

Gravel Runways Improving Operations

Typically 2½ to 5 cubic meters can be lost with each take off or landing.

A runway 75'x 3000' which loses 2" of gravel can require an expenditure of \$200,000 to \$300,000 for replacement materials. Performance on a gravel runway is degraded as fines and materials are lost, resulting in additional costs.

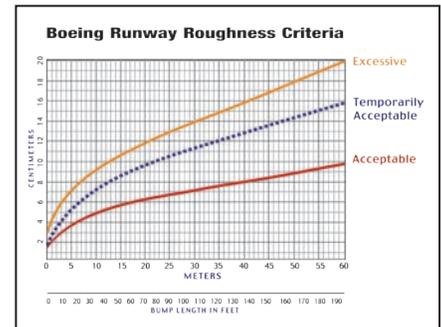
The primary airplane requirement for smoothness on a gravel runway is no different than it is for a hard surface runway. (See Boeing Runway Roughness Criteria - located right) An ordinary automobile at 60mph will have a smooth ride on a satisfactory runway. If the runway feels excessively rough in the auto, it is in need of smoothing. This is a simple test to determine if maintenance work is needed. Smoothness maintenance is required infrequently on a paved runway, but it is a continuous task on a gravel runway. Fortunately, it is easy to accomplish by grading to restore smoothness. After grading, the surface should be rolled to compact the disturbed material and drive loose stones into the surface to reduce rolling drag and the potential for flying gravel and airplane damage.

There are two principle factors creating the need for periodic surface smoothness.

- 1.) Permanent surface deformation under the airplane wheel loads and random loss of surface from engine jet blast. All gravel runways are not alike but for estimating purpose each 737 take off on a gravel runway blows off about 2 cubic meters of fines that is dust. In the long term this lost material must be replaced. The loss of material is not uniform and this results in an uneven surface and eventual roughness. The stones are not blown off, so the surface tends toward a condition of deep loose gravel. These areas of loose gravel increase the take off distance and the wear and tear on the airplane and must be recombined with fine material which will compact and better withstand the wheel loads and jet blast. The added material, with grading and compaction, automatically corrects the surface irregularities due to soil deformation.

This cycle is very expensive.

- 2.) The surface strength must be routinely monitored during all weather conditions to assure the strength is up to requirements. (See Boeing Unpaved Runway Hardness Requirements - located right)



Untreated runways lose material each year requiring hundreds of thousands of dollars to replace.



Airplanes operating on gravel runways will leave a visible wheel track due to the local compaction of any loose surface material but they will not produce a measurable rut. If a measurable rut is observed, it is an indication of inadequate surface strength. The affected area must be reconstituted with suitable material and compacted to the required hardness. The maintenance crew must keep in mind the following: if the CBR (California Bearing Ratio) is too low the airplane rolling drag will be increased making it more difficult to accelerate the airplane to flying speed in the runway distance available. The minimum surface CBR requirement is a mandatory safety item.

Midwest's evaluation of a potential runway for application of EnviroKleen® or EK35® includes an analysis of the runway materials for sizing analysis, material type and other requirements. We develop an application program with an initial application and maintenance applications designed with life cycle of the runway given primary consideration. The initial application has to deal with the differences in rate to be applied at the acceleration point and the rotation area, which may be exposed to jet blast of 300 to 400 mph. The maintenance program has to be devised with a frequency and a timing that takes all of the pulverization materials that are created by wheel friction and stabilizing them into the surface, preventing them from being lost as dust. The "dust control" program is in reality a Fines Preservation™ strategy. We also have to determine the appropriate depth penetration so that we have enough penetration given the ongoing grading done, and allowing for the grading operator digging in deeper than our penetration. We also project the increase in CBR value that is going to be achieved. The ongoing "usage plan" or "life of runway plan" needs to be detailed. Midwest evaluates the current equipment and makes recommendations for modifications to spray EnviroKleen or EK35.

