Evaluation of Existing Aggregate Roads to Determine Suitability for Resurfacing

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A major problem of counties in the United States is maintenance costs for local roads in an energy shrinking environment and under constraints that result from reduced revenues for maintenance. Many local roads have been built in the United States over the past century. In some cases these are largely nonsurfaced aggregate roads. On the county and state level, major construction of local roads is largely complete in the United States, but increased traffic has resulted in a need to upgrade many of these roads, particularly those near metropolitan areas. Increased truck traffic on many of these roads has caused considerable distress with resulting rising maintenance costs. There is a need to evaluate these roads to determine whether they are suitable for upgrading. Often a gravel surface that is satisfactory without a bituminous-wearing course becomes water logged and unsuitable after paving. This paper discusses concepts for evaluating existing nonsurfaced roads with the end point of determining suitability for placing a surface. Emphasis is placed on field tests that can be made to evaluate the in situ strengths of existing roads. Rapid tests that might be used for evaluation are discussed. These tests include the use of penetrometers and impact tests. Use of deflection measurements in evaluating nonsurfaced roads is presented. The advantages of performing a large number of tests by using quick and simplified methods are discussed. Location and types of tests that should be made are discussed. Methods for analyzing these data, including quantity and quality requirements, and recommendations that might be made for upgrading the surface are also presented.

A major problem of counties in the United States is maintenance costs for local roads in an energy shrinking environment and under constraints that result from reduced revenues for maintenance. Fifty to sixty years ago a concentrated effort was made by county, state, and federal governments to provide at least an aggregate wearing course for local low-volume roads. Gravel from local deposits and crushed stone from local quarries were hauled and spread on the road to provide a base course and support light traffic.

Major construction of local roads on the county and state level is largely complete in the United States, but increased traffic has resulted in a need to update many of these roads, particularly those near metropolitan areas. As traffic loads and volume increased, so also has the need to perform surface maintenance on these unpaved roads. In general, maintenance consisted of the periodic adding of additional gravel or crushed stones to locally failed areas. After the aggregate was spread, this was usually followed by drag maintenance to smooth the surface.

As a result, many of the existing gravel roads in the United States were not designed as such but came about through the evolution of road construction and road maintenance.

Maintenance needs for unpaved roads are still determined largely by visual inspection of what is needed to accommodate local traffic. In many cases, however, increased truck traffic on many of these roads has caused considerable distress with resulting rising maintenance costs.

As the need to upgrade county roads mounts and revenues decline, there is a need to make the most efficient use of available funds. Unfortunately, instances arise where placement of a wearing surface on an existing road can in fact cause detrimental effects. The base may become softened due to water accumulations since the road can no longer breathe due to the impervious surface. There is an obvious need to determine the quality of the existing base material before proceeding with application of a surface.

In a different context, in developing areas, roads are often planned for stage construction. In these cases the road may be placed under fairly close materials and design specifications and a planned resurface placed sometime during the life of the pavement. In this case also, there is a need to evaluate the existing road to determine what needs to be done to bring the base up to design standards before proceeding with the next stage of construction.

This paper focuses on quick field tests that can be used to evaluate existing aggregate roads. These methods measure equivalent California bearing ratio (CBR) values by using rapid field tests.

REASONS FOR EVALUATION

The type of evaluation process to use and the subsequent alternatives that might be considered depend on the needs for making the evaluation, as illustrated in Table 1. Data in this table present only a few of the items; it is difficult at best to generalize problems of this type but it is essential that the scope of the problem be kept in perspective.

Development of an Area

In the development of new areas, the justification may be both sociological and economical. This requires that a network analysis be made to determine potential growth of the area to determine the economic gain derived from the planning process. Alternatives for solution are listed in the last column of Table 1.

Environmental Factors

Dusting can be a problem not in terms of safety but also from environment of the surrounding terrain. Here again safety considerations, public opinion, and policy may dictate that something be done but this would not require a complete evaluation since application of a dust palliative may be all that is required.

