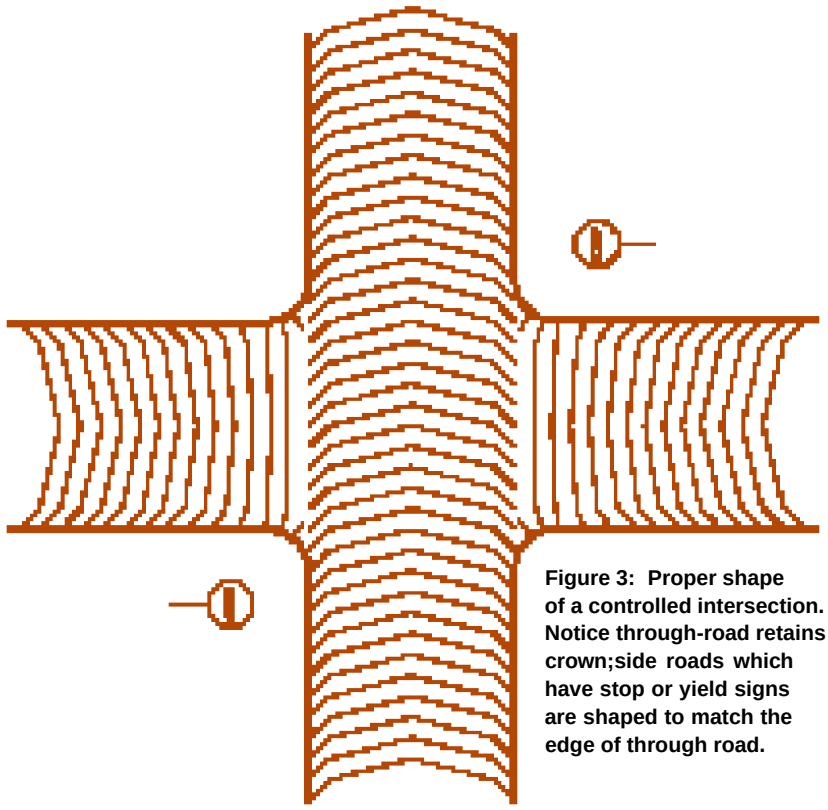


Figure 3: Proper shape of a controlled intersection. Notice through-road retains crown;side roads which have stop or yield signs are shaped to match the edge of through road.

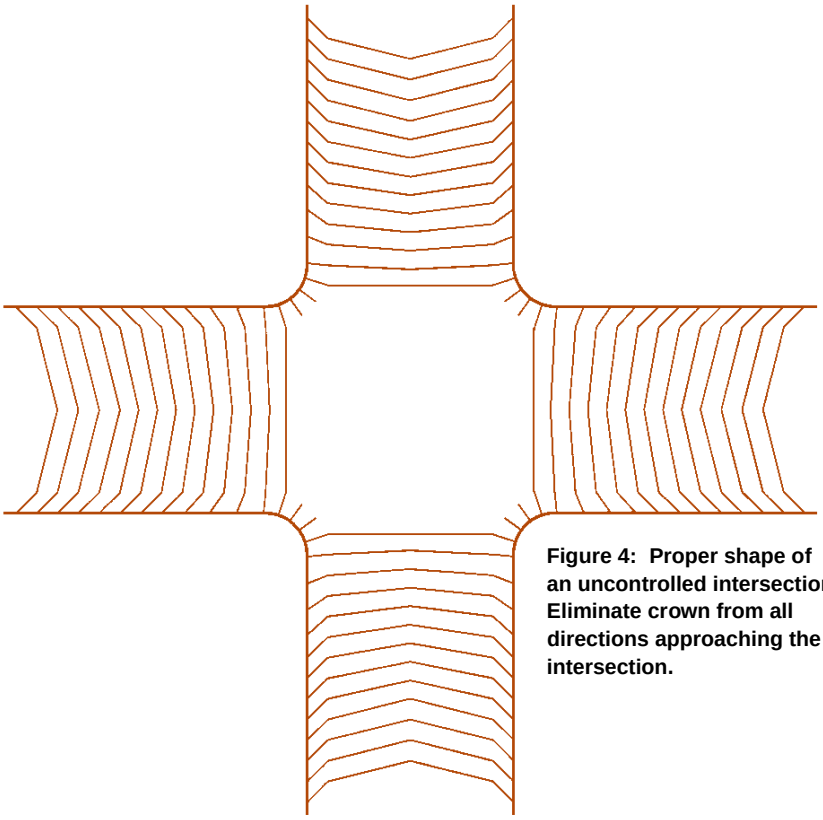


Figure 4: Proper shape of an uncontrolled intersection. Eliminate crown from all directions approaching the intersection.

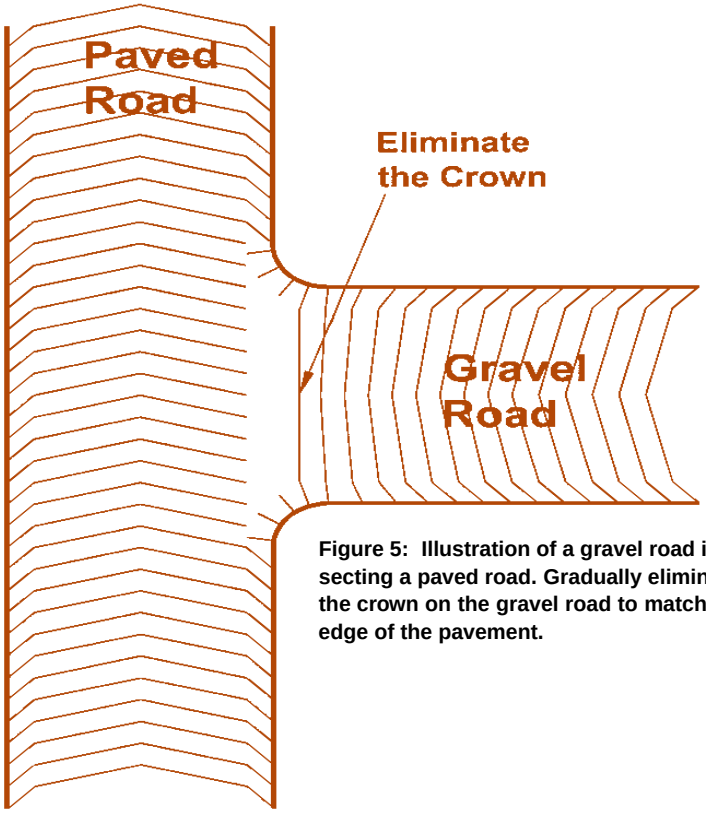


Figure 5: Illustration of a gravel road intersecting a paved road. Gradually eliminate the crown on the gravel road to match the edge of the pavement.

Intersections with Paved Roads

The rule for shaping these intersections is always the same. Begin to eliminate crown on the gravel road approximately 100 feet from the edge of the pavement. At the intersecting point, the gravel should match the paved surface. This requires continual attention since potholes can easily develop at the edge of pavement. However, be careful not to push gravel out onto the pavement since this causes a dangerous loss of skid resistance on the pavement.(35, 36) The technique of "backdragging" is useful in these operations. In order to fill a pothole at the edge of pavement, extra material may spill onto the pavement. Simply pick up the moldboard and set it down in front of the material, then back up and spread the excess back on the gravel road.



Hand work with a shovel is necessary at times to complement grader work.

Bridge Approaches

Once again, the rule for shaping a bridge approach is always the same. Approximately 100 feet from the bridge, begin to gradually take the crown out of the gravel road so that you can match the bridge deck as closely as possible. Potholes can easily form at the edge of the deck. Keep them filled, but don't push gravel onto the deck. (35, 36)



The grader must fill potholes and depressions formed near the bridge approach.



Nice job of blade work to shape road to match bridge deck.



The technique of backdragging can save time.

Superelevation at Curves

This is one of the biggest challenges in gravel road maintenance and a situation that is not understood very well by many operators. This is sometimes called "banking a curve" in the field. The outer edge of the roadway is higher than the inside edge and the road surface is shaped straight from the upper to the lower edge.

Once again, as the operator approaches a curve, adjustments should be made with the blade to take out the normal crown and begin to transition into a straight, superelevated surface. This shape should be maintained uniformly throughout the curve. A gentle transition is then made made at the other end back to a normal crowned road surface when you are once again on

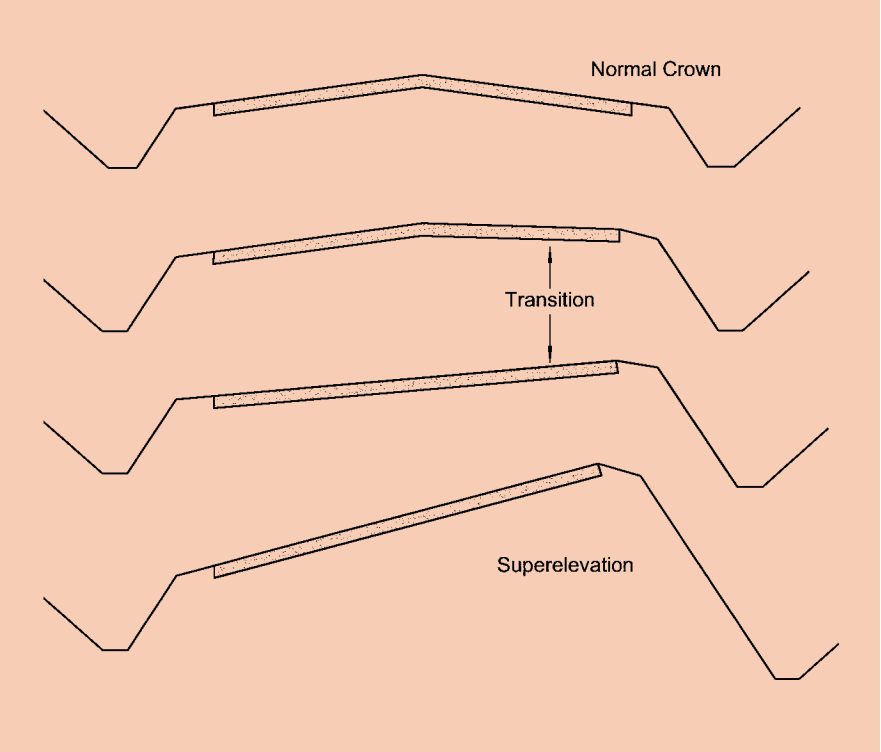


Figure 6: Illustration of the transition from a normal crown to the superelevated shape needed in a curve.



This photo shows lack of superelevation which can lead to accidents.



This superelevated road section makes driving safer.

a straight section of road. This requires constant attention during each maintenance pass over the road. Traffic will tend to displace the gravel towards the upper end of the road and the inside of the curve will become lower. Curves can very easily go out of proper shape. (1, 5, 7, 21, 24, 29, 36)

The correct amount of slope or "banking" of a curve can only be determined by engineering analysis. There is also a device available for determining the safe speed of a curve called a ball bank indicator. If you are unsure of correct shape on a curve, get professional advice if at all possible.



This road in Ecuador has excellent superelevation in the curve. It also has good shoulder drainage and ditches on both sides of the road. (Courtesy of Ron Anderson, Tensar Earth Technologies, Inc.,USA)



Grader working at a rural railroad crossing. The material that has been pushed into the flangeway should be removed.

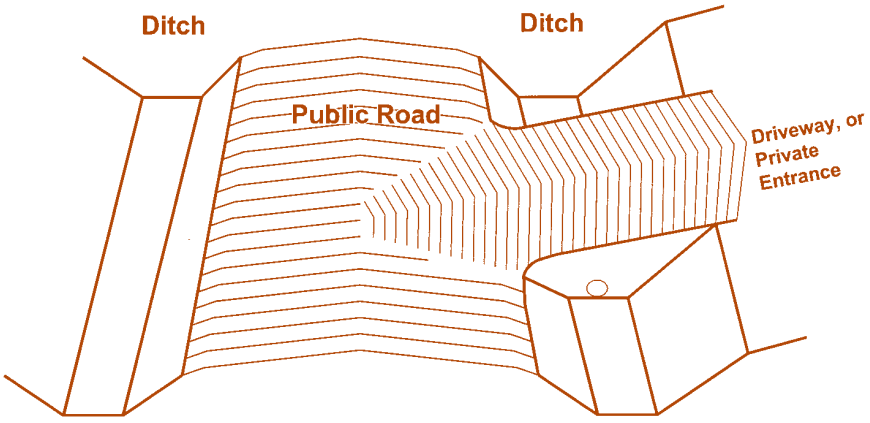


Figure 7: Improper matching of driveway and road edge

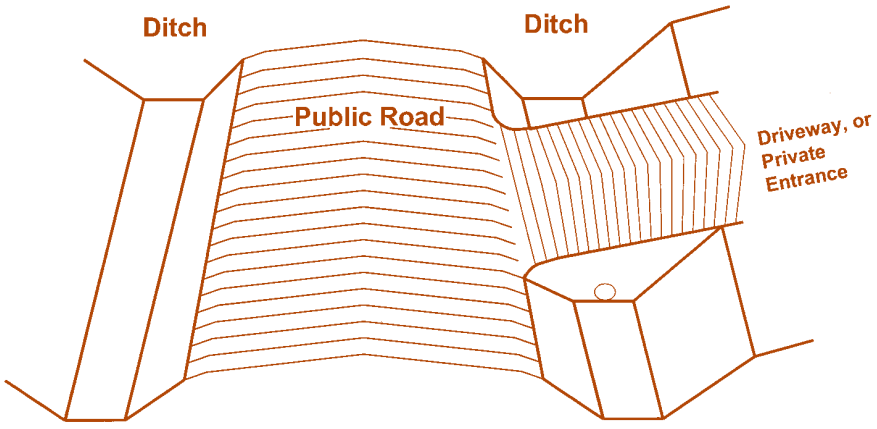


Figure 8: Proper matching of driveway and road edge

Railroad Crossings

Maintaining a road that intersects a rail crossing is very similar to bridge approaches or intersections with paved roads. Always begin to eliminate crown approximately 100 feet away and shape the road to match the crossing.A special consideration is to be extremely careful about keeping gravel out of the flangeways along the rails. This can cause a derailment — particularly when it combines with snowpack in northern regions of the country. Also, be extremely careful not to strike the rails themselves. In some cases, this could slightly displace the rails and again could cause a major disaster. If you snag or strike a rail with your equipment, report it immediately to your supervisor and the railroad. (35, 36)

Driveways

The public road should always retain its normal crowned shape while passing driveways. Too often the gravel builds up on the road at a driveway entrance as shown in Figure 7. This changes the shape of the roadway itself, which can cause loss of control of vehicles. These situations need to be reshaped. The driveway entrance should always match the edge of the public road as shown in Figure 8. (35, 36)

In heavily populated areas with gravel roads, poor installation of driveways can be a real problem. To reduce maintenance problems, implement a permitting process. It should address the proper control of grade to match road edge, adequate width, and drainage.

The solution to the problem shown in Figure 8 is demonstrated in a simple three-step operation which is shown on the next page.

Step 1. The operator restores the crown on the public road by removing excessive material extended from the driveway. Note the drop off created by this operation.





Step 2. The operator proceeds to correct the drop off at the end of the driveway by cutting the material loose and spreading it back on the driveway.

Step 3. The above two steps result in a well-shaped driveway that matches the edge of the public road.



Cattle Guards

A simple structure called a cattle guard is common in parts of the high plains and mountain west in the US. These devices are commonly found on low volume roads in national forests and on public lands where cattle or other livestock are allowed to graze on open range. The cattle guard allows traffic to pass from one parcel of land to another without opening and closing gates. The cattle guard is a series of heavy iron bars or pipes placed across the roadway, that generally appear like a heavy grate. There is a cavity below the bars or pipes that is generally twelve to eighteen inches deep. These structures confine cattle and other livestock since, by instinct, they will not cross them for fear of falling through the grate.

Cattle guards are a special maintenance challenge when installed on gravel roads. The approach to them should be treated much like blading up to a bridge deck. Begin to eliminate normal crown 50-100 feet from the guard. The road must then be shaped to match the cattle guard. However, gravel must never be spilled into the cavity below the grate. If this is done repeatedly, the hollow area below will be filled with gravel and cattle will simply walk out. Stop the grader two to three feet from the guard and backdrag loose material away from the structure. Then, handwork will often have to be done at the edge of the cattle guard to maintain a smooth crossing for traffic.



Example of good work done to reshape a roadway approaching a cattle guard and maintaining a very smooth crossing.

Soft and Weak Subgrade

Although it is extremely important to remove surface and subsurface water from the roadways, there are situations where water simply cannot be kept away. A good example is a section of road that passes through swampland or wetlands which naturally occur and cannot be drained. These areas will very often have weak subgrades, which cannot support heavy loads. Sometimes it is even hard to maintain the road for light traffic. The road will rut and pot-holes will be formed very quickly due to very poor soil support.



This gravel road with narrow right-of-way has turned to mud during wet spring conditions. It represents low-volume roads commonly found in several parts of the world.



A decision was made to stabilize the above road.A road crew is shown rolling out a fabric over the existing road surface.

This requires more than routine maintenance and reshaping if the problem is to be fixed permanently. Generally, there are only two solutions. One is to excavate and remove the weak, wet soil. Occasionally, the existing roadway is wide enough that after adding select material and shaping, the top width of the finished surface is adequate. In this case, undercutting will not be necessary. This "select material" will vary depending on what is available in the region. One thing is critical: it must be clean and drainable. It is also advisable to get engineering advice from consultants to make sure that materials are adequate before starting this rehabilitation challenge.

The second method is similar, except a product called a geotextile or geosynthetic is added. These products are often called "fabrics" and "grids" in the field. Here the procedure is virtually the same as described before, but a fabric and/or grid is placed over the subgrade soil before the select material is brought in.A woven or nonwoven fabric (geotextile) placed on the subgrade becomes a separator between the weak soil and the new material placed above it. The five photos shown on this and the next page demonstrate the proper sequence of placing geotextiles as explained in the following paragraphs. This prevents very fine, wet silt and clay type soils from pumping or migrating up into the new material. The pumping action occurs when traffic passes over the surface and the road deflects under the load.Pressure from the load will cause water in the subgrade to rise to the surface and carry fine soil particles with it. This will contaminate and weaken the new material very quickly and make it weak, undrainable, and unstable. A fabric prevents this by filtering



A truck is shown back-dumping a select, granular material onto the fabric.



The crawler/loader was used to spread the material over the fabric and is now being used to pull a grid roller to smooth the surface.

out the fine soils while allowing water to pass through it and drain out of the clean, granular material above.

