THE NEW U.S.A GRAVEL ROAD MANUAL

by

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ABSTRACT

In the Unites States alone there are over 1.6 million miles (2.6 million kilometers) of unpaved roads. Most of these miles are classified as gravel roads, which imply that the top surface layer is made out of gravel of certain thicknesses. In several nations around the globe the road network is predominantly gravel surfaced. This network makes up the farm-to-market roads and therefore it is very vital to any nation's economy. Because of the importance of gravel roads they must be properly maintained to insure their sustainable contribution to any nation's economy.

The maintenance of gravel roads varies widely from one nation to another, let alone within the same nation. Although the gravel road maintenance market has several manuals (1, 2, 3), none is comprehensive in nature and most are region specific.

This new manual is developed to address all aspects of gravel roads maintenance, rehabilitation, and design. A technical panel from various regions of the United States was assembled to contribute to the contents of the manual and reflect their experiences thus giving the manual a national flavor. Several international road agencies were also contacted to include the practices of other nations and therefore add an international touch to the manual.

The manual is written in a simple language so it can be understood by everyone involved in the road maintenance business from laymen operating simple equipments to the top managers who are faced with making crucial decisions. The manual contains over one hundred twenty five illustrations accompanied by captions to explain various maintenance practices. Several figures and tables are also part of the manual. The design section demonstrates the AASHTO method of determining the proper thickness of the gravel surface layer.

1. INTRODUCTION

Because of low traffic volume on several farm-to-market roads they tend to be surfaced with gravel instead of concrete or asphalt. The term aggregate is sometimes used instead of gravel; however, for the sake of explaining this type of unpaved roads the term gravel will be used consistently in this article.

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Good gravel road maintenance or rehabilitation depends on two principles: proper use of motor grader (or other grading device) and use of good surface gravel. The use of a grader to properly shape the road might be obvious to most people, but the quality and volume of gravel needed is not as well understood. Unfortunately, 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". This problem is often perceived as being caused by the grader but is primarily caused by the material itself. The developed manual provided a better understanding of what makes good surface gravel.

Another important matter that needs to be considered is the dramatic change in the vehicles and equipment using low volume roads. Trucks and agriculture equipment are increasing in size and horsepower. The trend is toward even larger machinery. The effect of larger and heavier vehicles on paved roads has been explained and documented through basic and applied research. 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 of the manual was included to address the design aspects of gravel thickness. The design section considers material properties of gravel and underlying layers as well as load applications.

The final section of the manual covers innovations in the maintenance/rehabilitation industry. Change is constant in almost every aspect of this dynamic world and maintaining gravel roads is no exception. There are new ways of stabilizing gravel roads, new methods of dust control, new and different kinds of equipment available for maintenance/rehabilitation, 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. Once the content of the new manual is well understood, an informed decision can be made about changing the way gravel roads has been maintained. Hopefully this will lead to providing a healthy and well-maintained network of gravel roads.

2. MAINTENANCE AND REHABILITATION

2.1 Cross Section

A typical surface of a gravel road consists of driving lanes and, occasionally, a shoulder. In order to properly maintain that road, the operator must understand three items: ***a crowned driving surface***, a ***shoulder*** that has a slope slightly steeper than that of the driving surface, and a ***ditch***. Unlike paved roads, the shoulder area and the ditch of many gravel roads may be minimal. This is particularly true in regions with very narrow right-of-ways. Other problems gravel roads encounter during the service life include rutting during wet weather, gravel displacement under traffic action, dusting, and ditch clogging to name a few. In order to maintain an acceptable cross section, the motor-grader operator must be skilled to correct the above problems, as they arise, with professional approach. The maintenance operator is also responsible for keeping the ditches clean to ensure flow

of water. Both standing water and subsurface water need to be removed as soon as possible as this will ultimately lead to distress and failure of the road.