Safety

Particularly at the county road level, increased traffic near metropolitan areas can cause safety problems from dusting, skidding, and other problems associated with nonsurfaced roads. Here public opinion and public policy coupled with safety aspects require that something be done to improve the surface. Along with this, increased truck traffic may cause an increase in maintenance costs. Before proceeding, the engineer would need to check the grade and alignment and all other physical aspects of the road and then make a general evaluation.

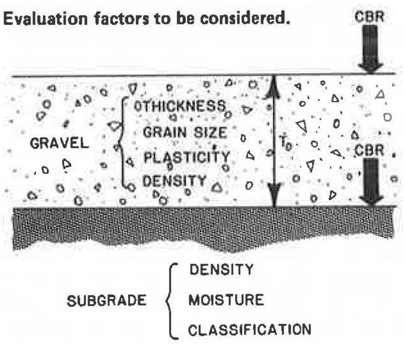
Planned Staging Other Than for Developing Areas

In many cases it can be shown that the most economical approach to pavement design is that of staging the construction of a pavement. Justification for improving the pavement can simply be the staging process itself although it should be based on sociological and economic factors.

Table 1. Reasons and alternatives for evaluation of existing aggregate roads.

Reason for Evaluation	Type of Evaluation	Alternative
Development of an area—sociological and economical	Network analysis	
Environmental factors—public opinion, public policy	Evaluate road materials	Stabilize base, apply surface
Safety—increased traffic, dangerous intersections, narrow bridges	Check grade, alignment, and other geometric factors	Widen, reconstruct
Planned staging other than for a new area	Economic analysis at the project level, evaluate structurally, evaluate materials	Continue to maintain, improve base, apply surface
Increased costs—maintenance, road user	Evaluate structurally, evaluate materials	Continue to maintain, apply surface

Figure 1. Evaluation factors to be considered.



Increased Maintenance and Road User Costs

As traffic increases on a road, costs of maintaining the gravel surface also increase appreciably. Whenever these maintenance costs begin to tax the budget of the governmental agency, it becomes necessary to make an evaluation before proceeding with surfacing of the road. The alternative strategies might include continued maintenance or application of a surface.

Road user costs might have the same effect on the decisionmaking process as maintenance costs. However, often there is a tendency at the county level, at least, to neglect the costs to the road user in the decisionmaking process.

FIELD INFORMATION REQUIRED

In the interest of economy, the reconstruction of a county road to a higher-type surface should, wherever practical, use the existing in-place materials. The in-place materials, however, are generally subject to wide variations in both quantity and quality. Therefore, to make the most-effective use of the existing materials, both of these properties need to be evaluated.

A list of items to consider in the evaluation is given below:

1. Geometrics--Relocate curves and raise grade;
2. Slopes--Correct landslides, clean benches, and correct fill movement;
3. Drainage--Clean ditches, improve cross fall, improve shoulders and reduce build up, and correct flooding conditions with culverts;
4. Pavement geometrics--Thickness of all components, uniformity of thickness, width, uniformity of width, and shoulder widths; and
5. Pavement properties--Quality of existing surface (grain size and plasticity), in situ strength of all components (field tests, laboratory tests, and density tests).

If the geometrics of the existing road require upgrading, this will have its effect on the decisions that will be made relative to the pavement itself. All existing deficiencies of the road should be corrected wherever possible within the economic constraints of the area. It may be necessary to relocate curves and correct grade deficiencies.

Corrective measures should be made regarding drainage of the road. This would include cleaning of the ditches, improving cross fall, and correcting flooding situations. To ensure reasonable pavement life and return on the investment of upgrading the road, all surface deficiencies that might affect the performance of the pavement should be corrected before proceeding.

Need for bridge replacement, improvement of culvert slopes, increasing drainage openings, cleaning drain pipes, and other factors many times present the major problem that confronts the policymaker in allocating funds for road improvement. In developing areas, correction of landslides, stability of fills and foundations, and other factors related to the roadway itself may be the governing consideration.

Insofar as the pavement structure itself is concerned, factors that should be evaluated include thickness and uniformity of thickness, width and uniformity of width, and shoulder width and condition. The evaluation process must consider the quality of the existing surface and in situ strength of all components along with an estimate of in-place strength values at the critical time of the year.