A grid can also be used either in combination with or without fabrics. Grids are very strong geosynthetics which, in simplest terms, confine the material placed on them and do not allow lateral movement or "shoving" of the material.Grids have been rolled out over swamps and roads built over them with remarkably good results. The ability to carry and distribute the soil and traffic load is referred to as a snowshoe effect.Grids can also be placed within layers of select material. There are many types and variations of these products. It is wise to get good engineering advice when dealing with difficult soil stabilization problems.

Once the subgrade has been strengthened, a good coat of surface gravel can be placed and the road can be maintained as any other gravel road. The initial cost of stabilizing a weak road section can be expensive, but it will result in low maintenance costs thereafter, and will often make these projects cost effective.



The road now performs very well after the stabilization was completed.



Workers are shown using a combination of grid and fabric being placed over an extremely weak subgrade. This is in a region of Ecuador that receives average annual rainfall of nearly 200 inches. Approximately twelve inches of select, clean sand-type material will be placed over the grid to serve as a base. The fabric will be wrapped over the side of the sand layer to keep the edge from eroding away. Then another layer of grid will be placed and covered with approximately ten inches of crushed surface gravel which will become the driving surface.



A section of the same road during construction.Select material is being placed over the grid and fabric. Notice the evidence of extremely weak subgrade shown by the rut at the bottom of the photo. This rut was left by a light vehicle which traveled beyond the stabilized section. Yet this road will have to carry oil field traffic when finished.



Here is the finished road which has performed remarkably well while being used to carry extremely heavy loads during construction and equipment for oil field development. It is a good example of how an extremely weak subgrade can be stabilized and a gravel road built over it with minimum disturbance to the surrounding terrain and the environment.

(Photos on this page are courtesy of Ron Anderson, Tensar Earth Techologies, Inc.,USA)

Section II: Drainage

An often-repeated adage in the road construction and maintenance business is that "The three most important things to understand in building and maintaining roads are drainage, drainage, and drainage!" This certainly does get an important message across. But, too often, this critical issue is ignored when building and maintaining local roads. When drainage is poor, the best efforts to rehabilitate or maintain roads will bring disappointing results. When water can be drained off of road surfaces and out of roadbed soils, the road will invariably become easier to maintain.

This can hardly be emphasized enough. But this is not a drainage manual and therefore the discussion will only cover basic drainage matters. A good reference is Roadway and Roadside Drainage by the Cornell Local Roads Program at Cornell University. (27) Call the LTAP center in your state to obtain a copy.

Too often the maintenance team deals with surface problems that really come from wet and weak soil conditions below the road. Since gravel roads generally carry low volumes of traffic and do not have large budget allocations for maintenance, a maintenance operator must do what it takes to reestablish and/or keep drainage working on gravel roads. Previous sections of this manual have already discussed the road profile which is the first line of defense for good drainage. The discussion will now continue with three more basic drainage topics: ditches, culverts, and underdrains.



Lack of a roadside ditch has caused major drainage problems on this road.(Courtesy of Road Research Ministry of Roads/Transportation,Sweden)



This road located in Poland has very poor cross section.Consequently, drainage and overall driving conditions are bad. (Courtesy of Mary O'Neill, Office of Remote Sensing, South Dakota State University, USA)





Remarkable difference in these two roads that carry similar volumes of traffic. They are located in the same region of the country and the photos were taken on the same day. The major difference is drainage. The upper photo shows a well-drained road while the lower photo shows a poorly maintained ditch that resulted in a poor performance.



An example of work with a grader to reshape a ditch on a mountain road.

Ditches

The most important and common drainage structure needed is the roadside ditch. Every effort must be made to maintain a minimal ditch. If the ditch becomes obstructed from eroded soil or debris, it must be cleaned. Sometimes this can be a major project requiring loaders, excavators, trucks or other equipment. However, during a dry period, a maintenance operator with nothing more than a grader can do wonders to restore ditch drainage.



A nicely reshaped ditch that meets the shoulder line of the road and allows good drainage.



An Egyptian gravel road which is heavily travelled with limited access. Notice that despite the lack of ditches the surface performs well.The reason is that in the arid region of Egypt rainfall averages less than three inches per year. (Courtesy of Ali Selim,SD LTAP, USA)

Culverts and Bridges

These drainage structures are critical to carry the natural flow of water under the road so that it may continue on its natural course. Small pipes and box culverts can easily become plugged from eroded soil and debris. It becomes part of road maintenance to inspect them at reasonable intervals and clean them so that drainage is unobstructed. Eventually, they will have to be replaced.A good maintenance and replacement program is too often lacking on gravel roads. (15, 27)



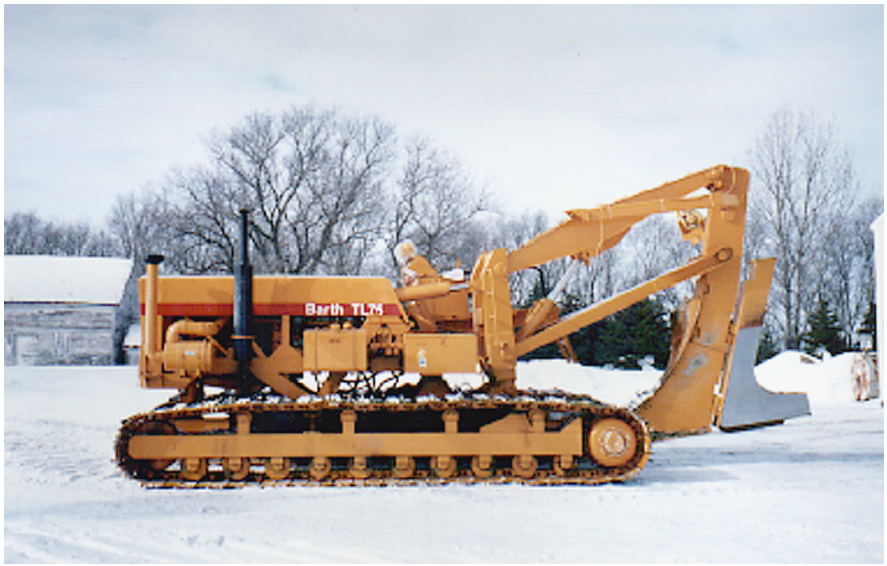
New culverts installed well and at correct elevation are essential for carrying water under a road.A reasonable maintenance schedule is required to keep them functioning well.



This road could fail if debris is not cleared before the next heavy rain.

Underdrains

When a road is built over water bearing soils or over natural springs which continually want to wick water upward toward the surface, the road is invariably weak and will perform poorly. It may be cost effective to consider installing either a "fabric," technically known as a geotextile, to stabilize the road, or a perforated pipe to carry water out of the roadbed. The use of fabrics has been discussed earlier in this manual. This discussion will briefly focus on the use of perforated drainage pipe.



Example of a machine called a tile plow that is commonly used in some regions to install polyethylene pipe into farm fields for drainage purposes. This type of machine has also been used to plow drain tile into gravel roads with great success in some areas.

This method has been used in several areas throughout the country. It is similar to field tile used for drainage of wet farmland. The product most commonly used is a flexible polyethylene pipe. The pipe is installed longitudinally, generally on the center line of the gravel road. It is often plowed into the roadbed with a laser-leveling device to keep the machine on grade. This method generally works best when the pipe has a fabric wrap or "sock" to keep very fine soils from infiltrating the pipe and plugging it.A trench can also be excavated to grade, pipe placed and small stone or clean fine gravel placed around the pipe. A geotextile lining in the trench can enhance the long-term performance of these drains. In either case, the pipe has to be brought out to an open end at or near the ditch bottom. Therefore, this method will not work if the ditch itself frequently fills with water and holds it for a period of time. This can actually cause the pipe to work backwards and carry water back under the road and weaken it further.

This drainage method may not be effective in all soil types, however it has proven effective in many areas.

Section III: Surface Gravel

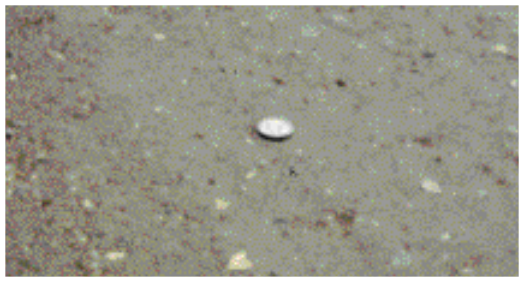
What is Good Gravel?

The answer to this question will vary depending on the region, local sources of aggregate available and other factors. Some regions of the country do not have good sources of gravel (technically called aggregate). A few coastal regions use seashells for surface material on their unpaved roads. However, this section of the manual will discuss the most common sources of material. They are quarry aggregates such as limestone, quartzite and granite; glacial deposits of stone, sand, silt and clay; and river run gravels that generally are a mix of stone and sand. One thing should be stressed: it pays to use the best quality material available. (31)

Difference in Surface Gravel and Other Uses

Too often surface gravel is taken from stockpiles that have actually been produced for other uses. For instance, the gravel could have been produced for use as base or cushion material for a paved road. There are two major differences between surface gravel and base (cushion) material. Good gravel for base courses will generally have larger top-sized stone and a very small percentage of clay or fine material. This is necessary for the strength and good drainability needed in base gravels. This material will not form a crust to keep the material bound together on a gravel road. It will become very difficult to maintain. Other gravel could have been produced simply as fill material for use at building sites. This material often has a high content of sand-sized particles which make it very drainable. This is a desirable characteristic in fill material since water can quickly flow through it and drain away from under building foundations and parking lots. But the same material will remain loose and unstable on a gravel road.What a gravel road needs is sufficient fine material that has a plastic or "binding" characteristic.





Notice the good blend of stone, sand and fine-sized particles tightly bound together on this road surface.

Good Gradation

Gravel is a mixture of three sizes or types of material: stone, sand and fines. This will be discussed further in the next section.Without a good blend of these three sizes, the gravel will perform poorly. Unfortunately, poor performing gravel will often be blamed on the maintenance operator. But the operator cannot make good gravel out of bad gravel. Bad or poorly graded gravel can not be changed to good gravel without additional costs, but it is often well worth it.

One common practice of improving surface gravel is to add new, clean, virgin fine gravel. Good surface gravel needs a percentage of stone which gives strength to support loads — particularly in wet weather. It also needs a percentage of sand-sized particles to fill the voids between the stones and give stability. But a percentage of good, plastic fines are also needed to bind the material together which allows a gravel road to form a crust and shed water. In many regions of the country, this is a natural clay which gives the gravel a strong cohesive characteristic and keeps a reasonably tight surface especially during periods of dry weather. Some of the fine material in surface gravel will be lost, under traffic action, in the form of dust that rises from the surface and simply blows away. This can be compensated for by specifying a higher percentage of fines in the new gravel. However, no gravel surface will perform like pavement! There will be some loose aggregate or "float"on the surface of virtually all gravel roads. But striving to get as good a material as budgets and local sources allow will improve the performance of a gravel road.



Example of a good blend of material for gravel surfacing. (Courtesy of Road Research Ministry of Roads/Transportation,Sweden)

Benefit of Crushing

In a few cases the gravel may simply be loaded onto trucks without processing. This is often referred to as "bank run" or "pit run" gravel. There are few natural deposits of material that have an ideal gradation without being processed. In some areas of the country it is still common to process gravel simply by screening to a maximum top size. A great benefit is gained from processing the material by crushing. This means that a good percentage of the stone will be fractured in the crushing process. The broken stones will embed into the surface of a gravel road much better than rounded, natural-shaped stone. It also means that the material resists movement under loads better and gives better strength or stability. This will vary throughout the country, but bank run gravels are nearly always improved through the crushing process. Quarry gravels are considered very good material since they are composed of virtually all fractured particles.

Recycled Asphalt

As more of our asphalt pavements wear out, many of them are recycled. This is usually done by milling or crushing. Sometimes the material is available for use on a gravel road. It can be a good surface, but there are pitfalls. In this material, the bituminous portion of the old pavement becomes the binder. When placed on a road in hot weather, the recycled asphalt can take on the characteristic of pavement. But it will be a weak pavement. It will often develop potholes and will be hard to maintain with simple blade maintenance. To help overcome this problem,the material should be placed at a minimum three inch compacted depth and only on a road that has a strong subgrade. A better option is to mix the recycled asphalt 50/50 with virgin gravel. This will generally provide a material that still has a good binding characteristic, but remains workable for maintenance and reshaping. Recycled asphalt has also been mixed with crushed, recycled concrete and the performance has been good.

The Benefit of Testing Aggregates

It is very important to understand that all gravels are not the same. One can tell a little about them by visual inspection or by running your hands through the material but real quality can only be determined by testing.

Reasons For Testing

All managers and decision makers in local government need a good understanding of the benefit of testing aggregates in order to work towards better quality in road and street maintenance. Not everyone needs to understand how to do the testing. Testing requires special knowledge and equipment which is generally not available or affordable to most local governments. We simply need to recognize the benefits of knowing more about the aggregate that is used in construction and maintenance operations. This knowledge gives power to decision makers to specify good materials, to know when to accept or reject materials, and to communicate better with crushing contractors, consultants, DOT, and others involved in the business of building and maintaining roads.

Often an objection is raised to sampling and testing because the cost is too high. This claim can be countered with the argument that if several thousand tons of aggregate are going to be purchased or crushed, is it not wise to invest a few hundred dollars in testing the material to insure that the right aggregate is used? It is a good practice to test the aggregate before placing it on the road.Also, if the tests fail, you can work with the crushing contractor to try to blend and improve or reject the material. This becomes even more critical in producing material for pavement or base.

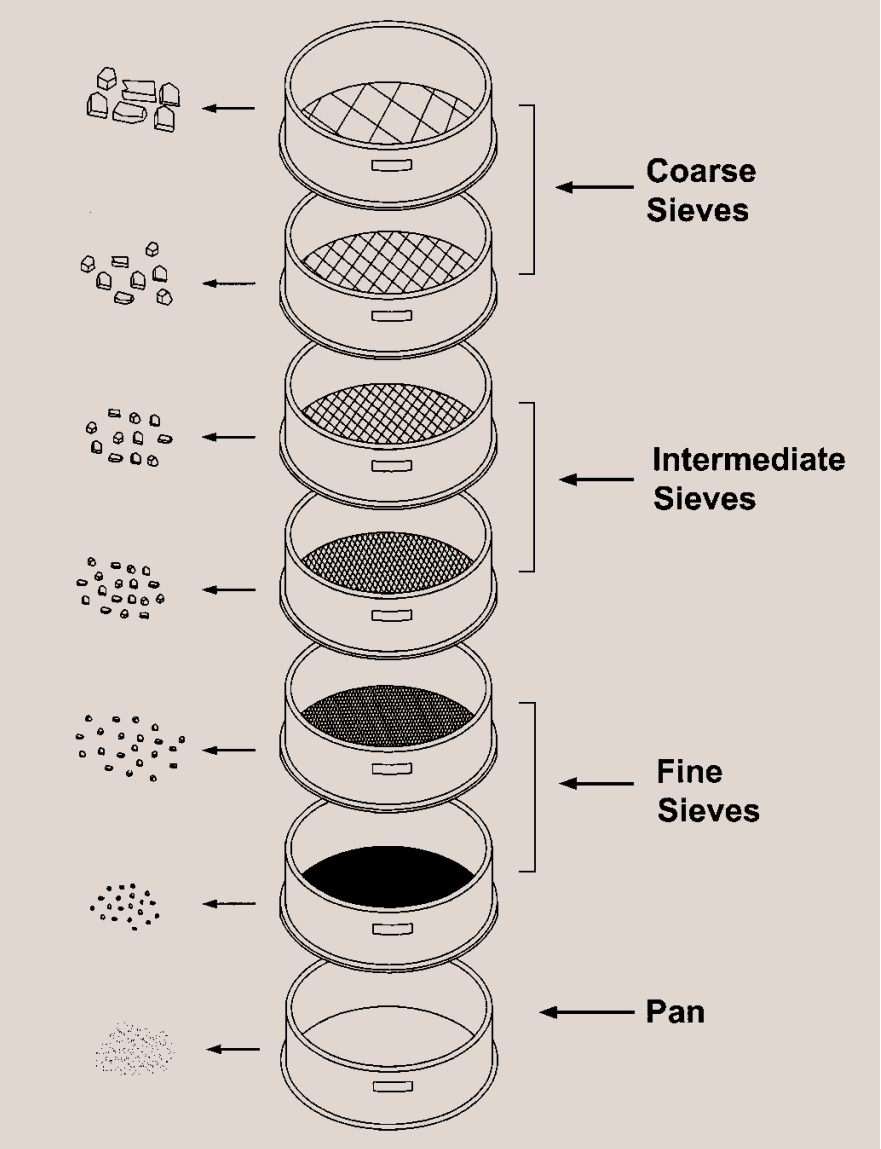


Figure 9: Stack of sieves used for testing the gradation of aggregate.

Sampling

Another issue critical to testing aggregate is obtaining a good sample of the material to be tested.Knowing how to get a good representative sample from a crushing operation, a stockpile, a windrow, or a paving operation is absolutely critical to getting good test results from a lab. Poor sampling techniques have led to more controversy in aggregate testing than any other factor. Every effort must be made to make sure that the sample brought to a lab is truly representative of the material in the field. It is wise to follow national standards such as

ASTM for aggregate sampling.A good video titled Sampling Aggregates, produced for the Michigan DOT, covers several interesting topics on the subject. This video should be available from any state's LTAP center. It is always advisable to work with an experienced sampler if you are not familiar with sampling.

What then are the benefits of testing aggregate? The primary concern here should be gradation of material. (18, 31, 34)

Table 1. Example of Gradation Requirements and Plasticity for Two Types of Materials.

Requirement Sieve	Aggregate Base Course Percent Passing	Gravel Surfacing Percent Passing
1"	100	
3/4"	80-100	100
1/2"	68-91	
No. 4	46-70	50-78
No. 8	34-54	37-67
No. 40	13-35	13-35
No. 200	3-12	4-15
Plasticity Index	0-6	4-12

From *South Dakota Standard Specifications*. (16)

Sieve Analysis

Gravel is made up of three groups of aggregate: stone, sand,and fines. Depending on what the material is to be used for, the ideal blend of these three groups varies greatly. For example, good surface material for a gravel road would need more material passing a #200 sieve than a good base material. There is also a difference in the need for plastic or cohesive material.Surface gravel needs some good natural clay which gives a "binding characteristic." The chart adjacent is an example of one state's base and gravel surfacing specifications. Most states have their own specifications and therefore it is highly recommended that state specifications be consulted.