2.2 Routine Shaping

One major difference between gravel roads and paved roads is that the latter will have a long lasting crown once it is properly constructed, but the former will lose its crown frequently and therefore needs constant reshaping. Because of the loose nature of the surface and the action of traffic and weather the shape of the surface is constantly changing. Corrugation, rutting, displacement of aggregate particles will ultimately lead to the distortion of the cross section. Unfortunately, most gravel roads will fail when exposed to heavy hauls even when shaped properly. This can be attributed to weak subgrade strength and marginal gravel depth. Once any or combination of the above problems occur, reshaping is inevitable and a well trained motor-grader operator should be able to restore the road to its original shape even if that means adding more aggregate. The success to routine shaping depends on the operator's familiarity with the following items:

Speed. Should be between 3-5 mph (5-8 kph). Higher speeds will cause loping, which results in deeper cuts and ridges leaving a wavy surface.

Moldboard Angle. As shown on Figure 1, this angle should be between 30 and 45 degrees. It is a challenge to recover loose aggregate from the shoulder of the roadway without spilling material around the leading edge (toe) of the moldboard. Improper angle will cause spilling.

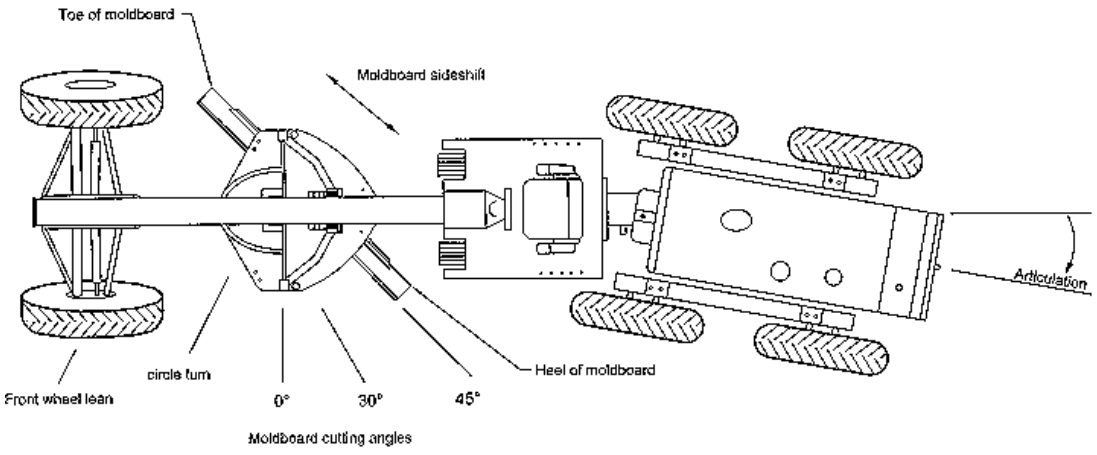


Figure 1: Components of a Modern Motor-Grader

Pitch. Along with the above correct angle it is important to provide the proper pitch or "tilt". If the moldboard is pitched back too far the material will tend to build up quick in front of the moldboard and will not fall forward and move along to the discharge end (heal) of the blade. This will also cause loss of material from the toe of the blade as well as reducing the mixing action that is needed when recovering material from the shoulder

and moving it across the roadways shown in Figure 2-a. Figure 2-b shows the right pitch for spreading material while Figure 2-c shows light blading.

(a) (b) (c)

Figure 2: Details of Moldboard Pitch or “tilt”

Motor-grader Stability. A motor-grader can face two problems relating to the machine’s stability: “loping” and “rocking”. The first term refers to the bouncing of the motor-grader as it travels. Lowering the speed can alleviate this problem. The second term refers to the motor-grader begins to rock from side to side, often called “duck walking”. This is usually caused by blade angle that closely matches the angle from corner to corner of the tires on the rear tandem. Changing the moldboard angle and slowly resuming blading can solve this problem. Experimenting with different tire pressure can also help stabilizing a machine as well as leaning the front wheels in the direction the material is being moved.