SCOPE OF THIS PAPER

This paper focuses on the field and laboratory evaluation of an existing gravel road that is scheduled for surfacing. We assume that the decision has been made to consider applying a surface, whether for one or for all the reasons listed in Table 1. The ultimate end point of the evaluation process is to determine whether the existing road is satisfactory for surfacing as it exists or whether some sort of improvement should be applied first. Many times the road may need to be reconstructed. The decision to surface a road is dependent on many factors, as listed in Table 1.

FIELD INVESTIGATION OF AGGREGATE SURFACES

Whenever an existing aggregate road is under consideration for surfacing, it is in the interest of economy to use the existing base to its fullest extent. Many times, the existing material can be used with a minimum amount of work. In other cases, however, stabilization or complete reconstruction may be required.

Field investigation and in-place testing of existing base materials and subgrades should be a standard procedure. To gamble against the unknown is a risky operation.

Factors of quantity and quality of the wearing surface and subgrade that should be determined are shown in Figure 1. For complete evaluation, a large number of tests need to be run; however, tests are expensive.

In field testing two different philosophies can be used. The first requires that tests be run with great accuracy so that exact values can be determined at one or two select locations. As suggested in Figure 1 and for the complete evaluation, field CBR tests should be made on both the surface and subgrade and then laboratory tests should be made on each of the materials for classification, grain size distribution, and many other properties. This approach is costly and requires a great amount of time. Often the size of the job and the required number of tests is overwhelming and the engineer in charge of the work will not make the required tests because he or she has more than enough to do to keep up with the routine duties of his or her office.

The second philosophy is based on a larger number of tests, by using quick portable devices. Research into quality control and use of statistics and design have indicated that the latter approach is the most feasible one for most situations. Admittedly some degree of accuracy at a specific location may be sacrificed over the detailed testing procedure, but the fact that a large number of tests can be made more than offsets the shortcomings of the detailed procedures.

IN-PLACE CBR TESTS

Based on the premise that quick, simplified tests are best for the evaluation of gravel roads, the Highway Extension and Research Project for Indiana Counties (HERPIC) at Purdue University has presented a series of manuals that outline techniques that can be used. In the first of these Shurig and Hittle (1) outlined simplified tests that can be used for field identification of soils and aggregates. These tests are based on standard American Society for Testing and Materials (ASTM) techniques and reliance is placed on the Unified Classification System and correlations of properties with this system.

In a second publication Shurig and others (2) outlined techniques for field investigation of county road bases and subgrades. In this latter report the tests presented in the identification manual are supplemented with field tests for determining in situ properties of aggregates and subgrades.

CBR Determinations

Three methods of rapid determination of field CBR have been evaluated at Purdue University for the counties. These include a high-load penetrometer developed by the Boeing Corporation for the evaluation of granular bases of airport pavements (3), the impact cone first developed in Australia and further evaluated in South Africa (4), and the Clegg impact device developed at the University of Western Australia (5). The Boeing cone requires a truck or other heavy equipment as a reaction; the instruments developed in Australia and South Africa are portable and can be carried by a single person. The impact cone is suitable for evaluating fine-grained materials. The Clegg meter is suitable for evaluating all materials and is particularly adaptable to evaluation of aggregate surfaces.

Dynamic Cone Penetrometer

Figure 2 shows the low-load penetrometer. It is a light portable tool used for the rapid determination of the equivalent CBR of in-place fine-grained subgrades. When the cone is driven into the soil by the drop hammer, an equivalent CBR of all soil layers may be determined. For sands the cone point is removed and a slightly rounded tip is attached. This penetrometer can measure equivalent CBR values up to 50 percent. A modification of this instrument is used for measuring bearing capacity of sands in Western Australia.

For evalution of subgrades, a hole is dug through the gravel surface. In general, two people operate the instrument, the first drops the hammer and the second reads the penetration of the cone. The penetration measured in units or millimeters per blow yields the equivalent CBR by using the calibration given in Table 2.

Normally, because one test can be run in about 4 or 5 min, a minimum of three tests are performed per hole. The rod permits determining in-place CBRs continuously from the top of the subgrade to a depth of about 4 ft below the top of subgrade. Figure 3 illustrates a typical test made at a location. Note that various layers can be detected by the slope of the depth versus CBR curve. For the example in Figure 3, a relatively hard layer is found several inches below the top of the subgrade.