Local governments are not held to these specifications when doing their own construction and maintenance work without state or federal funding and oversight. Yet, it is wise to be familiar with them and follow them whenever possible. Even if you choose to modify the specifications to suit a local material source or project, it is best to begin with a state specification.

Notice the major differences in the above specification in the top-sized material and the smallest sized material. The base course requires 100% of the material to pass a 1 inch sieve, but allows up to 20% of the stone to be retained on the 3/4 inch sieve. While this could make excellent base gravel, it would likely perform poorly if used as gravel surfacing. There would be too much large stone resulting in very difficult blade maintenance.

Also, the high percentage of coarse material would make a rough driving surface. Yet, a percentage of large stone is needed for strength in the base course.

Fines and Plasticity Index

Notice also the difference in the fine material and the plasticity index (PI). While gravel surfacing allows 4% and up to 15% of the material to pass a #200 sieve, base course can have as little as 3%, but not more than 12% passing the same sieve. More importantly, the PI can fall to 0 in base course and rise to no more than 6. The same index can rise as high as 12 or be no less than 4 in surface gravel. There is good reason for this. Good surface gravel needs a percentage of plastic material, usually natural clays, which will give the gravel a "binding" characteristic and hence a smooth driving surface. This is critical during dry weather. During wet weather, the surface may rut a bit, but will quickly dry and harden in sunny and windy weather. However, any great quantity of plastic fines in base gravel will cause problems. If moisture gets under the paved surface, the base will lose its strength and stability and cause rutting or even failure of the pavement. Too often the same gravel is used for both base work and surface gravel. Generally, it will be good for one purpose or the other, but will not work for both applications.

Appendix D contains a sample of a complete Screen Analysis and PI Worksheet typical of those used by testers across the country. Once again, it should be stressed that only by sampling and testing the aggregate can one really determine the quality of the material. Simple visual inspection can be misleading. One thing in particular that is very hard to determine without testing is plasticity. This is a laboratory test which, in simplified terms, tells you whether the fines are clays or silts. If you are not familiar with this testing, the whole process may appear very confusing. Yet, it really pays to increase your knowledge of these matters in order to be a better manager.

Every local road/street department manager has a big job and there is never enough money to cover all of the needs. It is imperative that money should be spent wisely.

Reduced Blading and Maintenance Costs

By spending some money to test material for quality, overall maintenance costs will be reduced. Good gravel that has good gradation and plasticity will compact well. It will develop a tightly bound surface that needs less maintenance. Problems with excess washboarding,rutting in wet weather, or loosening (floating) in dry weather, will be greatly reduced. It is well worth the effort to better understand the benefits of aggregate testing.

Process for Obtaining Good Gravel

An agency must strive to locate and use good gravel even if it costs a little extra. The long term benefits in terms of less maintenance will often pay for the extra cost. The initial cost should not be the primary consideration when purchasing gravel.

Establish Specifications

Gravel for local roads is often bought from a local supplier at a negotiated price for an estimated quantity. There may be some assurance that the gravel will perform well on the road based on past experience. However, material sources can change rapidly as the material is removed. The only real assurance of getting good quality material is to establish a specification and then sample and test the product to make sure these specifications are met.

A local agency generally would not be held to state specifications when doing maintenance work.However, this is what crushing contractors and aggregate suppliers are usually familiar with.

If one is confident in knowledge of surface gravel and wishes to change the specifications, that is fine; but it is wise to use the state specification as a benchmark to work from. For example,



These two roads show remarkable contrast in surface condition due to the quality of gravel. They carry virtually the same volume and type of traffic in an agricultural community. The top photo shows a good surface gravel with a nice blend of material,particularly some plastic fines which keep the surface tightly bound.The bottom photo shows a road surface that has too much stone and sand in proportion to the fine material. Consequently, the gravel remains loose and is hard to maintain.

state specifications may show a Class I Surface Aggregate designation for surface gravel. You may want a higher minimum requirement for plasticity or perhaps a smaller top size on the rock. State clearly in your specification that you want a Modified Class I Surface Aggregate and then clearly indicate what your modifications are. It is wise to familiarize yourself with your state specifications.

Communicate with Suppliers

Many problems are quickly solved when people make an effort to explain clearly what their problems or needs are. In regard to the specifications just discussed, many commercial aggregate suppliers can provide test data from their stockpiles to show the gradation of their material. They may have further data such as plasticity index, percentage of fractured faces, soundness, etc. You simply have to ask for it.It is wise to occasionally sample to verify their data. Good suppliers welcome this.

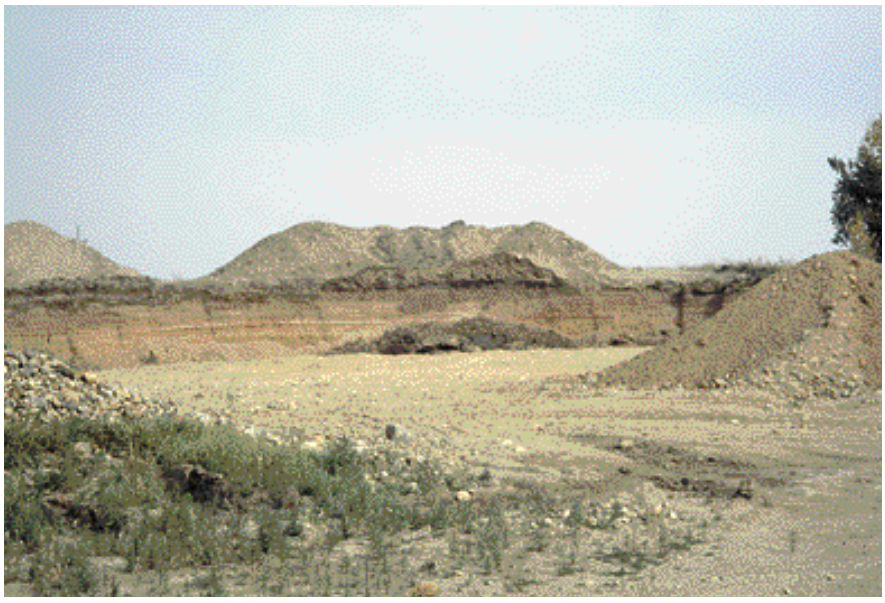
Good material is seldom the cheapest. An interesting example in Lawrence County, South Dakota, is a case in point. Local materials crushed to the state's Gravel Surfacing Specification did not perform well.After developing a modified specification and communicating clearly to crushing contractors what was needed,some very high quality surface gravel was produced. Some good natural clay material was mixed as the gravel was being crushed. The result was good surface gravel that has a very nice blend of stone, sand and good plastic fines which make a strong, tightly bound gravel surface. The material was more expensive up front, but resulted in reduced frequency of blade maintenance and longer intervals between regraveling. Total expense of maintenance over a five-year period was considerably less than purchasing cheap gravel,blading it more frequently and having to regravel more often. None of this is possible if the manager does not understand what good gravel is or does not communicate and cooperate with the supplier to provide it.

Handling Gravel

It is not common for maintenance operators or field supervisors to be involved in actually producing the gravel that is used on their roads. Yet it is very helpful to understand how the material should be handled from the time it is taken from the quarry face or the gravel bank in a pit. There are certain problems that can arise from the time the material is first removed from the earth until it is finally placed on the road.It may be wise to visit the site where your gravel is being produced to see if it is being handled well.

Pit/Quarry Operations

It is very important to remove topsoil and vegetation from the surface of the material source before beginning to process the material. Topsoil will contain organic matter which is never good for a road surface. Furthermore, in some agricultural regions of the country, the spread of noxious weeds can occur when parts of growing plants



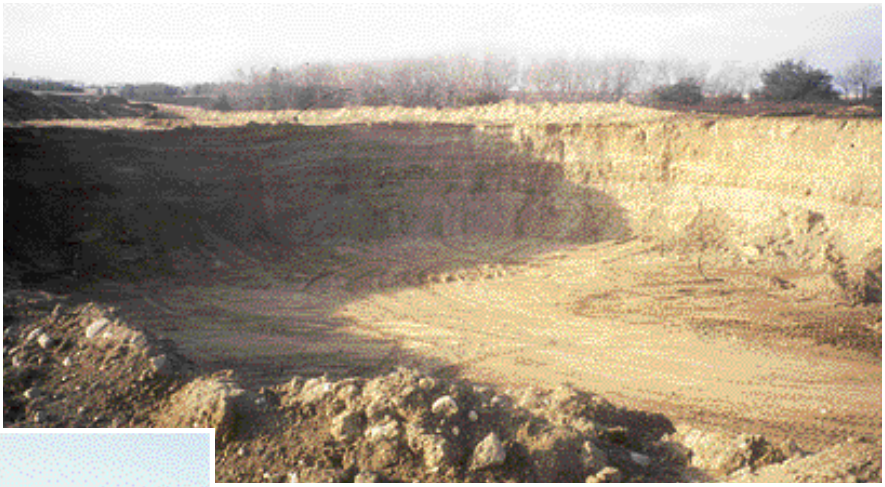
Here is an example of a poorly managed pit operation.The top soil pile shown at the center of the photo was not placed far enough beyond the working face of the pit. As additional material was removed from the face of the pit, materials from the top soil pile fell into the working area. This will lead to contamination of the gravel with organic material and,even worse, noxious weeds.

and/or the seeds are hauled out with the gravel and spread on rural roads. Several states have laws which allow authorities to quarantine material sources and stockpile sites to prevent the spread of weeds. Under these laws, the gravel cannot be removed even though your agency may already have ownership of it. It becomes very hard to guarantee that all problems have been eliminated before beginning to remove material again. The solution is to make sure the topsoil is removed and placed well out of the way.

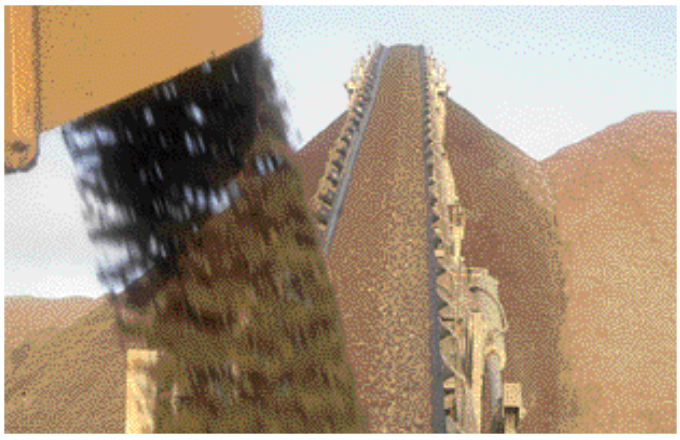
The next area of concern is how the material is being removed from the face of the quarry or pit.Almost any material source will have variations in the layers of gravel. Good crushing contractors will remove the material by working a broad area of the face. This is essential to have material that is blended well as it goes into the crusher. Even a pit or quarry that appears to have very uniform layers of material will still have variations such as clay or silt seams which can suddenly change in thickness. This can really affect the overall gradation of the gravel.Good loader or dozer operators are key players in getting a good blend of gravel right at the start of processing.



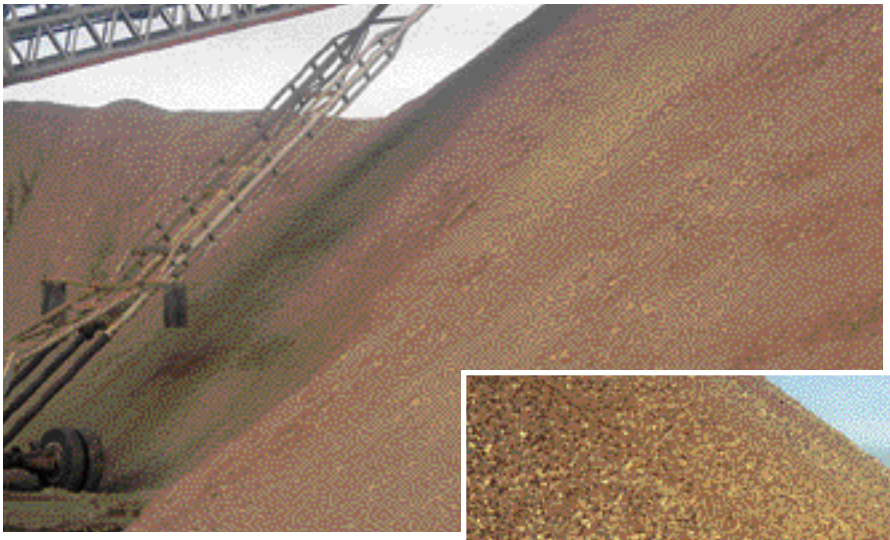
A very good example of working a gravel bank.Large loaders are being used to feed a crushing plant.Notice the good effort to work a broad area of the gravel bank.The operator virtually never takes a bucket of material from the same spot twice. This assures a good blend of material going into the crusher.



A good example of topsoil and vegetation that has been stripped from the surface of a gravel pit and placed beyond the working area. It can later be placed back over the bottom of the pit as part of the reclamation process. It will once again grow grass.



The discharge conveyor from a crushing plant is in the foreground. Notice how badly segregated the material is as it is carried up to the stockpile on a belt stacker. This invariably leads to problems illustrated in the following two photos.





Notice the dramatic difference in the two sides of the stockpile. The inside of the pile (top photo) has an excess of fine material while the back side has excess stone (bottom photo).This could have been prevented by eliminating segregation on the stacker belt.

Another problem commonly encountered is in the processing plant itself. These plants are made of different types and sizes and the detailed operation of each is beyond the scope of this manual.

The problem here is the segregation of material during processing.When segregation occurs, large-sized particles tend to group together and get isolated instead of being blended well with the rest of the material. This will lead to inconsistency in the material as well as difficulty in compaction.Surface areas containing an unusual amount of coarse particles will remain loose and unstable, while other areas, rich with fines, may rut excessively during prolonged wet weather. When a stockpile is segregated as badly as the one just illustrated,it is almost impossible to blend the material again before it is hauled out onto the road. One option would be to use a bulldozer and rework the stockpile to blend it. Some agencies require their stockpiles to be constructed in layers so that these problems do not occur in the first place. Work with suppliers to reduce these problems. Segregated material is always a problem.(18, 33)



This road is located about 50 miles from Cairo, Egypt.It displays segregation problems in several spots. (Photo courtesy of Ali Selim,SD LTAP, USA)

Loading From Stockpiles

Good loader operators who observe the stockpile and work hard to blend material evenly are essential in getting good gravel delivered to the road.In many small maintenance operations, every truckdriver may operate the loader to load his/her own truck. It then becomes important that every driver understand the need to observe the pile and load material uniformly. If large stockpiles have been placed with belt stackers, it is always best to work into the end of the pile and work the face of the pile uniformly. Again, as the loader places material in the trucks it is wise to get each bucket of material from a different location across the face of the pile. (18, 33)



A good example of loader operation — working uniformly across the end of the stockpile. Note also a very level stockpile site and a well maintained loading area on which the loader and trucks work.This demonstrates pride in doing a good job of handling material.

Roadway Preparation

When fresh gravel is to be placed on a road, it is vital that the road be in good shape. For example, a washboard area needs to be cut out and reshaped prior to placing new gravel over it. Otherwise, the washboard distress will quickly reflect right up into the new surface and the problem quickly reappears. Another critical matter is to take care of any surface drainage problems. If the road has lost crown, has potholed areas, high shoulders or severe rutting, all of these problems need to be eliminated. Then fresh gravel can be placed at a uniform depth and the road becomes easier to maintain. Generally it is not wise to simply fill these problem areas with new gravel. It can become very expensive and the gravel will not have uniform depth.



This road has been badly damaged from a heavy haul. It would be useless to begin hauling and placing fresh gravel until the entire roadway has been reshaped.

Preparing a road for new gravel can be as simple as cutting out a few potholes or a washboard area to reshaping the entire cross section. Even if the existing road is smooth and hard, it is often wise to lightly scarify the surface to get a good bond. One final tip: be sure the crown and shape of the road is as close as possible to the way the road needs to look after regraveling is finished. That is the only way a completely uniform layer of new gravel can be placed.

Calculating Quantity

The procedure for determining how much gravel needs to be hauled to add a predetermined depth to a road is not always well understood. One thing that is often overlooked is the shrinkage in volume that occurs from ordinary compaction. Ordinary compaction means the shrinkage that occurs from the material being placed, absorbing moisture from rainfall and then having traffic passing over it. In many parts of the country, this will result in 30% or greater reduction in volume.

Keep in mind some people often calculate the volume of material only as it is carried in the truck or as it exists in the stockpile. Material in the stockpile is very loose and has very low density. Remember to allow for shrinkage when calculating how much gravel depth is needed after the job is compacted and finished. Calculation then should be made for the distance that each truck can spread its load. This is not always done in maintenance operations, but it is recommended.It's the only way to really know for sure how much material is being placed.Appendix C of this manual has two charts to help in calculating quantities.

Hauling and Dumping

Traffic control is sometimes neglected in rural areas while the work is being done. It is not common in most areas of the country to place signs during routine blade maintenance. It is a mobile work area and the warning lights on the machine give adequate notice that maintenance work is being done. But hauling and spreading gravel should be treated as a work zone and signed as such. The Manual on Uniform Traffic Control Devices (MUTCD) or the state's uniform signing manual should be used as a guide to select appropriate warning signs. (38)



These two photos depict a the good job of spreading done by a county highway department using tandem end-dump trucks. The skill of the drivers makes this job look easy. Notice also the grader is ready to begin processing the material.



Once hauling begins, it is wise to have a motorgrader present to process and place the gravel immediately. The skill of the truck drivers can really make a regraveling operation work smoothly. When drivers are able to dump the load evenly and within the correct length that was marked, the grader operator's job becomes much easier.

Windrowing, Equalizing and Spreading

Once the gravel is dropped on the road, the grader operator should pick up the material and place it in a windrow. This will usually take more than one pass. It is called equalizing. This accomplishes two important things when handling gravel. It gives a final blending and mixing of the gravel, and it makes a windrow of very uniform volume. Once equalized, the material should be spread by the grader evenly on the roadway. Care must be taken not to carelessly cast material off the edge of the roadway where it cannot be recovered.When the material is finally placed across the roadway, it leaves a uniform depth of well-blended material that becomes the new gravel surface for the public to drive on. It all works better when everyone understands his/her job. While it is not possible everywhere, adding water and using rollers for compaction invariably makes a better gravel road. It is recommended whenever possible. (32)



The motorgrader operator has done a good job of picking up the fresh gravel and equalizing it into a very uniform windrow.



Only after completely windrowing and equalizing does the operator begin to place the material at a uniform depth across the roadway.