Articulation. Virtually all-modern motor-graders 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 regions, it is common to leave a small maintenance windrow (inventory windrow), which can be picked up later and worked back across the road for filling depressions and restoring the original shape. In regions with small right-of-ways, this practice might be forbidden. Check your local policies before allowing for maintenance windrows.

2.3 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 someone get too much? These are some questions often asked by local officials, traveling public, and equipment operators. First of all, without crown water will quickly collect on road surface during rain and will ultimately soften the crust. This will lead to rutting which can become severe if the Subgrade begins to soften. Potholes will eventually form and accelerate the deterioration process. The operator can also build too much crown into the road surface. This can lead to unsafe conditions in which motorists do not feel comfortable staying in their lane and even sliding towards the shoulder. There is additional risk driving on gravel roads with excessive crown in regions that experience snow and ice cover. In these regions motorists tends to drive right down the middle of the road regardless of how wide it is posing danger to the oncoming vehicles. The recommended crown is approximately ½ inch per foot (4%). The use of crown gauges is recommended. Another concern that the operator needs to be aware of is the cutting blade should remain straight. If the blade develops any curvature then a parabolic crown will result instead of the recommended straight crown. Keep the blade straight and sharp.

2.4 Shoulder

The function of shoulders in gravel roads is to provide lateral support to the main roadway, provide a recovery zone for motorists who leave the road surface for any reason, and to carry the surface water further away from the traveling surface to the side ditch. In order to perform these functions a shoulder must have certain shape. This shape should have a minimum, if the right-of-ways allow it, and slightly steeper slope than the main road's cross slope. If a shoulder is properly maintained the problem of shoulder drop-off should be eliminated. High shoulder can be a problem too. Excessive materials on the shoulder can lead to poor drainage and the creation of a secondary ditch near the travel way. Dealing with high shoulder can be easier if proper mowing is done in advance. In a survey of operators in the state of Iowa, USA, mowing the shoulder ranked as one of the top four primary functions needed to maintain a good gravel road. In snow bound regions mowing can add another benefit of preventing snow accumulation along the edges of the roadway thus reducing the cost of snow removal and improve safety.