Clegg Impact Device

Clegg at the University of Western Australia (5) developed a simple hand-operated device for measuring in situ CBRs of granular materials. Figure 4 shows this instrument in use. It consists of an accelerometer mounted in the head of a modified Proctor compaction hammer (10-lb weight) that is dropped from the standard 18-in height. The deceleration of

Figure 2. Diagram of dynamic cone penetrometer.

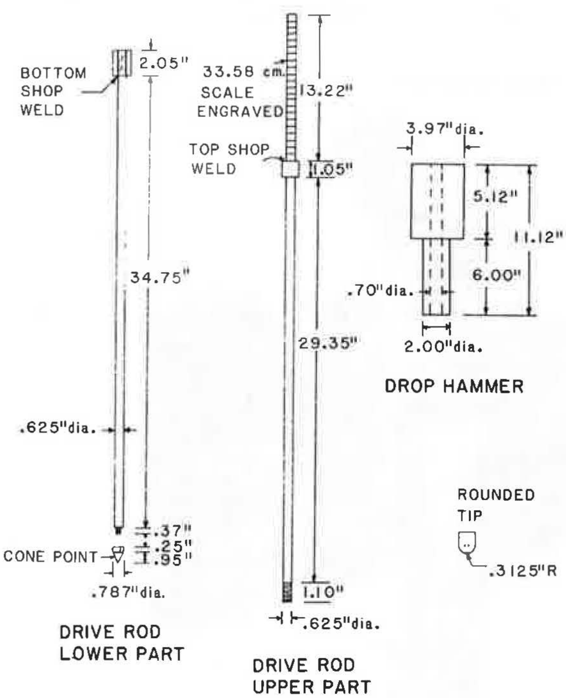


Table 2. Penetration versus equivalent CBR by using the dynamic cone penetrometer.

Cone Penetration (mm/blow)	CBR (%)	Cone Penetration (mm/blow)	CBR (%)
4	50+	16	13
5	50	18	12
6	40	19	11
7	33	20	10
8	29	23	9
9	25	25	8
10	22	28	7
11	20	33	6
12	19	38	5
13	17	45	4
14	16	60-70	3
15	14	80-90	2
		100	1

Figure 3. CBR versus depth for a given location.

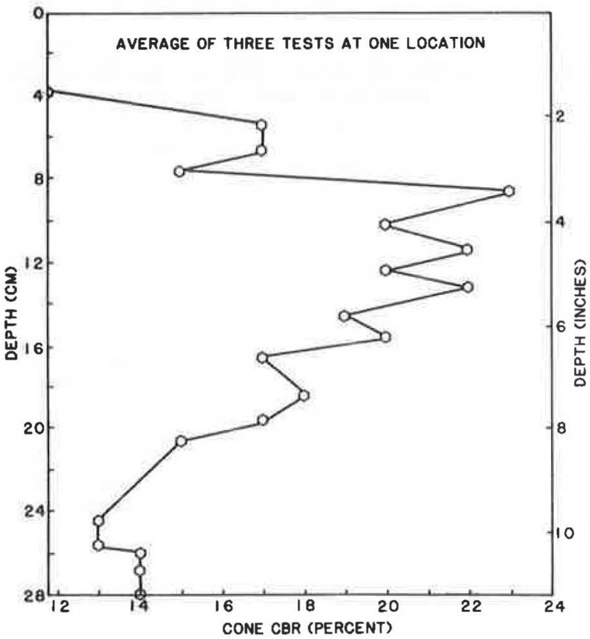


Figure 4. Clegg impact device.

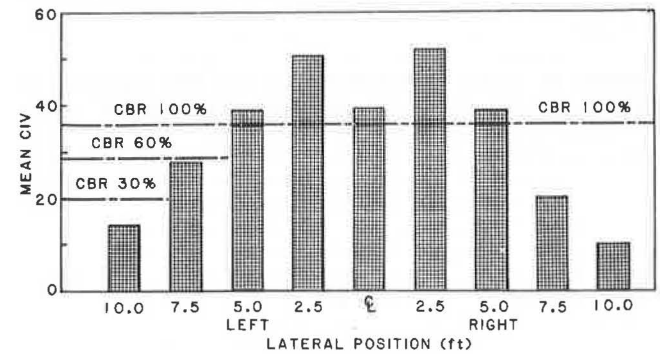
the hammer on hitting the surface is detected by the electronic instrument held in the operator's hand. The hammer is first dropped three times on the surface to ensure a firm seating before a reading is taken.