CATERPILLAR

Section IV: Dust Control and Stabilization

All gravel roads will give off dust under traffic.After all, they are unpaved roads that typically serve a low volume of traffic, and dust is usually an inherent problem. The amount of dust that a gravel road produces varies greatly. In areas of the country that receive a high amount of moisture, the problem is greatly reduced.Arid or semi-arid regions such as the desert southwest and much of the great plains region in the USA are prone to long periods of dry weather. Similar regions around the globe can have similar weather patterns. Dust can really bring complaints in these areas if there are residences located near the road and traffic is high.

The quality and type of gravel also has some effect on the amount of dust. Some limestone gravels can dust severely while some glacial deposits of gravel with a portion of highly plastic clay can take on a strong binding characteristic that will resist dusting remarkably well. Still, in prolonged dry weather, there will be dust! Whether to provide some type of dust control or not can be a hard decision to make. Virtually all methods of dust control require annual treatment.

The cost can be prohibitive if traffic volume is low. On the other hand, if traffic is high, the cost of dust control can more than pay for itself with the benefits of reduced material loss and reduced need for blade maintenance. (28) At this point, many agencies will face pressure to pave the road. It may actually be a good economic decision in the long run, especially if there is good indication that traffic will continue to increase in the future. However, never pave a road before it is ready! There is good information on making this decision in Appendix D.

Types of Stabilizers

Chlorides

These are the most commonly used products across the country. They fall into three categories: Calcium Chloride in flake or liquid form, Magnesium Chloride generally in liquid form, and Sodium Chloride (road salt). Sodium is seldom used and is the least effective. Calcium and Magnesium Chloride can be very effective if used properly. They are hygroscopic products which, in simplest terms, means they draw moisture from the air and keep the road surface constantly damp. They are reasonably simple to use.

Resins

These are products available under various commercial names. The basic composition is lignin sulfonate which is a by-product of the pulp milling industry. The product is sometimes called “tree sap” in the field. These products work best when incorporated into the surface gravel. They then provide cohesion to bind the soil particles together.

Natural Clays

Some regions of the country have excellent deposits of natural clay that

are highly plastic and provide strong cohesion when added in the right quantity to gravel.However, in prolonged dry weather, these roads will seldom be completely dust free. It can be difficult as well to haul the clay onto the road and mix it into the gravel. Because it is highly plastic,it tends to stick to the truck boxes and requires quite an effort to mix with the gravel.

Asphalts

The use of cut-back liquid asphalts to surface-treat gravel roads was once popular for dust control. However, because of the great amount of fuel oil or kerosene in these products, they have been banned in many places. Some emulsified asphalts may work for this purpose, but their use is very limited. The product must be applied with special asphalt application equipment.

Soybean Oil

This product is known technically as Acidulated Soybean Oil Soapstock. It is a by-product of the caustic refining process of soybean oil. It is a biodegradable material that has many of the characteristics of a light petroleum-based oil. It will penetrate a gravel surface and provide a light bonding of the gravel that effectively reduces dust when it is used properly.

Other Commercial Binders

There are too many of these to mention individually. They are marketed under various trade names across the country. It is always wise to try a test section of no more than 1000 feet in length to see how any of these products work with your gravel. One caution: do not use waste products such as crankcase drain oil from engines. This is harmful to the environment and is in violation of EPA rules.

Benefits of Stabilization

Once a road is stabilized there are several benefits. On high volume roads, these benefits can make stabilization very cost effective.

Reduced Dusting

It may be hard to justify the use of any of these products for dust control alone. However, when the products are working well, the added benefit of a stabilized surface that controls the loss of fines through dusting is a great economic benefit.When the fines are lost from a gravel surface, the stone and sand-sized particles that remain will tend to remain loose on the surface, leading to some distresses like washboarding and reduced skid resistance. It will become very hard to maintain. Fresh gravel with a higher percentage of fines needs to be hauled in. This becomes very expensive.

Reduced “Whip Off” of Aggregate

This is another economic bonus to dust control when it is working well. As mentioned earlier, when dust control products are working well, the fine material in the gravel cannot loosen and dust away. This also means that the stone portion of the gravel will tend to remain embedded in the surface and will not be lost to the edge of the road or even whipped off onto the inslope from heavy traffic. Studies have shown that as much as one ton of aggregate per mile is lost each year for each vehicle that passes over a road daily. This means that a road carrying 200 vehicles per day will experience the loss of 200 tons of aggregate per mile each year. (7) Obviously this will vary with the amount of rainfall received, the quality of the gravel and other factors. Retaining aggregate is a good added benefit to dust control.

Reduced Blade Maintenance

A road surface that remains tightly bound and stable will require much less blade maintenance. The manufacturers of some dust control products highly recommend that the surface should not be bladed at all after their products are applied.While extra blading, shaping and mixing is needed to prepare a road for dust control, the overall need for blade maintenance should be greatly reduced. This can be a great savings in equipment expense and labor. A county highway official once commented:“I don’t react to dust complaints. All gravel roads have dust. But I do react to high maintenance costs. When we have to regravel a road frequently and do blade maintenance frequently, then it’s time to look at stabilizing the surface with Magnesium Chloride. Reduced maintenance is what we’re after. Dust control is just a bonus!”

Application Tips

There is not enough space to cover application tips for all products. Since the Chlorides are the most commonly used products, we will address the use of those. However, some or all of these tips would apply to the use of most other products as well.

Need for Good Surface Gravel

Keep in mind the Chlorides are not binders. They simply draw moisture from the air. The gravel itself must have a good gradation — particularly a good percentage of fine material with some plasticity. This will give the gravel a natural binding char-acteristic. The Chlorides then will take over and keep the surface damp and it will remain tightly bound. It will not give up its fines in the form of dust. This point cannot be emphasized enough.If good gravel is not present on the road,it will be wise to haul in good fresh gravel prior to treatment. The cost of the Chloride treatment has been virtually wasted on some roads when the gravel was poor and very short-lived dust control resulted.

Road Preparation

This is another critical point in preparing for dust control treatment.Make sure the road has a good crown in the driving surface. Also, make sure there is good shoulder drainage. Standing water anywhere in the roadway will cause the surface to soften and fail. It will leave a pothole in an otherwise good, stabilized roadway. These can be hard to correct afterwards without disturbing the stabilized surface around it.Another key to preparation is to loosen a minimum of one to two inches of the existing surface and leave it loose at a uniform depth across the roadway. This allows the Chloride to penetrate evenly and quickly into the gravel.

Do not compact the surface at all prior to applying chlorides.



The carbide-tipped bits on a cutting edge can be a valuable tool in preparing a road for Chloride treatment.They penetrate the road and give a shallow scarifying effect to loosen and mix the existing gravel.This leaves a nice uniform loose layer of material on the surface.



This road has been prepared well for a liquid Magnesium Chloride treatment.Notice the uniform, loose and nicely crowned surface looking over the hilltop. There is also good shoulder drainage as well.This is an excellent example of road preparation.

Applying the Product

The most important need here is for equipment that can be calibrated accurately and that will apply either the liquid or flakes evenly across the surface. Then a good application rate needs to be selected. This will vary with the type of gravel being treated and the length of time dust control is needed.Check with vendors and experts in your area to see what recommended rates are. Next, watch the weather! If rain is forecast or appears to be likely, don't take a chance. Rain on a freshly treated surface will leach out and dilute the Chloride and cause it to run off the road. It can temporarily harm grass on adjacent areas. But the bigger problem will be very poor performance afterwards. Also, it is ideal to keep traffic off of the road for up to two hours after application. This is not always possible, but it is very helpful. It is recommended that one side of the road be treated at a time. Rolling can be helpful, but is not essential. If rollers are used, pneumatic ones are best, and watch to see that the gravel does not start picking up from the surface. If that happens, wait until the surface cures a bit before finishing rolling.



Example of a good piece of application equipment.This truck has a pressurized spray bar with a computerized application system that meters the liquid Chloride with extreme accuracy.



This photo shows part of the spray bar with spraying nozzles.



A very effective, yet simple method of applying flake Chloride accurately with an old farm fertilizer spreader. These machines can be calibrated with great accuracy. Quick cleanup afterward is important since Chloride is corrosive to equipment.Once it is bound in the gravel, corrosive effect on vehicles is very low.

Optimum Moisture

It is important to have the gravel close to optimum moisture just before applying Chlorides. This will cause the product to be absorbed much more quickly and evenly into the gravel.Never apply the Chloride to dry gravel. It will not be evenly absorbed and may show failure in spots.

Test Sections

It is always wise to try a test section of dust control/stabilization treatment if this type of work has not been done before. If there is uncertainty about the suitability of the gravel being used or if there is doubt about the equipment, and/or other products being applied, the process can be tried on a 500-1000 foot road test section. If the process fails at the test section level, then only a small investment and time are lost. Also you have less public complaint.

The outcome from the failed test section will present an opportunity to analyze what may have gone wrong. Another test section can then be tried with a modified process and/or materials. If field performance proves satisfactory, the process can then be applied to larger jobs.



A water truck being used to prewet some very dry gravel just prior to treatment.This dramatically improves the success of the treatment.



Section V: Innovations

Changes in Gravel Maintenance

Many people feel that gravel maintenance really hasn't changed much since the grader and drag were invented. This is not true. The use of our gravel roads has changed dramatically in many ways. In much of the Great Plains region of the country, the amount of traffic has actually declined as farms and ranches get larger. Even though the volume of traffic is less, the vehicles and equipment are much larger. Larger trucks use gravel roads everywhere in the country. This has forced a change in the way roads are maintained and some of the processes used.

Changing Conditions — Equipment, Trucks, Cars

While trucks and equipment on gravel roads are larger, cars have become smaller. It is important to be aware of this in maintenance operations. For example, when harvest begins, maintenance crews will often have to maintain gravel roads more frequently because of increased rutting and distress from



Example of very large trucks used today. These can often be found on gravel roads. Today's gravel roads are exposed to these heavy loads and therefore a more intensive maintenance program is required.



Another change to consider. Smaller vehicles cannot cross large windrows of material on the roadway. A greater effort has to be made to warn as well as to control traffic on these gravel roads while doing maintenance.

heavy loads. In contrast to this are the smaller-sized vehicles such as mini-vans that use gravel roads. It is critical to consider this when pulling large windrows of material out into the roadway during major reshaping. Larger cars of 25 years ago and more could pull through these windrows as long as they reduced their speed and drove prudently. The same condition could send a smaller car out of control.

Innovations

An ancient writer said, "There's nothing new under the sun." That's true in a sense. But one needs to look at different ways of doing work, of making one piece of equipment do more things, of trying different means of strengthening weak road base, etc. This section will show and discuss a few things, but always be alert for things that can make the maintenance better and/or more efficient. Maintenance operators are sometimes remarkably innovative with simple ways to change a machine or a process. Evaluate what you see. It may work for you, or perhaps you can adapt it further. For example, new products are becoming available that actually change the properties of soils. Evaluate these products as they become available in your region.It may be worth trying on a short section of road and then evaluating it for a period of time.

Innovative Equipment and Methods



A machine made in Canada pulverizes gravel windrows into usable material on the roadway.



A machine fabricated specially by Hyde County in South Dakota to pulverize heavy windrows of recovered gravel and grass from the shoulder. It quickly breaks down windrows for reuse on the road.

Windrow Pulverizers

The need to reshape a gravel road periodically to restore overall shape and drainage has been stressed. The need becomes even more urgent under heavy traffic when the road begins to rut and fail. But this often means pulling vegetation onto the road. This could come from cleaning a ditch or simply eliminating a high shoulder. Sometimes the material has to be removed and loaders and excavators may be needed. But sometimes the material is primarily recovered gravel that can be used on the road. How do you deal with the chunks of sod that come with it? At least one machine is on the market which is designed to quickly pulverize this material.

New Cutting Edges

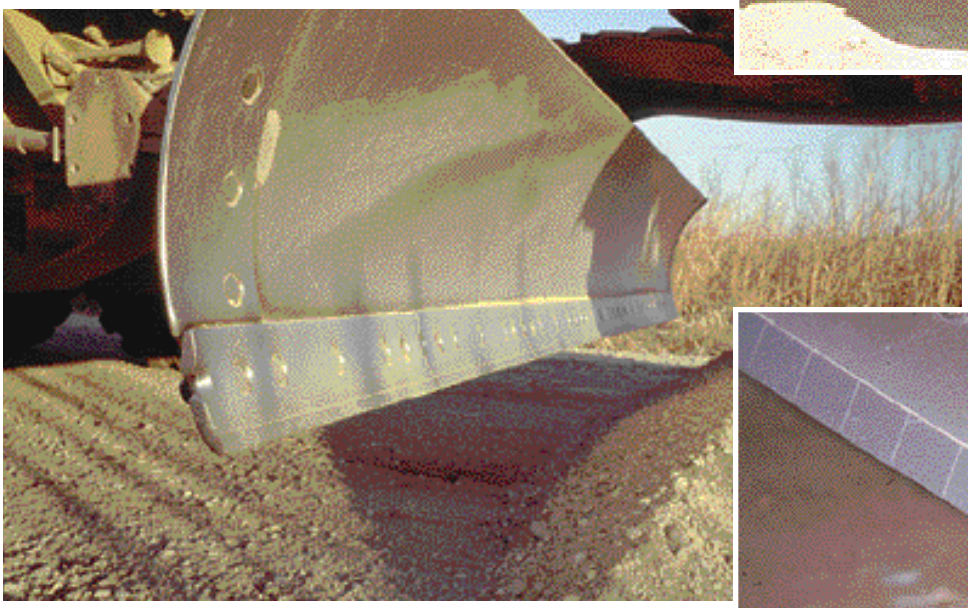
There have been several types of carbide-tipped bits adapted for use on the cutting edges of graders. For example, these will help an operator cut out a washboard area with less time and effort than a conventional cutting edge. They also do a better job of mixing material as it is cut from the road. They do not work for every situation in maintenance but do some special jobs very well.

Carbide-faced cutting edges are also available. Although expensive, they are extremely resistant to abrasive wear and are a great help in reducing center wear on the cutting edge.

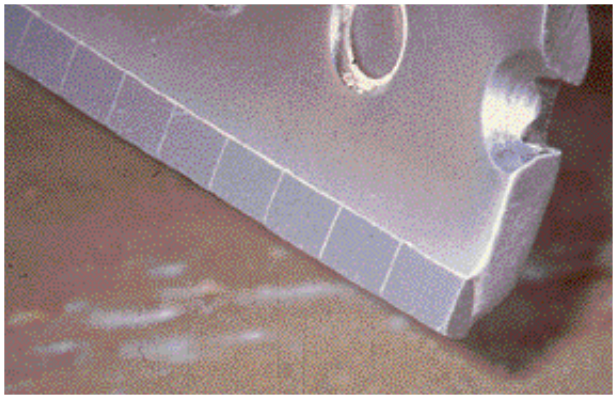




Examples of different types of replaceable bits for cutting edges.



An example of a carbide-faced blade after 650 hours of use. The center sections had been exchanged with the outer sections once during this time.



Shouldering Disks

Eliminating high shoulders that develop along the edge of gravel roads is always important. Special shouldering disks have been developed for use on motorgraders or tractors to make this job easier.



The use of a shouldering disk helps mulch up the sod and vegetation before it is pulled onto the roadway either to be removed or recycled on the road as reusable gravel.



Same machine mounted on a farm tractor to help break up material on shoulder.

Grader-mounted Dozer Blade

Modern motorgraders are often equipped with parallel lifts for front attachments. This is particularly common in northern regions for carrying snowplows. A grader becomes even more versatile if a dozer blade is attached for summer use. A bonus is the small amount of added weight that helps stabilize the machine for routine blading.



This dozer blade is also equipped with carbide bits which allows the operator to use it for particularly hard cutting such as taking out washboard areas on the road.The operator then uses the grader's moldboard with a conventional cutting edge to shape the area.



The dozer attachment allows this operator to push a load of rocks into a frost boil with the grader. Without this option, a loader would likely have to be brought to the job.

Grader-mounted Roller

In some rural regions of the country where more space is available for turning and maneuvering, a grader-mounted roller may be feasible. It is an efficient way to combine blading and compaction operations when budgets are tight and extra personnel are not available. When adequate moisture is present, the use of such a machine will definitely produce a tighter and smoother surface. These can be used in routine maintenance operations as well as in placing fresh gravel.



A grader-mounted roller being used on a rural gravel road.This department owns three of these units.

Rakes

The rake attachment is not new, but some methods of using it certainly are. Rakes are now available for pickup trucks and skid steer loaders. They work well for light maintenance — particularly in quarry-type gravels. They also work very well for lightly opening the surface to help dry out roads during the spring thaw when conventional equipment such as the grader are too heavy for the weak roads.



Other Tractor-mounted Blading Devices

Simple blades attached to tractors have been used for a long time. But recent changes improve the concept. The device illustrated below prevents the material from spilling from the sides of the blade and allows the operator to carry enough gravel along the way to fill small potholes and depressions. Skillful use of these will allow the performance of many types of light maintenance, especially in tight quarters.



A simple front-mounted rake attachment for a pickup truck.The vehicle can be used daily for other work such as sign maintenance, either while using the rake or after the rake has been removed.



A rear-mounted blading device on a farm tractor. The attachment can quickly be removed and the tractor can be used for other purposes such as mowing. These work well for tight quarters such as alley maintenance in towns.

Summary

The first and most basic thing to understand in road maintenance is proper shape of the cross section. The road surface must have enough crown to drain water to the shoulder, but not excessive crown, which makes the road hard to travel safely. Then, the shoulder area must not be higher than the edge of the traveled portion of the road.A high shoulder prevents water from draining to the ditch and therefore needs to be eliminated. Finally, a ditch must be established and maintained to drain water away from the roadside. Culverts and bridges at the right location and elevation are essential for carrying water under and away from the road.

Once the correct shape is established on a roadway and drainage matters are taken care of, attention must be given to obtaining and properly placing good gravel.It is very important to understand the makeup of good gravel. Simply stated, it is a proper blend of stone, sand and fine-sized particles. Materials vary greatly from region to region, but it is wise to use the best material available. Gravel must also be handled properly. Avoiding segregation while processing and handling material is important to maintain the quality of gravel.Calculating the volume of material and allowing for shrinkage from compaction is also needed to get the desired depth of surfacing on the road.

When proper shape is established and good surface gravel is placed, many gravel road maintenance problems simply go away and road users are provided the best service possible from gravel roads.

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Appendix A: Gravel Road Thickness Design Methods

Although this manual was developed with emphasis on the maintenance and operation of gravel roads, this Appendix is provided to discuss some aspects of design. Once the design is understood by a local official, estimating the amount of materials required to construct a section of road can be accomplished with ease, as can budgeting and prioritization. This section is provided to offer a taste, for those who are interested, of how thickness design is determined.