Improved "life of runway" operating performance, reduced maintenance expense, and value added results to be realized with EnviroKleen and EK35 usage.

Fines Preservation, stabilization, dust control

- Take off and landing - preserve fines with resulting elimination of "dust"
- Taxiing - preserve fines with resulting elimination of "dust"
- Minimize aggregate segregation
- Eliminate watering and water usage
- Reduce material loss and cycle of aggregate replacement and grading & compaction work
- Reduce grading frequency
- Compaction recommended as performance improves over time with compaction
- Reduce other maintenance
- Minimize dust/aggregate related aircraft damage
- Reduce aircraft maintenance
- Eliminate nearby community dust intrusion



Runway Surface Related

- Increase CBR
- Reduce rolling resistance
- Improve braking
- Improved runway smoothness
- Minimize rutting
- Improve rated performance of runway
- Improve surface drainage and frost protection



The Midwest Samitron® testing device.

Midwest Runway Dust Control Stabilization Program utilizing EnviroKleen and EK35 includes the following: Analysis and data gathering of site-specific characteristics, which include:

- 1.) Definition of existing conditions: water and equipment used, man hours required, days and hours of operations, volume of water sprayed annually, grading frequency and expense, volume aggregate necessary to be added over time to the existing runway, other maintenance issues and recommended compaction to improve and extend runway life.
- 2.) Grand operation objectives: dust elimination, aircraft performance, runway maintenance improvements, and requirements based on aircraft type, speeds, loads, terrain, weather and existing conditions.

As part of this data gathering process, Samitron® (Stiffness and Modulus Instrument) testing of the runways is performed to determine the current specific strength characteristics of the runways. This information will be compared to the strength requirements for aircraft performance. A conclusion will be drawn as to the improved parameters required of the runway by the Runway Dust Control Stabilization Program in order to achieve objectives.

NOTE: Boeing has approved EnviroKleen and EK35 as being non-corrosive to aircraftparts provided that application rates and curing techniques as specified by Midwest are followed.

Material samples are sent to Midwest's engineering and testing laboratories. At Midwest, a runway analysis of the materials will be made including sieve analysis, soil characterizations, moisture content, etc. The Boeing approved products will be used in testing for optimized performance in the specific application and a recommendation made. This recommendation will incorporate the improvements to be realized, such as increased CBR value, density, and other features necessary to produce optimum runway surface, rolling resistance, shear modulus, stiffness and result in optimum dust control. When EnviroKleen or EK35 is recommended, an application design will be made which will include product volume and frequencies and other specifics as existing runway maintenance program changes are anticipated.

During installation of the EnviroKleen or EK35 according to the application design provided by Midwest, Samitron testing is performed to confirm that the installation technique is achieving the desired result.

Upon completion and after an appropriate aging, final Samitron testing as quality assurance is performed which will verify that the desired results have been achieved.

During the runway life cycle Dust Control Stabilization Program, Midwest technical personnel or Runway Operations monitor the conditions of the runway using Samitron techniques. This data provides direction in maintenance applications to maintain the runway stability and operating characteristics as well as to anticipate maintenance volumes that are needed for optimum runway performance. Deterioration in the monitored characteristics of a runway signal the potential for high levels of dust or conversely, dust will signal a deterioration in the engineering conditions. The Runway Dust Control Stabilization Program is pro-active and is designed to preserve and optimize the ground inventory of EnviroKleen or EK35 given actual variable site conditions.

Soils are categorized into groups for their frost susceptibility. Generally, coarse grained soils such as gravel and sands have low frost susceptibility, where as, fined grained soils such as silts have high frost susceptibility. Detrimental effects of frost action may be manifested by non-uniform heave and loss of soil strength during frost melting. Other effects include loss of compaction, development of roughness, restriction of drainage, and deterioration of surface. Three conditions must be met for detrimental frost action to occur. The soil must be frost susceptible, freezing temperatures must penetrate the frost susceptible soil and there must be sufficient free moisture to form ice.