The Clegg Impact Value (CIV) can be determined in about 2 min, which permits obtaining CIV profiles at close intervals. The relation of CBR and impact values is $CBR = 0.07(CIV)^2$.

EXAMPLE USE OF DEVICES

As a part of the research conducted for the counties

Figure 5. CBR across the transverse section of a gravel surface.



in Indiana, extensive laboratory calibrations of the instruments mentioned in previous sections were carried out. In addition, criteria for use of the instruments in the field were developed after selected pavements were tested.

To demonstrate the use of the dynamic cone penetrometer and the Clegg impact meter, data for a typical road are presented in subsequent paragraphs. The road under consideration is a gravel surface that has a nominal thickness of 6 in. The subgrade is a silty clay.

The impact value of the existing gravel surface was obtained by using the Clegg impact device at 50-ft intervals. On the transverse, readings were taken at 2.5-ft intervals, although this was varied depending on the circumstance. Thickness measurements and subgrade CBRs were made at 500-ft intervals.

A principal advantage of using a light, portable, and quick device for evaluating gravel surfaces is illustrated in Figure 5, which shows the variation of CBR with lateral position. For this graph, the longitudinal values were averaged over a uniform section.

Data in Figure 5 are typical of those obtained on most gravel roads in that the wheel tracks (2.5 ft right and left of center line) have higher values than the center and the CBR decreases rapidly toward the edge of the roadway surface. The road in Figure 5 has a usable roadway surface of about 15 ft and the drop-off of values at the edge of the pavement illustrates markedly why so many of the failures during spring break-up take place at the pavement edge.

Thickness of this particular gravel surface was about 6 in at the center line and decreased to about 2 in at the pavement edge. The gravel at the pavement edge is contaminated with subgrade material and, as is noted by the CBR values, the gravel is inadequate for a road of this type.

As a first comment, particular attention would need to be paid to the pavement edges of this surface if an asphalt surface is to be placed or even if additional gravel is to be placed on the road. The hand-carried impact device can detect this situation and can alert the engineer to the need for special attention at these locations during maintenance or rehabilitation.

Further, if this road is to be surfaced with asphalt, a minimum CBR of 80 percent or greater is required and the data show a need to recompact and reshape the road to bring it up to uniform standards.

Recommendations for this road would include cleaning the ditches, dressing up the shoulders, and applying additional material at the edges. It would probably also be necessary to add gravel to increase thickness, depending on the subgrade CBR values.

Figure 6. Longitudinal variation of CIV for a gravel road.

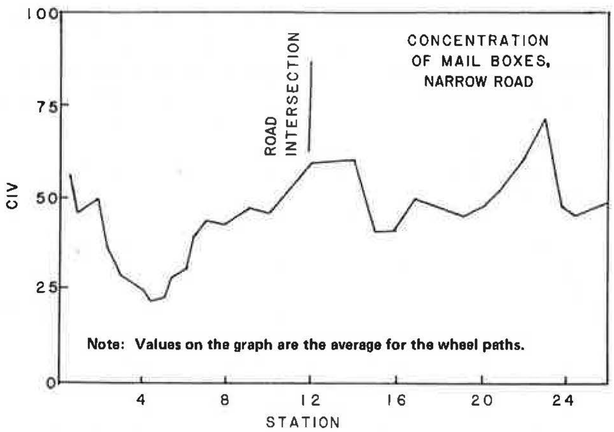
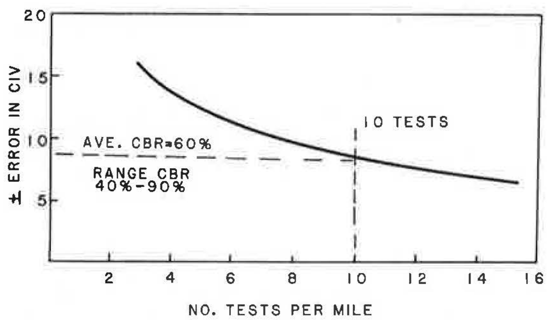


Figure 7. Required number of impact tests versus accuracy.