Theories of thickness design of unpaved roads can be rather complicated and cumbersome, but this guide has selected some simple and user-friendly approaches to illustrate how the thickness of a gravel mat can be determined.It is highly recommended that local governments seek the services of professional engineering consultants before a final decision is made concerning thickness.

Several factors are known to affect road surface performance during its life span.Some of these factors are: axle load, which is referred to as the 18-kip equivalent single axle load (ESAL); cover aggregate characteristics; surface/subsurface drainage; freeze/thaw; subgrade properties; resilient modulus; and moisture change, to name a few. The ESAL factor is considered vital to gravel road thickness design and must be calculated. Private automobiles and light weight trucks do not seem to have any influence in thickness determination. The American Association of State Highway and Transportation Officials (AASHTO) recommends the use of a maximum of 100,000 ESAL applications, while the practical minimum level (during a single performance period) is 10,000 ESAL (39).

The following two approaches will illustrate the proper procedure for the determination of gravel thickness. The first approach is based on theories and relies on charts and nomographs, while the second approach is based on design catalogs.

I. Design Chart Procedure

To completely understand this method of design it is imperative that the user be familiar with the following terms. Their values must be determined before the design procedure is pursued.

A. Predicted Future Traffic (W_{18})

Any pavement must be designed to accommodate accumulated traffic for several years into the future. Due to the presence of mixed traffic on the road, i.e. passenger cars, semi-trailers, busses, etc., accumulated traffic volume must be presented in terms of a standard Equivalent Single Axle Load (ESAL).AASHTO defines ESAL as 18,000 lbs.; it is denoted in the literature by the symbol (W_{18}). Conversion factors are available to express axle loads other than 18,000 lbs. in terms of ESAL and are presented in Appendix D of AASHTO Guide for Design of Pavement Structures. (39)

B. Roadbed Soil Resilient Modulus (M_R) in PSI

All material exhibits some deformation (strain) when subjected to loads per unit area (stress).As long as the stress is less than the strength,no failure is likely to occur. The relationship between the stress and strain can be expressed as resilient modulus (M_R). It is well known that most paving materials experience some permanent deformation after each load application. This might lead to rutting of asphalt pavements or cracking of concrete pavements. Therefore the value of resilient modulus of different materials and supporting soils is desired,as well as that of the pavement mixture itself. (40)

C. Length of Season

One of the factors that affects pavement performance is length of season. Figure 1 shows how the United States is divided into six different climatic regions and the environmental characteristics associated with each region. Based on these different climatic characteristics, Table 2 is used to determine the season lengths for measuring the effective roadbed soil resilient modulus. Table 3 is used to find the roadbed soil resilient modulus values for aggregate surfaced road (41).

D. Elastic Modulus of Aggregate Sub-Base Layer (E_{SB}) and Aggregate Base Layer (E_{BS}) in PSI

For materials subjected to significant permanent deformation under loads, elastic modulus is a fundamental property that must be considered. Resilient modulus defines the material's

stress-strain behavior under normal pavement loading conditions. Here the notation M_R is used only for roadbed resilient modulus while other notations such as (E_{BS}) and (E_{SB}) are used for modulus of base and sub-base respectively (40).

E. Design Serviceability Loss (ΔPSI)

Serviceability is the ability of a specific section of pavement to serve traffic in its existing conditions. The present serviceability index (PSI) is the primary measure of serviceability. PSI ranges from 0 to 5 where 0 means the existing road condition is impossible for driving, and 5 means the road is in perfect condition for driving. The lowest serviceability motorists can tolerate, before rehabilitation, resurfacing or reconstruction,is called terminal serviceability (P_t). Common values for terminal serviceability index are P_t=2.5 or higher when used for the design of major highways and P_t=2.0 when used for low volume roads. The minimum level of serviceability is mostly dependent on people's acceptance. There are some minimum levels of P_t, which are obtained from AASHTO road tests, and which are given below:

Terminal serviceability level (P_t)	3.0	2.5	2.0
Percent of people stating unacceptable	12%	55%	85%

For minor highways like aggregate surfaced roads where funds or economy is the main factor, the design is done by reducing the traffic or design life rather than reducing the terminal serviceability to a number lower than 2.00. In designing new roads the terminal serviceability is set up based on original or initial serviceability P_o. It is observed that the difference between P_t and P_o, (= DPSI) has a great influence in the design of aggregate surfaced road and therefore must be determined as part of the design.(39)

F. Allowable Rutting (RD) in Surface Layer

Rutting is bound to occur in aggregate surfaced road, and is considered as performance criteria. If the rut is too high, then it is very difficult to drive on the road surface due to the creation of channels along wheel paths. This rutting will ultimately lead the road into permanent deterioration. A certain amount of rutting, however, can be tolerated without causing any hazards. The designer should decide upon an allowable rut depth before applying the design procedures. The typical value of allowable rut depth for designing an aggregate surfaced road falls between 1.00 and 2.00 inches. (39)

G. Aggregate Loss of Surface Layer

It is inevitable that gravel roads will lose some of the surface aggregate due to several factors like the action of traffic loads, erosion, precipitation,etc.As a result,the load carrying capacity is reduced and the road becomes thinner;this leads to surface deterioration. This aggregate loss must be accounted for during the design of the aggregate surfaced roads. It is important to estimate the total thickness that will be lost during the design period and the minimum thickness of aggregate which will keep a maintainable working surface for the roads. (33)

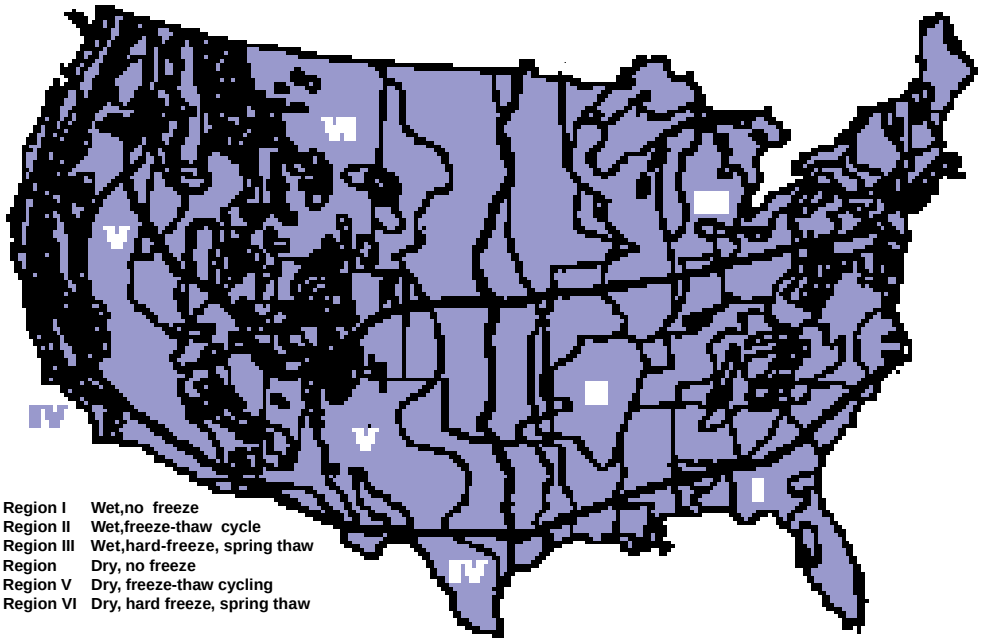


Figure 10: The Six Climatic Regions in the United States. (39)

Table 2: Suggested Seasons Length (Months) for Six U.S.Climatic Regions. (39)

	Season (Roadbed Soil Moisture Condition)			
U.S.CLIMATIC REGION	Winter (Roadbed Frozen)	Spring/Thaw (Roadbed Saturated)	Spring/Fall (Roadbed Wet)	Summer (Roadbed Dry)
I	0.0[1]	0.0	7.5	4.5
II	1.0	0.5	7.0	3.5
III	2.5	1.5	4.0	4.0
IV	0.0	0.0	4.0	8.0
V	1.0	0.5	3.0	7.5
VI	3.0	1.5	3.0	4.5

[1] Number of month for the season

Table 3: Suggested Seasonal Roadbed Soil Resilient Moduli, M_R (psi), as a Function of the Relative Quality of the Roadbed Material. (39)

	Season (Roadbed Soil Moisture Condition)			
RELATIVE QUALITY OF ROADBED MATERIAL	Winter (Roadbed Frozen)	Spring/Thaw (Roadbed Saturated)	Spring/Fall (Roadbed Wet)	Summer (Roadbed Dry)
Very Good	20,000[1]	2,500	8,000	20,000
Good	20,000	2,000	6,000	10,000
Fair	20,000	2,000	4,500	6,500
Poor	20,000	1,500	3,300	4,900
Very Poor	20,000	1,500	2,500	4,000

[1] Values shown are Resilient Modulus in psi

Steps in Thickness Design of Gravel Roads

According to the AASHTO design method, ten steps are followed to calculate the thickness of aggregate surfaced road. (39) The method is based on a trial-and-error approach. It assumes a thickness; then the expected damage due to serviceability and rutting criterion is calculated. The thickness that yields a damage of 100% is the one selected as the design thickness. Details of the procedure are listed below:

Step 1: Select trial base thickness. Normally four trial thicknesses are assumed (D_{BS}) although additional trials might be needed. These thicknesses are recorded in the upper left-hand corner of Table 4 (work sheet), which is used for this purpose. Several additional types of data are also recorded and used in subsequent calculations.

Step 2: Select an allowable serviceability loss (ΔPSI), and allowable rutting depth (RD). These values need to be selected and recorded on the top of each of the four or more trial Tables.

Step 3: Select seasonal resilient modulus for roadbed (M_R) and elastic modulus of aggregate base material (E_{BS}). Once the approximate seasonal roadbed resilient modulus (M_R), from Table 3, and aggregate base resilient modulus (E_{BS}) are selected,they should be placed in columns 2 and 3 of Table 4 respectively. These same numbers are used in each of the four or more trial sheets (Table 4).

Step 4: Determine projected 18-kip. ESAL traffic. Seasonal 18-kip ESAL traffic is entered in column 4 of Table 4. The length of the season, from Table 2, should be used to determine the proportion of the total projected traffic for each season.

Step 5: Determine allowable 18-kip EASL traffic for serviceability criteria. Within each of the four or more tables, estimate the allowable 18-kip ESAL traffic for each of the four seasons using the serviceability-based nomograph in Figure 11 and enter in column 5 of Table 4. For values falling outside the nomograph assume a practical value of 500,000 18-kip ESAL.

Step 6: Determine allowable 18-kip EASL traffic for rutting criteria. Within each of the four tables, estimate the allowable 18-kip ESAL traffic for each of the four seasons using the rutting-based nomograph in Figure 12 and enter in column 7. For values falling outside the nomograph assume a practical value of 500,000 18-kip ESAL.

Step 7: Determine seasonal damage (serviceability and rutting criteria). Columns 6 and 8 carry values of seasonal damage under serviceability and rutting criterion respectively. Seasonal damage for the serviceability criteria is computed by dividing the projected seasonal traffic (column 4) by the allowable traffic in that season (column 5). Enter this seasonal damage value in column 6 of Table 4. Follow the same instructions for rutting criteria,i.e., divide column 4 by column 7 and enter in column 8.

Step 8: Determine average base thickness ($\bar{D}_{BS}$). Compute the total damage for both the serviceability and rutting criteria by adding the seasonal damages. Once this is accomplished for all four or more tables (corresponding to the four or more trial base thicknesses), a graph of total damage versus base layer thickness should be drawn. The average base layer thickness, DBS, required is determined by interpolating in this graph for a total damage equal to 1.0. Figure 14 provides an example, which will be explained later. Two values of D_{BS} can be found, one for serviceability criteria and the other for rutting criteria. The design $\bar{D}_{BS}$ will be the greater of the two values.

Table 4: Chart for Computing Total Pavement Damage (for Both Serviceability and Rutting Criteria).Based on a Trial Aggregate Base Thickness.(39)

TRIAL BASE THICKNESS, D_{BS} = _____inches				Serviceability Criteria ΔPSI =		Rutting Criteria RD (Inches) =	
1 Season (Roadbed Moisture Condition)	**2** Roadbed Resilient Modulus M_R (psi)	**3** Base Elastic Modulus M_R (psi)	**4** Projected 18-kip ESAL Traffic, W_{18}	**5** Allowable 18-kip ESAL Traffic (W_{18})PSI	**6** Seasonal Damage, $W_{18}/(W_{18})$ PSI	**7** Allowable 18-kip ESAL Traffic, (W_{18})	RUT **8** Seasonal Damage, $W_{18}/(W_{18})$
Winter (Frozen)							
Spring/Thaw (Saturated)							
Spring/Fall (Wet)							
Summer (Dry)							
		Total Traffic =		**Total Damage =**		**Total Damage =**	

Step 9: Correct average base aggregate thickness due to aggregate loss. This step is important for aggregate surface road. In this step, aggregate loss is calculated and determination of actual base thickness is accomplished by using the following formula:

$$D_{BS} = \bar{D}_{BS} + 0.5\ GL$$

Where GL = The total aggregate loss in inches.
D_{BS} = Design Base Thickness in inches. Obtained in step 8 above.

Step 10: Convert base to equivalent sub-base thickness. This step helps to convert the aggregate base thickness to an equivalent thickness of sub-base. This step might be deemed necessary if base course material is very expensive compared to that used in the sub-base. This is done with help of Figure 4.

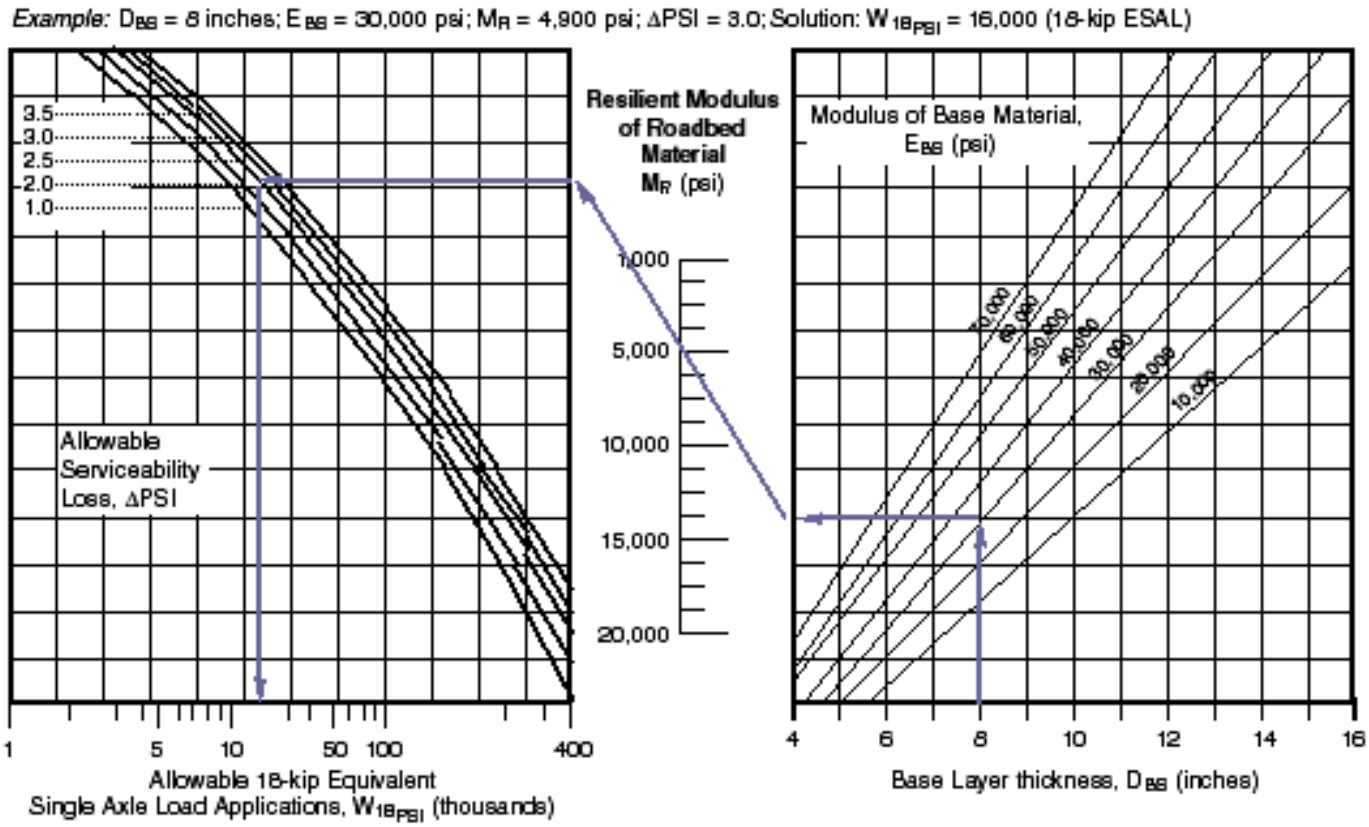


Figure 11: Design Chart for Aggregate-Surfaced Roads Considering Allowable Serviceability Loss. (39) From *AASHTO Guide for Design of Pavement Structures*. Copyright 1993, by the American Association of State Highway and Transportation Officials, Washington, D.C. Used by permission.

Example:
An aggregate surfaced road is to be designed using the following information:

18-kip ESAL repetitions (W_{18})	= 35,000
Gravel bed Resilient Modulus	= Good
Base Elastic Modulus (E_{BS})	= 25,000 psi
Sub base Elastic Modulus (E_{SB})	= 15,000 psi
Climatic region	= VI

Solution:

Step 1: Select trial base thickness. This method of thickness design is based on trial and error and therefore several thickness trials are needed. Each trial will result in an answer point that can be plotted with other points to form a curve of total damage versus aggregate base thickness. Although the more trials (and therefore the more points on the curve), the better the curve fitting and therefore the more accurate the design, about four trials will be considered adequate in most designs. In this example, five trial base thicknesses were needed to determine the best probable solution. For this, five separate tables identical to Table 4 are completely filled. The assumed trial thicknesses are 10, 11, 12, 13, and 14 inches.

Step 2: Select an allowable serviceability loss and allowable rutting depth. Assume ΔPSI = 2psi and allowable rut depth RD = 2.0 inches.

Step 3: Assume appropriate seasonal resilient moduli M_R and base elastic modulus E_{BS}. The approximate seasonal roadbed resilient modulus and aggregate base resilient modulus E_{BS} can be selected from Table 2 and Table 3.