The deflection of the surface of a gravel runway under an applied load depends on the strength of the surface and the strength of the underlying layers. The strength of the gravel surface depends on the interlock of the aggregates, particle friction and cohesion. The surface strength also depends on the properties of the surface materials under the influence of moisture. This results in the surfaces of gravel runways being susceptible to shear failures, particularly in wet conditions.

The most common cause of operational problems on gravel runways is the failure of the surface layers due to shear caused by high aircraft tire loading. Surface shear strength can be estimated by measuring the force required to deflect or penetrate the surface to a specified depth. This force, divided by the area over which it is applied, can be taken as the soil failure pressure. This pressure can be obtained from Samitron, flat plate or penetrometer type measurement devices and is often correlated to CBR.

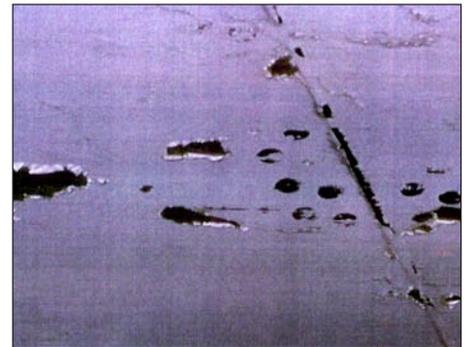
Using Midwest's Samitron, Young's modulus, shear modulus, CBR, and rolling resistance values are derived from in-situ soil stiffness values. These values are obtained using the Samitron's ability to measure the stress imparted to the surface and the resulting surface velocity as a function of time.



A principle component of the dust control and stabilization objective is an increase in CBR. The increase in CBR will provide aircraft with safer operation by reducing gravel spray, rolling resistance, and take-off and landing distances. The improved CBR will also reduce maintenance requirements of the runway. Transport Canada, Airports and Construction; report AK-67-09-280 provides general guidelines for estimating the maximum allowable tire pressure for gravel runways. Multiplying the maximum tire pressure by a safety factor of 2 and using that value as soil failure pressure is used to estimate the CBR required for a given maximum tire pressure.

Another useful parameter is correlation of rolling resistance to maximum tire pressure and CBR. On weaker runway surfaces, the rolling coefficient of friction has an adverse effect on aircraft rolling resistance. Excessive tire pressures may cause shear failures of the surface and deflections in the form of rutting. This action extracts energy from the wheel motion and causes an increased rolling coefficient of friction. The result is reduced aircraft acceleration at take off and increased stop distances. Using the Samitron technology and algorithms constructed from testing conducted by the U.S. Corps of Engineers rolling resistance values can be measured, optimized, and monitored for given aircraft and tire pressures.

Gravel runway surfaces are typically nonhomogenous in composition and may contain various types of soils. The standard method of classifying soils for engineering purposes is ASTM D2487, commonly called the Unified System. One of the purposes of soil classification is to predict the probable behavior of soils under the influence of frost and moisture. Soil classification systems could also be useful for the identification and definition of the gravel runway surface for certification and operational use. CBR values for well graded gravel soils range from 60 to 80 and for well graded sands 20 to 40. The potential for frost actions of these soils is minimal with almost no compressibility and expansion and the drainage characteristics are generally excellent. The presence of clay soils can result in a marked reduction of the strength values and frost properties of these soils.



FOD damage to engine blades (below) and wings (above) can be dangerously severe.



Indications and effects of gravel runway failures are as follows: the definition of runway failure, although somewhat arbitrary is typically identified by the formation of ruts, increased roughness in the surface or permanent deformation. These indications of gravel runway failures are discussed next.