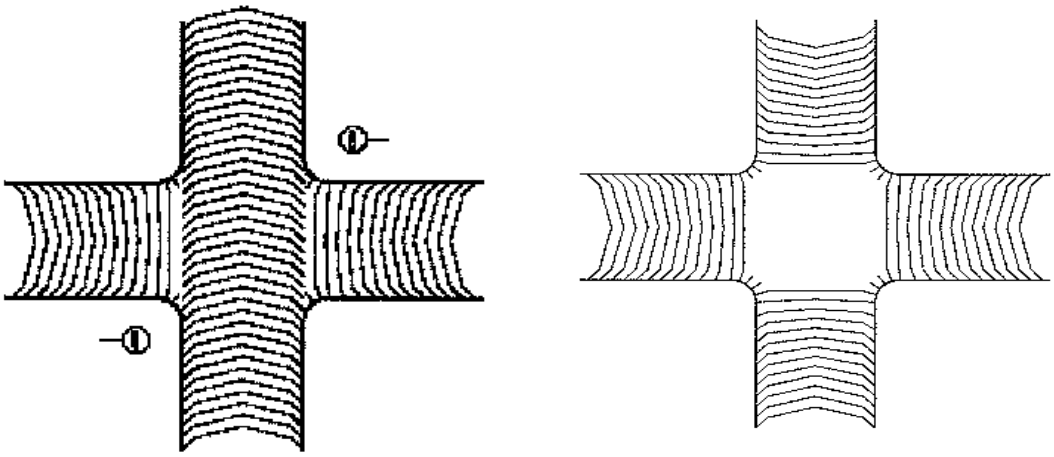
3. AREAS OF CONCERN

Corrugation: This problem, often called washboarding, can bring more complaints than any other. It is very annoying to motorists and when it becomes severe it can lead to loss of a vehicle's control. Figure 3 shows a typically corrugated gravel road. There are three primary causes: the driving habits of individuals, lack of moisture, and poor quality gravel. Driving habits are clearly evident when washboarding is present at intersections, going up or down steep hills, leading into or out of sharp curves, and sometimes even near driveways. In all these places motorists tend to accelerate hard or break aggressively. (1,2,3,4). Lack of moisture will accelerate washboarding and prolonged dry weather can aggregate the problem. This is because the crust that forms on the surface of good gravel road will tend to loosen allowing fines to be air born under traffic action which leaves stone and sand-sized particles to "float" and the material then can easily align itself into a washboarding pattern. The aforementioned causes are out of the control of the operator. The third primary cause – the quality of the gravel – is controlled by the agency's staff and therefore needs more attention. Good gravel must have the proper combination of stone, sand, and fines (Passing 200 sieve). The stone should be of the crushed type and the fines must have the binding characteristics, technically called plasticity. Materials must conform to specifications before it is used. With the best of maintenance, washboarding can never be eliminated. However, the key to reducing it is to obtain quality gravel with good binding property. Controlling speed can also reduce the potential for washboarding.

Figure 3: Corrugation or Washboarding

Intersections The two types intersections are either controlled or uncontrolled. At intersections controlled with a 2-way stop sign, the crown should be maintained along the

major road. Along the minor road, the crown should be gradually deleted (100-200 ft.) from the minor road so by the time the minor road reaches the edge of the major road the crown is no longer there. Figure 4-a shows the proper treatment of crowns at the intersection. In case of uncontrolled intersections, the crown should be gradually deleted so the intersection area is relatively flat. See Figure 4-b.



(a) (b)

Figure 4: Treating Crown at Intersections

Bridge Approaches Crowns must be treated in a similar fashion where they are gradually tapered from full crown to no crown at the edge of the approach slab.

Superelevation The principles of providing super-elevation (banking) are discussed in several textbooks. Providing super-elevation is very critical on gravel roads because of the nature of the relatively loose surface. The correct amount of super-elevation can be determined by engineering analysis. Commercial devices are also available to assist operators in providing the right amount of super-elevation.

Railroad Crossing Maintaining a road that intersects a rail crossing is very similar to bridge approaches or intersections with paved roads. Special attention is given to not leave any loose gravel along the flangeway. This can cause a derailment, particularly when it combines with packed snow in snow-bound regions.

Driveways Public roads should maintain their crown as they pass driveways. Too often gravel builds up on the public road by the driveways as stopping vehicles shove gravel forward towards the public road. This changes the shape of the public road and immediate reshaping must be done so the crown on the public road is restored and the crown on the driveway is tapered gradually to a flat section as it touches the edge of the public road.

Soft and Weak Subgrade Sometimes it is virtually impossible to remove surface/subsurface water from road surface particularly in flat terrain and wetlands. In this case the subgrade loses some of its bearing capacity resulting in several potholes and rutting problems. When that occurs, generally two potential solutions are available. One

is to completely remove the weak soil and replace it with good quality virgin gravel. The second is to use geotextile or geosynthetics. These products are often called “fabrics” and “grids”. This material is placed between the subgrade and the gravel layer to prevent the intrusion of the soft subgrade into the gravel layer.

4. DRAINAGE

It has been universally recognized that proper drainage is the most important element in paved or unpaved longevity. Therefore special attention must be paid to this element and ignoring it will ultimately spell disaster. Because gravel roads carry significantly lower traffic volume than other roads, it receives less maintenance funds. This leads to serious maintenance problems. Successful maintenance operation must address the following three topics;

Ditches Roadside ditch is considered the most important and common drainage structure. It is important to maintain a minimal ditch free of sediment and debris. An excavator and a truck might be what are needed to reshape the ditch, however a motor-grader can be the suitable machine to accomplish the same task.

Culverts and Bridges These structures are critical to 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 floating debris and eroded soil. It becomes part of road maintenance to inspect these structures at reasonable intervals and be cleaned so drainage is unobstructed.