Season	Winter	Spring/Thaw	Spring/Fall	Summer
M_R (psi)	20,000	2,000	6,000	10,000

Step 4: Determine projected 18-kip ESAL traffic. Total traffic = 35,000 (given). Using Table 1,W18 can be calculated for each season.

Item	Winter	Spring/Thaw	Spring/Fall	Summer
W_{18}	35,000 x (3/12) = 8,750	35,000 x (1.5/12) = 4,375	35,000 x (3/12) = 8,750	35,000 x (4.5/12) = 13,125

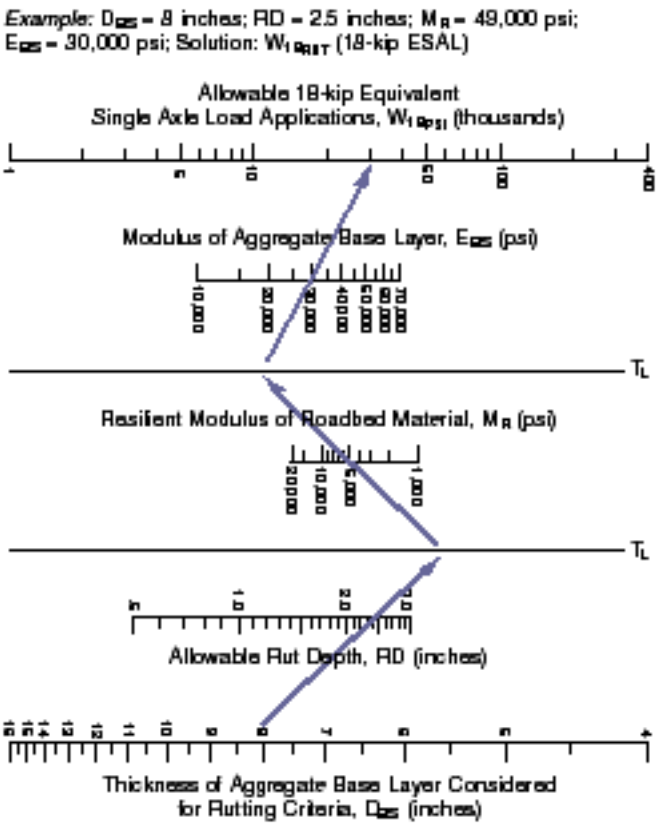


Figure 12: Design Chart for Aggregate-Surfaced Roads Considering Allowable Rutting. (39) From *AASHTO Guide for Design of Pavement Structures*. Copyright 1993, by the American Association of State Highway and Transportation Officials, Washington, D.C. Used by permission.

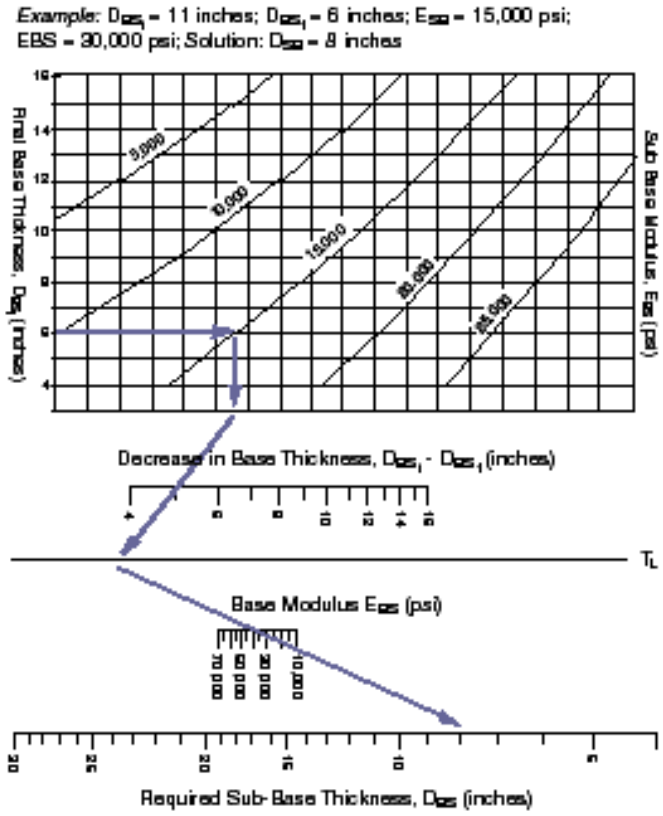


Figure 13: Chart to Convert a Portion of the Aggregate Base Layer Thickness to an Equivalent Thickness of Sub-base. (39) From *AASHTO Guide for Design of Pavement Structures*. Copyright 1993, by the American Association of State Highway and Transportation Officials, Washington, D.C. Used by permission.

Step 5: Determine allowable 18-kip EASL traffic for serviceability criteria. For each trial base thickness the allowable W_{18} ESAL can be calculated from the serviceability base nomograph of Figure 11. For example, the 11-inch trial thickness yields the following allowable W_{18} for the above stated criteria: W_{18} = 400,000 for Winter season, 10,000 for Spring/Thaw season, 32,000 for Spring/Fall season, and 90,000 for Summer season as shown in the table of the 2nd trial. These values are recorded in column 5 of Table 4.

Step 6: Determine allowable 18-kip EASL traffic for rutting criteria. For each trial base thickness the allowable W18 ESAL can be calculated from the rutting depth-base nomograph of Figure 12. From the nomograph, W_{18} = 80,000 for Winter season, 7,300 for Spring/Thaw season, 23,000 for Spring/Fall season, and 38,000 for Summer season as shown in the table of the 1st trial. These values are recorded in column 7 of Table 4.

Step 7: Determine seasonal damage (serviceability and rutting criteria). The seasonal values of damages are calculated for serviceability criteria by dividing the projected seasonal traffic (column 4) by allowable traffic in that season (column 5). The corresponding damage for the serviceability criteria is then calculated as (Damage) = 8,750/400,000 = 0.022 and recorded in column 6 as shown in the table of the 1st trial. The same procedure is applied for rutting criteria where the seasonal damages are calculated by dividing column 4 by column 7 and recorded in column 8 as: [Damage = 8,750/80,000 = 0.109].

Step 8: Determine average base thickness. Once the total damages for both serviceability and rutting criteria are completed for the four trial thicknesses, two curves are developed as shown in Figure 14. The first curve represents the relationship between serviceability failure and base thickness (D_{BS}) and the other curve represent rutting failure and base thickness. Average base thickness for each damage criteria is determined by interpolating the corresponding base thickness value for a total damage of 1.0. From Figure 5 these values are $\overline{D}_{BS}$ = 12.9 inches for rutting criteria and $\overline{D}_{BS}$ = 10.6 inches for serviceability criteria. In this example rutting governs, so the design base thickness should be 13 inches.

First Trial

TRIAL BASE THICKNESS, D_{BS} (inches) = **10.00**				Serviceability Criteria ΔPSI = **2.5**		Rutting Criteria RD (Inches) = **2.00**	
1 Season (Roadbed Moisture Condition)	**2** Roadbed Resilient Modulus M_R (psi)	**3** Base Elastic Modulus M_R (psi)	**4** Projected 18-kip ESAL Traffic, W_{18}	**5** Allowable 18-kip ESAL Traffic (W_{18}) PSI	**6** Seasonal Damage, $W_{18}/(W_{18})$ PSI	**7** Allowable 18-kip ESAL Traffic, (W_{18})	RUT **8** Seasonal Damage, $W_{18}/(W_{18})$
Winter (Frozen)	20,000	25,000	8,750	400,000	0.022	80,000	0.109
Spring/Thaw (Saturated)	2,000	25,000	4,375	18,500	0.643	5,800	0.754
Spring/Fall (Wet)	6,000	25,000	8,750	25,000	0.350	19,000	0.461
Summer (Dry)	10,000	25,000	13,125	67,000	0.196	31,500	0.417
		Total Traffic =	**35,000**	Total Damage =	**1.211**	Total Damage =	**1.741**

Second Trial

TRIAL BASE THICKNESS, D_{BS} (inches) = **11.00**				Serviceability Criteria ΔPSI = **2.5**		Rutting Criteria RD (Inches) = **2.00**	
1 Season (Roadbed Moisture Condition)	**2** Roadbed Resilient Modulus M_R (psi)	**3** Base Elastic Modulus M_R (psi)	**4** Projected 18-kip ESAL Traffic, W_{18}	**5** Allowable 18-kip ESAL Traffic (W_{18}) PSI	**6** Seasonal Damage, $W_{18}/(W_{18})$ PSI	**7** Allowable 18-kip ESAL Traffic, (W_{18})	RUT **8** Seasonal Damage, $W_{18}/(W_{18})$
Winter (Frozen)	20,000	25,000	8,750	400,000	0.022	80,000	0.109
Spring/Thaw (Saturated)	2,000	25,000	4,375	10,000	0.438	7,300	0.599
Spring/Fall (Wet)	6,000	25,000	8,750	32,000	0.273	23,000	0.380
Summer (Dry)	10,000	25,000	13,125	90,000	0.146	38,000	0.345
		Total Traffic =	**35,000**	Total Damage =	**0.879**	Total Damage =	**1.433**

Third Trial

TRIAL BASE THICKNESS, D_{BS} (inches) = **12.00**				Serviceability Criteria ΔPSI = **2.5**		Rutting Criteria RD (Inches) = **2.00**	
1 Season (Roadbed Moisture Condition)	**2** Roadbed Resilient Modulus M_R (psi)	**3** Base Elastic Modulus M_R (psi)	**4** Projected 18-kip ESAL Traffic, W_{18}	**5** Allowable 18-kip ESAL Traffic (W_{18}) PSI	**6** Seasonal Damage, $W_{18}/(W_{18})$ PSI	**7** Allowable 18-kip ESAL Traffic, (W_{18})	RUT **8** Seasonal Damage, $W_{18}/(W_{18})$
Winter (Frozen)	20,000	25,000	8,750	400,000	0.022	100,000	0.088
Spring/Thaw (Saturated)	2,000	25,000	4,375	14,000	0.313	8,500	0.515
Spring/Fall (Wet)	6,000	25,000	8,750	40,000	0.219	29,000	0.302
Summer (Dry)	10,000	25,000	13,125	110,000	0.119	48,000	0.273
		Total Traffic =	**35,000**	Total Damage =	**0.673**	Total Damage =	**1.178**

Fourth Trial

TRIAL BASE THICKNESS, D_{BS} (inches) = **13.00**				Serviceability Criteria ΔPSI = **2.5**		Rutting Criteria RD (Inches) = **2.00**	
1 Season (Roadbed Moisture Condition)	**2** Roadbed Resilient Modulus M_R (psi)	**3** Base Elastic Modulus M_R (psi)	**4** Projected 18-kip ESAL Traffic, W_{18}	**5** Allowable 18-kip ESAL Traffic (W_{18}) PSI	**6** Seasonal Damage, $W_{18}/(W_{18})$ PSI	**7** Allowable 18-kip ESAL Traffic, (W_{18})	RUT **8** Seasonal Damage, $W_{18}/(W_{18})$
Winter (Frozen)	20,000	25,000	8,750	400,000	0.022	140,000	0.063
Spring/Thaw (Saturated)	2,000	25,000	4,375	18,500	0.236	11,000	0.398
Spring/Fall (Wet)	6,000	25,000	8,750	54,000	0.162	32,000	0.273
Summer (Dry)	10,000	25,000	13,125	130,000	0.101	50,000	0.263
		Total Traffic =	**35,000**	Total Damage =	**0.521**	Total Damage =	**0.997**

Fifth Trial

TRIAL BASE THICKNESS, D_{BS} (inches) = **14.00**				Serviceability Criteria ΔPSI = **2.5**		Rutting Criteria RD (Inches) = **2.00**	
1 Season (Roadbed Moisture Condition)	**2** Roadbed Resilient Modulus M_R (psi)	**3** Base Elastic Modulus M_R (psi)	**4** Projected 18-kip ESAL Traffic, W_{18}	**5** Allowable 18-kip ESAL Traffic (W_{18}) PSI	**6** Seasonal Damage, $W_{18}/(W_{18})$ PSI	**7** Allowable 18-kip ESAL Traffic, (W_{18})	RUT **8** Seasonal Damage, $W_{18}/(W_{18})$
Winter (Frozen)	20,000	25,000	8,750	400,000	0.022	170,000	0.051
Spring/Thaw (Saturated)	2,000	25,000	4,375	22,000	0.199	12,000	0.365
Spring/Fall (Wet)	6,000	25,000	8,750	66,000	0.133	40,000	0.219
Summer (Dry)	10,000	25,000	13,125	170,000	0.077	68,000	0.193
		Total Traffic =	**35,000**	Total Damage =	**0.431**	Total Damage =	**0.828**

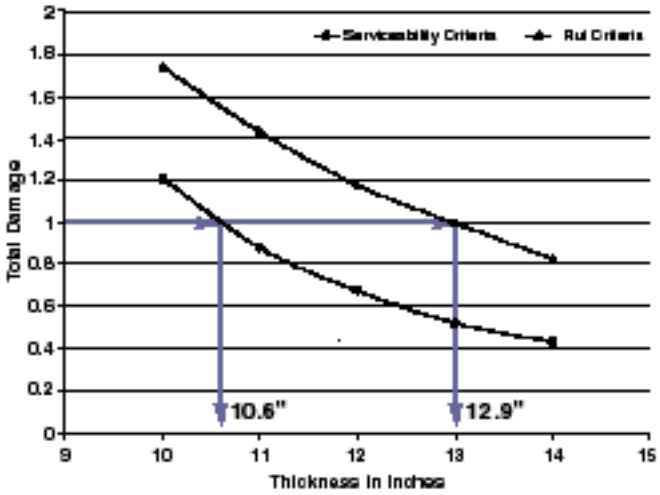


Figure 14: Total Damage versus Thickness for Serviceability and Rutting Criteria.

Step 9: Correction of average base aggregate thickness for aggregate loss. This step is important for aggregate surface road; in this step aggregate loss is calculated.Actual base thickness is then determined by using the following formula:

$D_{BS} = D_{BS} + 0.5$ GL;Where GL is allowable aggregate loss.
In this example, corrected thickness is:
$D_{BS} = 13.0 + 0.5 * 1 = 13.5$ inches

Step 10: Convert base to equivalent sub-base thickness. Occasionally the designer can place an inferior sub-base material under the good gravel layer. This will lead, most of the time, to savings in material cost. Therefore placing a sub-base can reduce the thickness of the more expensive gravel layer. To accomplish that,part of the good gravel layer can be converted to an equivalent thickness of sub-base layer. This is done with the help of Figure 13.Assuming that only 6 inches of good base material will be placed instead of the proposed 13.5 inches obtained by the complete analysis as shown in step 9 above. The reduction of base thickness = 13.5 - 6 = 7.5 inches. This 7.5 inches of good gravel base needs to be converted to an equivalent sub-base layer. This is accomplished by entering Figure 13 with 6 inches of good base thickness and moving up to the E_{SB} curve of 15,000, then turning right. Connect with the decrease in base thickness of 7.5 inches and extend to the T_L line. Connect the point on the T_L line with the E_{BS} of 25,000 and extend to the required sub-base thickness line. Therefore sub-base thickness = 11 inches. This approach yields a gravel thickness that consists of 6 inches of good base gravel and 11 inches of sub-base gravel.

If the quality of roadbed soil is not good enough,i.e. is of poor quality, then the roadbed resilient modulus will be smaller. Table 3 shows that if the quality of roadbed is lower, seasonal roadbed modulus will also be less. This will lead the road surface to accommodate less traffic. In that case the base thickness will be greater. So it is very clear that before designing aggregate surface roads, high quality roadbed soil should be given serious considerations.

II. Design Catalogs

When not enough detailed information is available, the design catalog approach is recommended to design aggregate surface roads. Table 5 presents a catalog of aggregate base layer thickness that may be used for the design of low-volume roads. The thicknesses shown are based on specific ranges of 18-kip ESAL applications at traffic levels (39):

Level	18-kip ESAL Traffic Load
High	60,000 - 100,000
Medium	30,000 - 60,000
Low	10,000 - 30,000

Table 5: Aggregate Surfaced Road Design Catalog: Recommended Aggregate Base Thickness (in Inches) For Six U.S. Regions, Five Relative Qualities of Roadbed Soil, and Three Traffic Levels. (39)

Relative Quality of Roadbed Soil	Traffic Level	U.S. Climatic Region					
		I	II	III	IV	V	VI
Very Good	High	8*	10	15	7	9	15
	Medium	6	8	11	5	7	11
	Low	4	4	6	4	4	6
Good	High	11	12	17	10	11	17
	Medium	8	9	12	7	9	12
	Low	4	5	7	4	5	7
Fair	High	13	14	17	12	13	17
	Medium	11	11	12	10	10	12
	Low	6	6	7	5	5	7
Poor	High	**	**	**	**	**	**
	Medium	**	**	**	15	15	**
	Low	9	10	9	8	8	9
Very Poor	High	**	**	**	**	**	**
	Medium	**	**	**	**	**	**
	Low	11	11	10	8	8	9

* Thickness of aggregate base required (in inches) ** Higher type pavement design recommended

The South Dakota Catalog Design Method

A similar approach to the above procedure is suggested for local and other agencies in the state of South Dakota to determine gravel layer thickness. The method is rather crude because it only relies on two parameters, heavy trucks and subgrade support condition. Table 6 represents suggested thicknesses. (3)

Table 6: Suggested Gravel Layer Thickness for New Or Reconstructed Rural Roads.

Estimated Daily Number of Heavy Trucks	Subgrade Support Condition[1]	Suggested Minimum Gravel Layer Thickness,mm (in.)
	Low	165 (6.5)
0 to 5	Medium	140 (5.5)
	High	115 (4.5)
	Low	215 (8.5)
5 to 10	Medium	180 (7.0)
	High	140 (5.5)
	Low	290 (11.5)
10 to 25	Medium	230 (9.0)
	High	180 (7.0)
	Low	370 (14.5)
25 to 50	Medium	290 (11.5)
	High	215 (8.5)

Notes: [1] Low Subgrade support: CBR ≤3 percent;
Medium Subgrade support: 3 < CBR ≤ 10 percent;
High Subgrade support: CBR >10 percent.