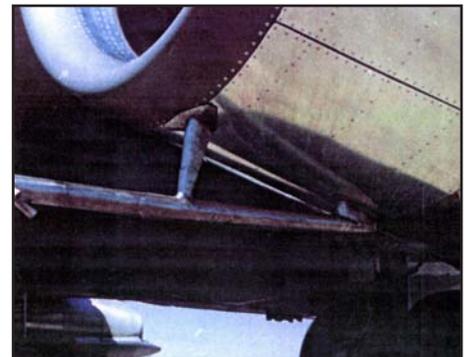
- a) Loss of material — Indications of surface material loss are bare spots, base or subbase or subgrade material appearing on the surface and a build up of granular material at the edge of the runway. The primary causes are loss of material during snow removal, tire action or infiltration of lower layer material to the surface layer. This condition results in a reduction of the surface strength of the runway and reduced braking action as a result of the loss of the coarse material. Pre EnviroKleen or EK35 this condition can be corrected by adding new material and compacting.
- b) Segregation — Segregation is accumulation of loose noncohesive aggregates on the surface. Causes are the loss of finer materials due to the jet propeller blast, tire action and weathering. Adverse performance effects and increased landing gear loads from the accumulation of loose materials may occur. The potential for damage to the aircraft from debris is increased. This condition is corrected by regrading and adding new material.
- c) Rutting — Rutting is defined as longitudinal deformation in the wheel path. Rutting without shoving of adjacent material is an indication of failure in deeper layers of the pavement due to inadequate foundation strength. Rutting with shoving indicates a shear failure in the surface layer due to poor cohesion (that is low surface shear strength). Poor cohesion may be the result of high moisture content, poor gradation, segregation or poor compaction. Rutting may cause reduced acceleration and braking performance, directional control problems and landing gear loads. Rutting is corrected by regrading and compaction of the runway surface.

Operational problems which may be encountered during runway operations include medium sized propeller and jet aircraft occasionally getting stuck during spring or after rainy periods because of inadequate surface hardness. Poor drainage was noted as a cause of rutting during wet conditions and severe roughness occurs after the surface dries. Operators report problems with fine materials damaging propellers and engines. Ride quality is important in a runway and the ride quality can be evaluated by driving a pickup truck at automobile highway speeds to check the smoothness of the runway for suitability for aircraft. Jet exhaust from a typical Boeing 737 takeoff can result in the loss of up to 2 cubic yards of material. The material may blow off unevenly causing the formation of bare spots and hollows. This can become the mechanism for the start of longer term damage to the runway. This problem can be corrected by regularly grading, the addition of new material and compacting.

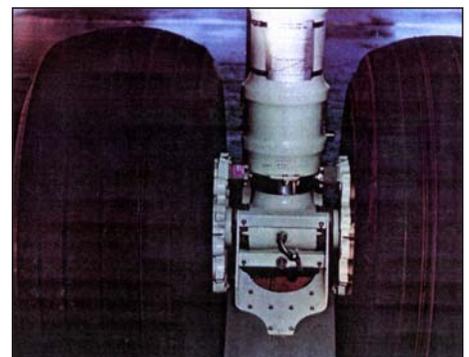
Protection of aircraft — operations on gravel runway surfaces require protecting the aircraft from the effects of flying dust, debris and stones. Protection systems are typically characterized as “gravel runway kits” and are comprehensive modifications to minimize the adverse effects of gravel runway operations.