Under-drains When a road is built over water bearing soils or over natural springs, which continually permit water to wick upward toward the surface, the road will inevitably perform poorly. Available options to correct this problem are stabilizing the road, using geotextile, or install under-drains. Flexible, perforated polyethylene pipes are commonly used for that purpose. The pipe is often plowed into the roadbed with a laser-leveling device to keep the machine on grade. A trench can also be excavated to grade, pipe placed and small stone or clean fine gravel placed around the pipe. The pipe is ultimately day-lighted close to the side ditch. It is important that the water from the pipe is drained toward the ditch to ensure the effectiveness of the treatment.

5. SURFACE GRAVEL

Good surface gravel is hard to define because it is region specific. Some regions do not have any gravel sources and therefore have to do with whatever is available. A few coastal regions use seashells for surface material on their unpaved roads. The discussion here, however, will be limited to regions that have acceptable source(s) of gravel. The three common sources are quarry aggregates such as limestone, granite, and quartzite; glacial deposits of stone, sand, and clay/silt; and river bottom gravels that generally are a mix of stone and sand. Too often surface gravel is taken from stockpiles that have been produced for other uses such as base course of paved roads or as fill material for use at

building sites. This gravel might serve the above two purposes but might not serve as a good surface gravel because the gravel lacks the proper ingredients to form a crust under traffic.

Gradation is also of great importance to good performance. Gravel is a mixture of three sizes of material: stone, sand, and fines. The stone provides the strength and load carrying ability, the sand serve in filling the voids and provides contact between particles and therefore contributes to the stability, and the fines provide the needed plasticity to bind the material together and allows the formation of crust on the surface. A good blend of these three sizes is very vital to the long-lasting performance of gravel roads. One common practice of improving surface gravel is to add new, clean, virgin gravel. The new gravel often contains larger amounts of fines to replenish what was lost due to dusting under traffic action.

Another factor that can enhance the performance of gravel roads is crushing. Quarry gravel is crushed material and is considered the best type to use. In the absence of crushed gravel, normally, natural gravel is used. This natural gravel is normally rounded in shape and lacks angularity and therefore can't produce a strong blend. It is a good practice to crush the rounded gravel to create the angularity that enhances the internal friction among gravel particles thus yielding a stronger mix.

Considering limitations of good gravel and budget constraints, some regions are using old, recycled asphalt pavement as a surface material on gravel roads. This can produce good surface, but there are pitfalls. The asphalt portion, under summer heat, will take the characteristics of a weak paved surface. It will often develop potholes and using simple blades for maintenance can become a problem. It is recommended to use a blend of 50/50 virgin gravel mixed with recycled asphalt.

It is also important to conduct a simple gradation test before the gravel is used on any job. Specifications and procedures are available in several national/international standards. Local agencies are encouraged to develop good specifications or use state specifications to guarantee good performance. The cost of running the test is very minimal compared to the total cost of the job and it can save several thousands of dollars.

6. DUST CONTROL/STABILIZATION

All gravel roads will give off dust under traffic. The amount of dust produced by a gravel road varies. Regions with a high rate of precipitation will produce less dust than those considered arid or semi-arid. Dust will inevitably cause complains by nearby residents and therefore local government officials are faced with this problem. The type of gravel also can affect the amount of dusting. Limestone will produce more dust than glacial gravel like quartzite or granite. Decisions regarding dust control can be difficult to make. The cost of dust control on very low volume roads can be prohibitive. On the other hand, if traffic is high, the cost can more than pay for itself with the benefit of reduced material

loss and reduced need for blade maintenance. The following types of stabilizers are commonly used:

Chlorides These are the most commonly used products. Calcium Chloride in flake or liquid form, Magnesium Chloride generally in liquid form, are the two products available on the market for dust control. These products are hygroscopic which, in simple terms, means they draw moisture from the air and keep the road surface constantly damp.

Resins The basic composition of this product is lignin sulfonate which is a by-product of the pulp milling industry. This product works best when incorporated into the surface gravel. They provide cohesion to bind the soil particles together.