Appendix B: Gradation and P.I. Determination

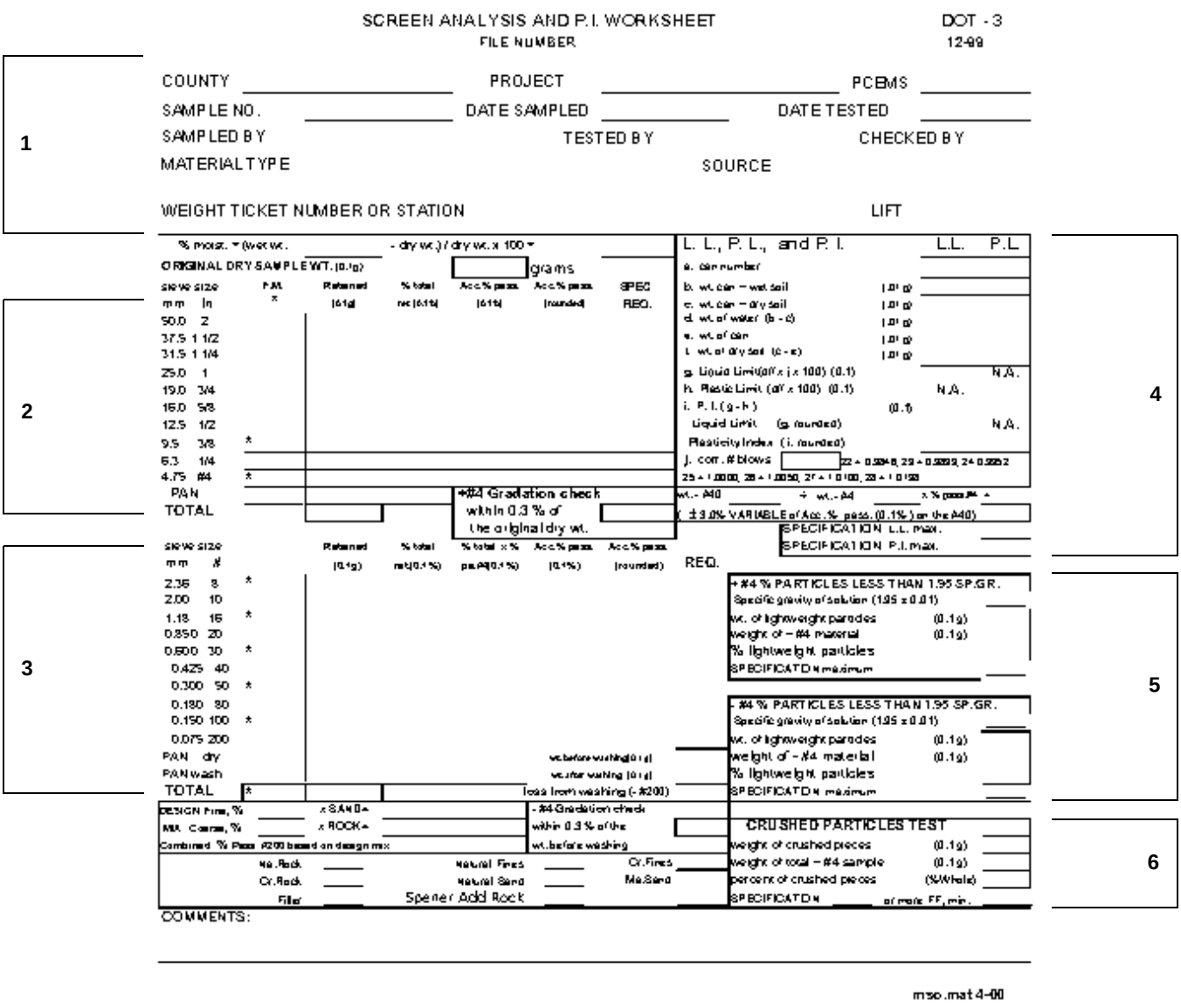


Figure 15: Standard Analysis Sheet from the South Dakota Department of Transportation (16)

Key to Screen Analysis and P.I. Worksheet

1. This is important data, especially for the sake of others who may use the information in the future. Proper data when submitting the sample for testing is critical. Too often, certain information is missing from the heading of the analysis worksheet.Always check to see that the information is correct.

2. This section, along with the next section, gives the breakdown of size (gradation) of the material. This alone tells a lot about material. Is it too coarse or fine, or is the blend of stone, sand, and fines wrong? Notice that the top section of gradation shows all material retained on the #4 sieve and larger. This is the stone-size category.

3. The bottom left section gives the gradation breakdown of sand sized particles on the appropriate sieves from #8 through #80 as well as the percentage of fines which will pass the #100 or 200 sieves.

4. This section is important in determining the stability or strength that the material will have when used as a base material and also the "binding characteristic"that material will have as surface gravel. The PI or plasticity index is of particular importance. Surface gravel needs a minimum index of 3 to assure a small percentage of true clays for binder. Good base gravel needs no plasticity and ideally should be clean and drainable to retain strength for supporting the pavement above it.

5. This section is not as important for base or surface materials, but is critical in determining the quality of material for making asphalt concrete since it shows the durability or "soundness" of aggregate. However, in some regions where aggregate is known to be poor, this test is good even for surface gravel.

6. This final section is very important when testing material for use in asphalt or base. However, it can be very useful even in testing base or surface gravel because it shows what percentage of the stone has at least one fractured face. When crushing pit-run type gravels, many of the small, natural stones will go through the crushing plant without being fractured. Gravel has more strength when there are more crushed particles since they will interlock better with the particles surrounding them. Natural stone with a rounded shape will tend to shift and move under loads more easily.

Appendix C: Quantity Calculations

Gravel Coverage Chart Showing Depth of Gravel in Inches**

Width of Road in Feet

Cubic Yards Per Mile	10	12	14	16	18	20	22	24
400	2.45	2.05	1.75	1.53	1.32	1.23	1.12	1.02
500	3.07	2.56	2.19	1.92	1.70	1.53	1.39	1.28
600	3.68	3.07	2.63	2.30	2.05	1.84	1.67	1.53
700	4.30	3.58	3.07	2.68	2.39	2.15	1.95	1.79
800	4.91	4.09	3.51	3.07	2.73	2.45	2.23	2.05
900	5.52	4.60	3.94	3.45	3.07	2.76	2.51	2.30
1000	6.14	5.12	4.39	3.84	3.41	3.07	2.79	2.56
1100	6.75	5.63	4.82	4.22	3.75	3.38	3.07	2.81
1200	7.36	6.14	5.26	4.60	4.09	3.68	3.35	3.07
1300	7.99	6.66	5.71	4.99	4.44	4.00	3.63	3.33
1400	8.61	7.17	6.15	5.38	4.78	4.30	3.91	3.59
1500	9.19	7.65	6.56	5.74	5.10	4.59	4.18	3.83
2000	12.29	10.24	8.79	7.68	6.83	6.14	5.59	5.12
2500	15.36	12.80	10.97	9.60	8.53	7.68	6.98	6.40
3000	18.37	15.31	13.12	11.48	10.21	9.19	8.35	7.65
3500	21.47	17.89	15.34	13.42	11.93	10.73	9.76	8.95
4000	24.41	20.34	17.44	15.26	13.56	12.21	11.10	10.20
4500	27.42	22.85	19.58	17.13	15.23	13.71	12.46	11.40
5000	30.72	25.60	21.95	19.20	17.07	15.36	13.97	12.80

**This chart shows gravel depth with no compaction. Ordinary compaction from traffic and rainfall will cause most gravels to shrink a minimum of 20 percent.

How to Use This chart

1. On the Coverage Chart, find the width of the road you will be graveling. Read down the column to the desired depth of gravel you wish to add. Then check the left hand column to determine how many cubic yards per mile you need.
2. Go to the Spreading Chart (next page). In the left hand column, find the number of cubic yards per mile that you need.At the top of the chart,find the capacity in cubic yards of the trucks you will be using. Then use the chart to find out how many feet each truck load will cover.

Gravel Spreading Chart in feet per truckload

Truck Capacity in Cubic Yards

Cubic Yards Per Mile	5	6	6.5	7	10	12
400	66.0	79.2	85.8	92.4	132.0	158.4
500	52.8	63.4	68.6	73.9	105.6	126.8
600	44.0	52.8	57.2	61.6	88	105.6
700	37.7	45.3	49.0	52.8	75.4	90.6
800	33.0	39.6	42.9	46.2	66	79.2
900	29.3	35.2	38.1	41.0	58.6	70.4
1000	26.4	31.7	34.3	36.9	52.8	63.4
1100	24.0	28.8	31.2	33.6	48.0	57.6
1200	22.0	26.4	28.6	30.8	44.0	52.8
1300	20.3	24.4	26.4	28.4	40.6	48.8
1400	18.9	22.6	24.6	26.4	37.8	45.2
1500	17.6	21.1	22.9	24.6	35.2	42.2
2000	13.2	15.8	17.2	18.5	26.4	31.6
2500	10.6	12.7	13.8	14.8	21.2	25.4
3000	8.8	10.6	11.4	12.3	17.6	21.2
3500	7.5	9.1	9.8	10.6	15	18.2
4000	6.6	7.9	8.6	9.2	13.2	15.8
4500	5.9	7.0	7.7	8.2	11.8	14.0
5000	5.3	6.3	6.9	7.4	10.6	12.6

(This chart originally provided to the SD LTAP by Scott Construction of Lake Delton, WI.)

Appendix D: When to Pave a Gravel* Road

by Kentucky Transportation Center, University of Kentucky at Lexington,KY

Contents

- A Word About the Term "Paved"
- Introduction
- Gravel or Paved: A Matter of Trade-offs
- When Should We Pave This Gravel Road? A Ten Part Answer
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  2. When the Local Agency Is Committed to Excellence
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  5. After Considering Safety and Design
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  7. After Determining the Costs of Road Preparation
  8. After Comparing Pavement Life and Maintenance Costs
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  10. After Weighing Public Opinion
- Stage Construction
- Summary
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*Gravel as used here may refer to sand and gravel,or to crushed stone.

A Word About the Term "Paved"

What is meant by a "paved" road? For some, a light chip seal coat is considered paving. For others, paving is four or more inches of bituminous asphalt or "hot mix." The primary purpose of a pavement is to protect the subgrade. As the loads get heavier, the pavement thickness must be increased.

Generally speaking, bituminous concrete (hot mix asphalt) has little real load-bearing capacity of its own until it reaches a thickness of two inches. In fact, the Asphalt Institute has a firm policy of recommending a minimum pavement thickness of 4 inches full depth asphalt or 3 inches asphaltic concrete plus a suitable granular base even for low volume roads. Their research shows that 4 inches of hot mix will carry about 10 times as much traffic as 2 inches of hot mix when constructed over thin granular bases.

A pavement less than two inches thick primarily protects the base materials by shedding water and providing a smooth riding surface. Such a road is more properly called a surface-treated road. Roads with thin pavements must have excellent drainage designed into them and be diligently maintained throughout their service life.

In this paper we will consider even a light surface treatment as paving,however. The assumption is that,when a town first applies a chip seal treatment,for example, it has taken a first step toward eventually achieving a load-bearing pavement.

Introduction

Two-thirds of the highway systems in the United States and more than 90 percent of all the roads in the world are unsurfaced or lightly surfaced low volume roads. In Kentucky, more than 19,000 miles of local roads have gravel surfaces.

Most local roads were not designed with the same considerations used in the design of state and interstate highways. Most have evolved from primitive trails. Paths of least resistance first created by wild animals were later used by settlers. As needs and traffic increased, these traveled ways became roads which were gradually improved with gravel or crushed rock. Little engineering went into these improvements. Using available materials and "keeping them out of the mud" were the extent of efforts to maintain a road.

As paving occurred, the tendency was to make minor modifications to the foundations of the evolved road and to seal or pave the surface. As a result,many low volume roads in Kentucky now have continual maintenance problems because of inadequate base support in addition to alignment and drainage problems.

To add to the problem, roads throughout Kentucky are experiencing ever-increasing weights and volumes of traffic. Population growth and tourism make traffic demands. Coal trucks and other commercial vehicles are carrying heavier loads than ever before. These higher volumes and greater weights are putting a steadily increasing strain on local road maintenance and reconstruction budgets.

Gravel or Paved: A Matter of Trade-Offs

The decision to pave is a matter of trade-offs. Paving helps to seal the surface from rainfall, and thus protects the base and subgrade material.It eliminates dust problems, has high user acceptance because of increased smoothness, and can accommodate many types of vehicles such as tractor-trailers that do not operate as effectively on unsurfaced roads.

In spite of the benefits of paved roads, well-maintained gravel roads are an effective alternative. In fact, some local agencies are reverting to gravel roads. Gravel roads have the advantage of lower construction and sometimes lower maintenance costs. They may be easier to maintain, requiring less equipment and possibly lower operator skill levels. Potholes can be patched more effectively. Gravel roads generate lower speeds than paved surfaces. Another advantage of the unpaved road is its forgiveness of external forces. For example, today vehicles with gross weights of 100,000 pounds or more operate on Kentucky's local roads. Such vehicles would damage a lightly paved road so as to require resealing, or even reconstruction. The damage on a gravel road would be much easier and less expensive to correct.

There is nothing wrong with a good gravel road. Properly maintained, a gravel road can serve general traffic adequately for many years.

Should We Pave This Gravel Road? A Ten Part Answer

When a local government considers paving a road,it is usually with a view toward reducing road maintenance costs and providing a smooth riding surface. But is paving always the right answer? After all, paving is expensive. How does a county or city know it is making the most cost-effective decision?

We will consider ten answers to the question,"Should we pave this gravel road?" In fact they are ten parts of one answer. If one of the ten is not considered, the final decision may not be complete. The ten answers taken together provide a framework for careful decision making.

Answer 1: After Developing a Road Management Program

If the road being considered for paving does not fit into a countywide road improvement program,it is quite possible that funds will not be used to the fullest advantage. The goal of a road management system is to improve all roads or streets by using good management practices. A particular road is only one of many in the road system.

A road management system is a common sense, step-by-step approach to scheduling and budgeting for road maintenance work. It consists of surveying the mileage and condition of all roads in the system,establishing short-term and long-term maintenance goals and prioritizing road projects according to budget constraints.

A road management system helps the agency develop its road budget and allows the use of dollars wisely because its priorities and needs are clearly defined.

Through roadway management, local governments can determine the most cost-effective, long-term treatments for their roads, control their road maintenance costs, and spend tax dollars more wisely. Local governments that stick with the program will be rewarded with roads that are easier and less costly to maintain on a yearly basis. Pertinent information about all roads will be readily available for years to come instead of scattered among files or tucked away in an employee's head.

Steps in a Road Management Program:

1. Inventory the roads. The amount of time available and the miles of road in a county or city will determine how much detail to go into.
2. Assess the condition of the roads. Develop simple and easy techniques to use each year. Maintain a continuing record of the assessed condition of each road so that changes in condition can be noted easily and quickly.
3. Select a road management plan. Select the most appropriate treatment to repair each road, bridge, or problem area.
4. Determine overall needs. Estimate the cost of each repair job using generalized average costs and tally up the total.Establish long-range goals and objectives that in turn will help the agency justify its budget requests.
5. Establish priorities. Keep good roads in good shape (preventive maintenance) and establish a separate budget, or request a temporary increase, to reconstruct really bad roads.

Answer 2: When the Local Agency Is Committed to Effective Management

A commitment to effective management is an attitude. It is a matter of making sure that taxpayers' money is well spent—as if it were one's own money. It does not mean paving streets with gold but it does mean using the best materials available. It does not mean taking short cuts resulting in a shoddy project but it does mean using correct construction techniques and quality control.A commitment to effective management means planning for 5 or even 10 years instead of putting a band-aid on today's problem. It means taking the time to do things right the first time and constructing projects to last.

Consider a child's tree house compared to a typical three-bedroom house in a Kentucky town. Because each protects people from the wind and rain each comes under the definition of a shelter. However, the tree house was built with available materials and little craftsmanship. The other was planned, has a foundation, sound walls and roof and, with care, can last hundreds of years. One is a shack and the other is a family dwelling. Only one was built with a commitment to excellence.

Many roads are like the tree house. They qualify under the definition but they are not built to last.

The horse and buggy days are over. We are in an age of travelers' demands, increasing traffic, declining revenues and taxpayer revolts. We are expected to do more with less. Building roads to last requires an attitude of excellence. Such an attitude helps to make better decisions, saves money in the long run, and results in a better overall road system.

Answer 3: When Traffic Demands It

The life of a road is affected by the number of vehicles and the weight of the vehicles using it.Generally speaking, the more vehicles using a road,the faster it will deteriorate.

The average daily traffic volumes (ADT) used to justify paving generally range from a low of 50 vehicles per day to 400 or 500.When traffic volumes reach this range, serious consideration should be given to some kind of paving.

Traffic volumes alone are merely guides. Types of traffic should also be considered. Different types of traffic (and drivers) make different demands on roads. Will the road be used primarily by standard passenger cars or will it be a connecting road with considerable truck traffic? Overloaded trucks are most damaging to paved roads.

The functional importance of the highway should also be considered.Generally speaking, if the road is a major road, it probably should be paved before residential or side roads are paved. On the other hand, a residential street may be economically sealed or paved while a road with heavy truck usage may best be surfaced with gravel and left unpaved until sufficient funds are available to place a thick load-bearing pavement on the road.

Answer 4: After Standards Have Been Adopted

Written standards in the areas of design,construction and maintenance define the level of service we hope to achieve. They are goals to aim for. Without written standards there is no common understanding about what a local government is striving for in road design, construction and maintenance. In deciding to pave a gravel road, is the local government confident it would be achieving the desired standards?

Design and construction standards do not have to be complex. It takes only a few pages to outline such things as right-of-way width, traveled way width, depth of base, drainage considerations (such as specifying minimum 18”culvert pipe),types of surfacing and the like.

Maintenance standards address the need for planned periodic maintenance. A good maintenance plan protects local roads, which for most counties represents many millions of dollars of investment. It also is an excellent aid when it comes time to create a budget.

Considerations include: How often shall new gravel be applied to a gravel road? (Some roads require it more than others do.) How many times per year are roads to be graded? How often and in what locations should calcium chloride or other road stabilizers be applied? What is our plan for checking road signs? (Because of legal liability, a missing sign can be very costly if not replaced.) What is our plan for ditching and shouldering?

Answer 5: After Considering Safety and Design

Paving a road tempts drivers to drive faster. As speed increases, the road must be straighter, wider, and as free as possible from obstructions for it to be safe. Paving low volume roads before correcting safety and design inadequacies encourages speeds which are unsafe, especially when the inadequacies “surprise” the driver. Because of the vast mileage of low volume roads, it is difficult to reduce speeds by enforcement.