- a) Reduction of gravel spray from the landing gear — the debris spray in wake of rolling wheels may be reduced by the installation of gravel deflectors and other methods.
- b) Protection of aircraft surfaces — aircraft surfaces that need to be protected include belly surfaces, inboard flap panels, cables and pipes routed on the landing gear, external lights and antennas.
- c) Protection of engines — Jet and propeller driven aircraft have unique protection requirements for operation on gravel surfaces. Both types of propulsion must avoid the ingestion of debris, especially gas turbine engines because of the possibility of severe engine damage occurring.
- d) Tires — Increased tire wear is common on unpaved surfaces because of the rough texture of unpaved surfaces. Tires are also vulnerable to cutting and penetration from sharp stones that may be found on gravel surface runways. Braking application may have to be reduced to minimize tire damage from inadvertent skidding, which in turn will have an adverse affect on braking performance. This may be more critical at lower speeds.
- e) Effects of dust and debris on systems — Flying debris and dust may result in gradual blockage of intakes, ducts, drains and air data sources and may eventually increase the possibilities of flight controls jamming. The abrasive qualities of dust may promote the erosion of paint surfaces and the crazing of windows if correct cleaning procedures are not applied. The infiltration of dust into the mechanical linkages may promote increased wear. Limitation against the operation of air conditioning systems or the prohibition of specific bleed air configurations while on the ground may be required.
- f) Increased structural loading — Aircraft landing gear and tire structures will likely be exposed to greater static and dynamic loadings on gravel runways as compared to hard surface runways.
- g) Inspection and maintenance — Increased inspection requirements are necessary for gravel runway operations. Propellers, engine intakes, compressor blades, aircraft surfaces, landing gear systems, tires, filters and proturbances should be checked more frequently for dust and debris damage. It may be necessary to perform an inspection before each flight from any damage from the previous flight. Minor paint touch ups and repairs in the field may be necessary before more permanent repairs can be made at the maintenance base. The frequency of cleaning of the aircraft and the lubrication of linkages should also be increased because of the increased dust in the gravel runway environment. Operation on gravel runways require maintenance programs to be modified and approved for such operations.



Aircraft Gravel Runway Kits (Three photos above)



Gravel Runway Kit

Summary

A gravel runway is essentially a flexible pavement with a surface course of unbound granular material. Although there is a minimum surface strength requirement for a given aircraft weight and tire loading, the most common operational problems result from the shear failure of the surface (rutting) caused by excessive aircraft tire loading. Gravel runway surface strength depends on the surface composition, moisture content, gradation, compaction and aggregate interlock. Gravel surfaces are susceptible to weakening from moisture penetration and frost action. Loose material associated with gravel runway surfaces also results in the requirement to protect the aircraft from debris. The rough texture of gravel surfaces contribute to increased tire wear.

A certified runway

Currently, airlines are legally responsible to comply with the air flight manual minimum California Bearing Ratio (CBR) value for various types of aircraft which are specified for safe operation. Boeing recommends that gravel runways be assessed every three years. However, it is strongly advised that with a weak runway, additional assessments should be carried out so that runway improvements are completed before regulations become rigorously enforced. As part of the Midwest Runway Dust Control Stabilization Program, Samitron testing is used to perform analysis of the runway prior to, during and after a Runway Dust Control Stabilization Program. Midwest provides accurate instructions for the use of the Samitron equipment and the data collected can be used to establish the proper treatment necessary to enable the runway conform to optimum California Bearing Ratio standards. If requested, a field engineer from Midwest will be sent to further help in the application and testing procedures and provide information to correlate Samitron testing results to California Bearing Ratio standards and requirements. The final results of the Midwest Runway Dust Control Stabilization Program can then be used by the Runway Operator to call for independent testing of the runway and to gain subsequent runway certification.

CBR Technology, Inc., one of Canada's leading assessors in this field, provides independent testing using the California Bearing Ratio standards. Gordon Drysdale, President of CBR Technology, Inc., or Cliff Beck, Principal Engineer Analyst, can be reached at 1-800-438-2334 or 403-285-6432.

Credits

"Gravel Runway Surface Strength Measurements and Aircraft Certification Requirements," Roman A. Marushko, Flight Test Engineer, Transport Canada Aircraft Certification, with the assistance of Bruce Denyes, Airport Pavement Engineer, Transport Canada Aerodrome Safety.

"Boeing Unpaved Runway Maintenance — D6-48945"

Many photos contained herein are provided courtesy of Boeing.