Natural Clay When clay is added, in the right amount, to the surface aggregate it can provide strong cohesion.

Asphalts The use of cut-back liquid asphalts was once popular for dust control. Because of environmental reasons, this practice has been banned in many places. Emulsified asphalt has been used instead, but their use has been very limited.

Soybean Oil This by-product of the caustic refining process of soybean oil is a biodegradable material that has the same characteristics of light petroleum based oil. It will penetrate the gravel surface and provide a light bonding of the gravel.

Other Commercial Binders There are several of these products. It is wise to try a 1000 ft. section before treating the entire road(s). It is also wise not to use waste products such as crankcase drain oil from engines. They are not only harmful to the environment, but also in violation of environmental laws.

7. INNOVATIONS

There is a notion that gravel maintenance hasn't changed much since the grader and drag were invented. In reality dramatic changes have occurred in many ways. Although the amount of traffic on many gravel roads has declined due to the increase in farm and ranch sizes, but the size of equipment using gravel roads and the weight got much larger. This has forced a change in the way roads are maintained and some of the processes used. While trucks and equipments became heavier and larger, cars became more compact.

During harvest season, maintenance crews need to maintain gravel roads more often because of the increased rutting and other surface distresses like potholes and washboarding produced by heavy vehicles/loads. During maintenance operation these large vehicles can negotiate windrows formed on road surfaces. It is critical to consider these smaller cars when pulling large windrows of material out into the roadway during major reshaping. Large cars of mid 1970 models could pull through these windrows, but the same condition can easily send small cars, of recent models, out of control. Some of the recent development in equipment design is presented below:

Windrow Pulverizer To properly reshape a gravel road, it often involves pulling vegetation onto the roadway from the shoulder or cleaning a ditch. Sometimes the material has to be removed and loaders/excavators might be needed. The windrow can contain chunks of sod. Several pulverizers are available; some are homemade while others are marketed by commercial entities. Figure 5 shows a pulverizer that was made in the shop of a local county in South Dakota, USA.

New Cutting Edges There have been several types of carbide-tipped bits adapted for use on the cutting edges of graders. These edges will help the operator cut out a washboard area with less time and effort than a conventional cutting edge. Carbide-faced cutting edges are also available. Although expensive, they are extremely resistant to abrasive wear especially at the center of the cutting edge. Figure 6 shows a carbide-faced blade after 650 hours of service.

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 motor graders or tractors to make this job easier.

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

Figure 5: Locally Manufactured Pulverizer

Grader Mounted Roller In gravel roads with sufficient width, the use of a grader-mounted roller can be feasible because of the space availability for turning maneuvers. It is an effective way to combine blading and compaction operations when budgets are tight and extra personnel are not available.

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 gravel. 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.

Figure 6: Carbide Faced Cutting Edge.

Other Tractor-Mounted Blading Devices Simple blades attached to tractors have been used for long time. Recent changes improved the concept. The device shown in Figure 7 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.

Figure 7: A removable rear-mounted blading attachment on a tractor

8. DESIGN OF GRAVEL LAYER THICKNESS

The adequate thickness of a gravel layer depends on several factors such as Subgrade soil and aggregate (gravel) properties and characteristics, traffic load in terms of ESAL, weather conditions to name a few. Several methods are available to design the required thickness such as AASHTO (4), Forest Service etc. Appendix A of the manual demonstrates the use of the AASHTO method with examples.

9. SUMMARY

Several gravel maintenance manuals were developed by various entities, however none of these manuals were comprehensive in nature and most were region specific. The need for a comprehensive manual that addresses all maintenance, operation and design of gravel roads was lacking. A panel of professionals who are involved in the maintenance, operation and design of gravel roads subjected this manual to an extensive peer review.

The manual also contains several interesting features that can help the user. Five appendices are included at the end of the manual that covers the subjects of thickness design, gradation, quantity calculations, when to pave a road, and walk-around grader inspection.

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LIST OF FIGURES