Roads must be designed to provide safe travel for the expected volume at the design speed. To do this a number of physical features must be considered:

- Sight Distance
- Alignment and Curves
- Lane Width
- Design Speed
- Surface Friction
- Superelevation

It may be necessary to remove trees or other obstructions such as boulders from the road’s edge. Some engineers insist that no road should be paved that is less than 22 feet wide. If this standard is accepted, gravel roads must be widened before paving. Bridges may need widening. Considering these and other safety and design factors in the early stages of decision making can help to achieve the most economical road and one that will meet transportation needs. It makes no sense to pave a gravel road which is poorly designed and hazardous.

Answer 6: After the Base and Drainage Are Improved

"Build up the road base and improve drainage before paving." This cardinal rule cannot be stressed enough. If the foundation fails, the pavement fails. If water is not drained away from the road, the pavement fails. Paving a road with poor base or with inadequate drainage is a waste of money. It is far more important to ask,"Does this road need strengthening and drainage work?" than it is to ask,"Should we pave this gravel road?"

Soil is the foundation of the road and, as such, it is the most important part of the road structure. A basic knowledge of soil characteristics in the area is very helpful and can help avoid failures and unneeded expense. Soils vary throughout the country. For highway construction in general, the most important properties of a soil are its size grading, its plasticity, and its optimum moisture content.

There is a substantial difference in the type of crushed stone or gravel used for a gravel road-riding surface versus that used as a base under a pavement. The gravel road surface needs to have more fines plus some plasticity to bind it together, make it drain quicker and create a hard riding surface. Such material is an inferior base for pavement. If pavement is laid over such material, it traps water in the base. The high fines and the plasticity of the material make the wet base soft. The result is premature pavement failure.

Answer 7: After Determining the Costs of Road Preparation

The decision to pave a gravel road is ultimately an economic one. Policy makers want to know when it becomes economical to pave.

There are two categories of costs to consider:total road costs and maintenance costs.

Local government needs to determine what the costs are to prepare a road for paving. Road preparation costs are the costs of construction before paving actually takes place.

For example, if standards call for a traveling surface of 22 feet and shoulders of two feet for a paved road, the costs of new material must be calculated. Removing trees, brush or boulders, adding new culverts or other drainage improvements, straightening a dangerous curve, improving slopes and elevations, constructing new guardrails, upgrading signs and making other preparations – all must be estimated.

Costs will vary greatly from project to project depending on topography, types of soils, availability of good crushed stone or gravel, traffic demands and other factors. One important factor is the standards. That is one reason why we should carefully consider what is contained in the road policy (#4 above). For larger projects it may be desirable to hire an engineering consulting firm (another cost) to design the road and make cost estimations. For smaller projects construction costs can be fairly closely calculated by adding the estimated costs of materials, equipment and labor required to complete the job.

Answer 8: After Comparing Pavement Costs, Pavement Life and Maintenance Costs

A second financial consideration is to compare maintenance costs of a paved road to maintenance costs of a gravel road. To make a realistic comparison we must estimate the years of pavement life (how long the pavement will be of service before it requires treatment or overlay) and the actual cost of paving. It is at this point that we can begin to actually compare costs between the two types of roads.

Consider the following maintenance options:

A. For both paved and gravel roads, a local government must: maintain shoulders – keep ditches clean – clean culverts regularly – maintain roadsides (brush, grass, etc.) – replace signs and signposts.
B. PAVED roadways require: patching – resealing (chip, slurry, crack seal) and striping.
C. GRAVEL roadways require: regraveling – grading and stabilization of soils or dust control.

Since the maintenance options in "A" are common to both paved and gravel roads, they do not have to be considered when comparing maintenance costs. These costs for either type of road should be about the same. But the costs of the maintenance options in "B" and "C"are different and therefore should be compared.

Figure 16 shows costs for maintaining gravel roads over a six-year period in a hypothetical situation.If records of costs are not readily available, you may use a "best guess"allowing for annual inflation costs.

Three paving options are listed in Figure 17. Each includes estimated costs for paving and an estimated pavement life. You should obtain up-to-date cost estimates and expected pavement life figures for these and other paving options by talking to your state department of transportation,contractors, and neighboring towns and counties.

YEAR	1	2	3	4	5	6	TOTALS
GRADING							
Equipment	270	280	290	300	310	320	1,770
Labor	90	100	110	120	130	140	690
REGRAVEL							
Materials	–	–	4,000	–	–	–	4,000
Equipment	–	–	2,500	–	–	–	2,500
Labor	–	–	2,300	–	–	–	2,300
STABILIZATION/DUST CONTROL							
Materials	800	900	1,200	920	950	975	5,745
Equipment	30	35	70	40	50	60	285
Labor	100	110	150	125	140	150	775
Totals	1,290	1,425	10,620	1,505	1,580	1,645	$18,065

Figure 16: Gravel Road Maintenance Cost Per Mile

Let's consider the cost of a double surface treatment operation and the projected cost of maintaining it before anything major has to be done to the pavement (end of pavement life). We see in Figure 17 that the estimated cost to double surface treat one mile of road is $20,533. Estimated maintenance costs over a six-year period could be:

Patching	$1,800	Total maintenance	$4,300
Striping	$500	Construction	$20,533
Sealing	$2,000	Total cost over six years	$24,833
	$4,300		

When we compare this cost to the cost of maintaining an average mile of gravel road over the same period of six years ($18,065), we find a difference in dollar costs of $6,768.It is not cost beneficial to pave in this hypothetical example, even without considering the costs of road preparation (#7).

This is not a foolproof method, but it does give us a handle on relative maintenance costs in relation to paving costs and pavement life. The more accurate the information,the more accurate the comparisons will be. The same method can be used in helping to make the decision to turn paved roads back to gravel.

Option	Life	Cost Per Mile	Cost/Mile Per Year	Calculations	Maintenance Per Mile/Year
Chip Seal-Double Surface Treatment	6 yrs.	$20,533	$3,422	Based on price of $1.75 per sy; 20 ft. wide x 5,280 ft. = 105,600 sf 105,600 sf ÷ 9 = 11,733 sy 5 $1.75 = $20,533	?
Bituminous Concrete-Hot Mix	12 yrs.	$58,080	$4,840	Based on estimated price of $30 per ton; 1 sy of stone and hot mix/ cold mix 1" thick weighs about 110 lbs. Therefore 3" = 330 lbs. per sy. 11,733 sy (1 mile of pavement) 5 330 lbs. = 3,871,890 lbs. 3,871,890 lbs. = 1936T x $30 = $58,080	?
Cold Mix	8 yrs.	$48,390	$6,048	At $30 per ton, using same formula as hot mix, 2 1/2" of cold mix equals 1,613T x $30 = $48,390	?

*These costs must be determined before any conclusions can be reached regarding the most cost-effective pavement method. The thinner the pavement, the greater the maintenance cost. Traffic, weather conditions, proper preparation before paving and many other factors can affect maintenance costs. No Kentucky data exists upon which to base estimates of maintenance costs on low volume roads of these paving options; and, therefore, we offer no conclusion as to the "best" way to pave.

Figure 17: Paving Options (Costs and road life are estimates and may vary)

Answer 9: After Comparing User Costs

Not all road costs are reflected in a highway budget. There is a significant difference in the cost to the user between driving on a gravel surface and on a paved surface. User costs, therefore, are appropriate to consider in the pave/not pave decision. By including vehicle-operating costs with construction and maintenance costs, a more comprehensive total cost can be derived.

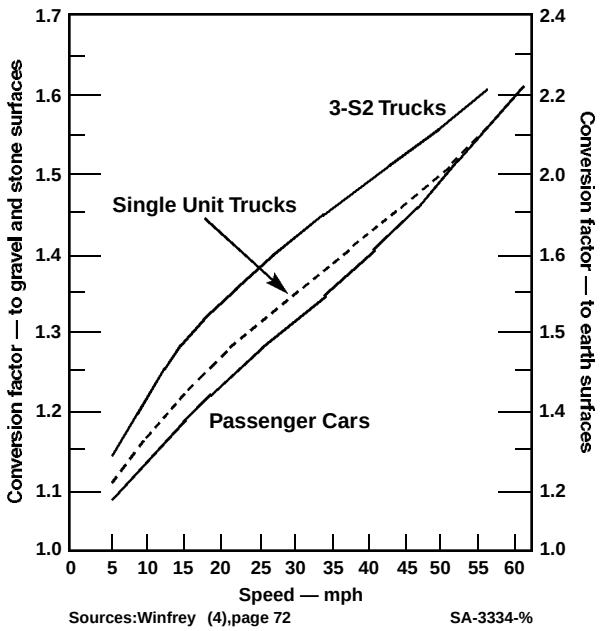
Vehicles cost more to operate on gravel surfaces than on paved surfaces, often 2 or 3 times greater than for bituminous concrete roads in the same locations. There is greater rolling resistance and less traction which increase fuel consumption. The roughness of the surface contributes to additional tire wear and influences maintenance and repair expenses. Dust causes extra engine wear, oil consumption and maintenance costs. Figure 18 from AASHTO'S "A Manual on User Benefit Analysis of Highway and Bus-Transit Improvements" shows the impacts of gravel surfaces on user costs. For example, an average running speed of 40 MPH on a gravel surface will increase the user costs of passenger cars by 40% (1.4 conversion factor). The general public is not aware that their costs would actually be less if some of these roads were surface treated.

Add to the gravel road maintenance the user costs over a six-year period. Estimate an average daily traffic (ADT) of 100 cars and 50 single unit trucks, traveling at 40 mph. Estimate that it costs $.25 per mile to operate the vehicles on pavement. Using the chart in Figure 3, we see it costs 1.4 times as much (or $.35) to drive a car 40 mph one mile on gravel road and 1.43 times as much (or $.36) to drive a single unit (straight frame) truck 40 mph one mile on gravel road.

100 cars x 365 days x $.10 added cost x 1 mile = $3,650

50 trucks x 365 days x $.11 added cost x 1 mile = $2,008

User costs for the gravel road is $5,659 per year or $33,954 for a six-year period.Assuming we still do not consider road preparation costs, it now appears justified to pave the road.Such an approach can be used to establish a "rule of thumb"ADT. For example, some agencies give serious consideration to paving roads with an ADT above 125.



To use this chart, determine the type of vehicle, the speed and the type of road surface. Follow the speed line vertically to the vehicle type. Go horizontally to multiplier factor of road surface. Multiply the cost of travelling on a paved surface by this number to determine the cost of operating the same vehicle on gravel surface or dirt surface. Example: If it costs 28¢ per mile to operate a passenger car* at 40 mph on pavement, it will cost 39¢ per mile to operate it on a gravel road at the same speed and 50¢ per mile on a dirt road.

*1984 Federal Highway Administration Statistics quotes an operating cost of 28¢ per mile for an intermediate size passenger car traveling on average suburban pavement. You must determine your own vehicle operating costs on pavement in order to use these multiplicative factors to calculate

Figure 18: Impacts of Gravel Surfaces on User Costs

Answer 10: After Weighing Public Opinion

Public opinion as to whether to pave a road can be revealing, but it should not be relied upon to the exclusion of any one of points 1-9 already discussed.If a decision to pave is not based on facts, it can be very costly. Public opinion should not be ignored, of course, but there is an obligation by government leaders to inform the public about other important factors before making the decision to pave.

Stage Construction

Local government may consider using "stage construction design"as an approach to improving roads. This is how it works. A design is prepared for the completed road,from base and drainage to completed paving. Rather than accomplishing all the work in one season, the construction is spread out over three to five years. Paving occurs only after the base and drainage have been proven over approximately one year. Crushed gravel treated with calcium chloride serves as the wearing course for the interim period. Once all weak spots have been repaired,the road can be shaped for paving.

There are some advantages to keeping a road open to traffic for one or more seasons before paving:

1. Weak spots that show up in the sub-grade or base can be corrected before the hard surface is applied,eliminating later expensive repair;
2. Risky late season paving is eliminated;
3. More mileage is improved sooner;
4. The cost of construction is spread over several years.

Note:Advantages may disappear if timely maintenance is not performed. Surface may deteriorate more rapidly because it is thinner than a designed pavement.

Summary

Some local roads are not well engineered. Today, larger volumes of heavy trucks and other vehicles are weakening them at a fast rate. Paving roads as a sole means of improving them without considering other factors is almost always a costly mistake. Counties and cities should consider these ten points first. Carefully considering them will help to assure local government officials that they are making the right decision about paving a gravel road.

Appendix E: Walk-around Grader Inspection

A Good Operator Takes Care of the Machinery

For maintenance and operator personnel safety, and maximum service life of the machine, make a thorough walk-around inspection when performing lubrication and maintenance work. Inspect under and around the machine for such items as loose or missing bolts, trash build-up, cut or gouged tires; damaged hydraulic lines or hoses; oil, fuel, or coolant leaks; and condition of blade.



The grease gun is a very important maintenance tool.



In addition to routine machine maintenance, it is very important to keep all warning devices clean and visible.

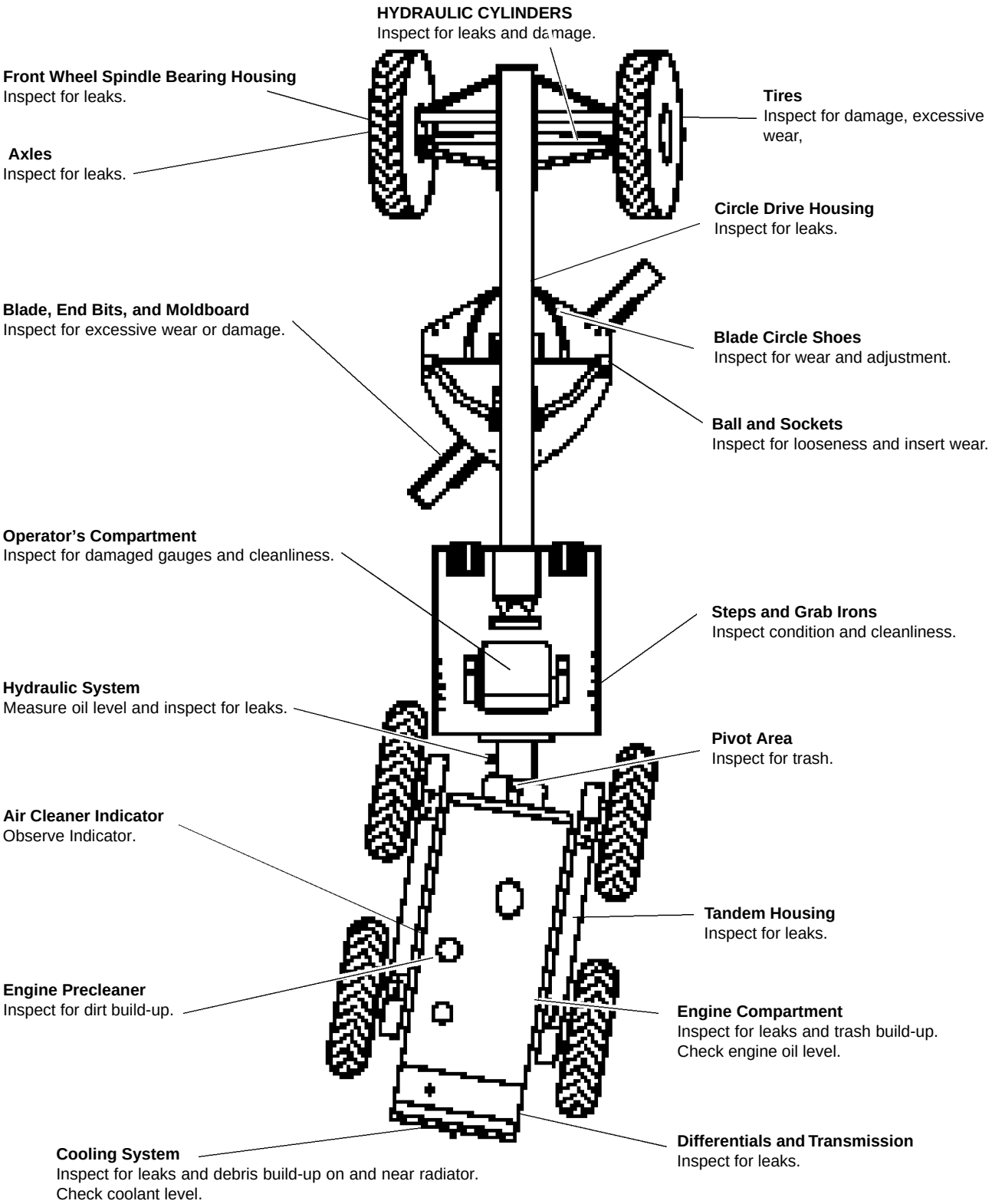


Figure 19: Walk-around Inspection Diagram (From *Maintaining Gravel Roads Training Manual*, 1999. Maine Department of Transportation, Federal Highway Administration.)

MOTOR GRADER PREVENTATIVE MAINTENANCE CHECK LIST

Vehicle #_____ Date _____ PM Location _____ # Hours _____

	OK	REPAIR	FOLLOW UP
150 HOUR SERVICE (90 DAYS)			
Change Engine Oil & Filter	_____	_____	_____
Check Air Filter Elements – replace if necessary	_____	_____	_____
Check Exhaust System	_____	_____	_____
Check Air Inlet System for Leaks	_____	_____	_____
Check Wiring for Chafing, Loose Connections, etc.	_____	_____	_____
Check Battery Electrolyte Level	_____	_____	_____
Check Front End	_____	_____	_____
Check and Tighten Wheel Studs	_____	_____	_____
Check Drive Axle Oil	_____	_____	_____
Check Oil Level in Tandem Drives	_____	_____	_____
Check Parking Brake Adjustment	_____	_____	_____
Check Oil Level in Circle Drive Gear Box	_____	_____	_____
300 HOUR SERVICE			
Change Fuel Filter	_____	_____	_____
Change Hydraulic Filter & Clean Magnets	_____	_____	_____
Change Transmission Filter	_____	_____	_____
Visually Inspect Engine Mounts	_____	_____	_____
Take Oil Sample	_____	_____	_____
Check and Adjust Brake Pedal Linkage	_____	_____	_____
Steam Clean Radiator	_____	_____	_____
1000 HOUR SERVICE			
Steam Clean Engine	_____	_____	_____
Check and Adjust Engine Speeds	_____	_____	_____
Check and Adjust Valve Clearance	_____	_____	_____
Clean and Repack Front Wheel Bearings	_____	_____	_____
Clean Hydraulic Tank Breather Filter	_____	_____	_____
Check Pivot Pins and Bushings	_____	_____	_____
Road Test Prior to Releasing to Using Agency	_____	_____	_____

Performed by_____

Figure 20: Motor Grader Preventative Maintenance Check List (From *Maintaining Gravel Roads Training Manual*, 1999. Maine Department of Transportation, Federal Highway Administration.)