Longitudinal CIV Profiles

Another use to which the impact device can be put is to detect changes in material along the roadway. Values along the road can be determined by a team of two walking the center line; one operates the device and the other records data.

Figure 6 shows the longitudinal variation of impact values of the gravel surface that was depicted in Figure 5. The following features of the roadway are pertinent. From station 0+00 to station 4+00 there is a distinct downward trend in the CIV values. This drop represents CBR values from greater than 100 percent to less than 40 percent at station 4+00. At station 4+00 the values again increase to the road intersection noted at station 12+00.

Special attention needs to be placed on the section of road up to station 12+00 due to the low and erratic CBR values. Recall that the values shown are wheel track values and thus represent the critical condition. Reasons for the inadequacies need to be determined. Solutions for the problem include stabilization of this short section of road with cement or some other admixture, recompaction, or other alternatives that the engineer might consider.

Note that the detailed evaluation shown in Figures 6 and 7 would not have been possible if conventional techniques had been used.

Testing Frequency

Figure 7 shows the error of measurement of surface CIV as a function of the number of tests per mile. For 90 percent confidence and an assumed limit of accuracy of ±10 CIV, 10 tests/mile are required. At first glance this might seem like an unusually large number of tests, but recall that this is a hand-operated instrument that can be used readily. The actual time required to perform the surface tests, assuming that a complete transverse section of values is required, would be about 15 min at a site and, hence, the actual time required would be this value per site plus the time required for walking the 500 ft between test sites.

Prediction of Spring Values from Fall Values

Ideally, evaluations of this type should be done in the springtime but, due to the short time that the base is in the weakened condition, this often is not possible. Further, during the spring months highway forces are busy maintaining the roads to keep them passable and time for evaluation is rarely available.

The time situation can be circumvented by performing the tests in the summer and fall if the relation between the spring and fall readings is known with some certainty. Figure 8 shows the relation developed for the glacial gravels of central Indiana. On the basis of the reduction values shown in the figure, the spring values can be inferred through the correlations.

Effect of Base Depth and Subgrade CBR on Base CIV

Tests performed by Clegg (5) suggest that depth of base has some effect on the impact values. Likewise, the stiffness of the underlying subgrade also has an effect. Measured surface CIV of the base, depth of base, and CBR of the subgrade are interrelated when considering classification of the base under action of traffic. Soft subgrades yield under load with resultant lower densities of the base than those over stiff subgrades. Likewise, lower in situ CIVs exist at the pavement edge than under the wheel tracks. Results of this study have suggested that depth of surface has a minor effect on the test values. The analysis has indicated that the subgrade has a greater effect on the base CIV than thickness, but recall that the two are interactive and depend on lateral position.

USE OF DEFLECTION MEASUREMENTS FOR EVALUATION

Deflection measuring devices such as the Benkelman beam, Dynaflect, and the road rater can be used for evaluating gravel surfaces. The primary limitation that might exist is cost of equipment and, in certain cases, time involved in making the measurements. Figure 9 shows the results of deflection measurements made on a gravel surface for the purpose of determining corrective measures prior to placing an asphalt surface.

The Benkleman beam can be used with success if done with care. The probe must be placed firmly on the gravel surface, making certain that there are no loose pebbles in the vicinity of the probe. The data are analyzed in the conventional manner and depth of surface is determined by using techniques documented in the literature.

QUALITY CONSIDERATIONS

When evaluating any pavement for rehabilitation, it is necessary to account for the quality of the base and subbase materials, particularly from the standpoint of grain size distribution and plasticity. A danger exists that little or no consideration might be given to the quality of the existing gravel. If low values are found in the field, is the existence of a low CIV on the gravel due to high plasticity, low thickness, or some other factor? In the final

Figure 8. Prediction of mean spring CIV from the mean fall CIV.

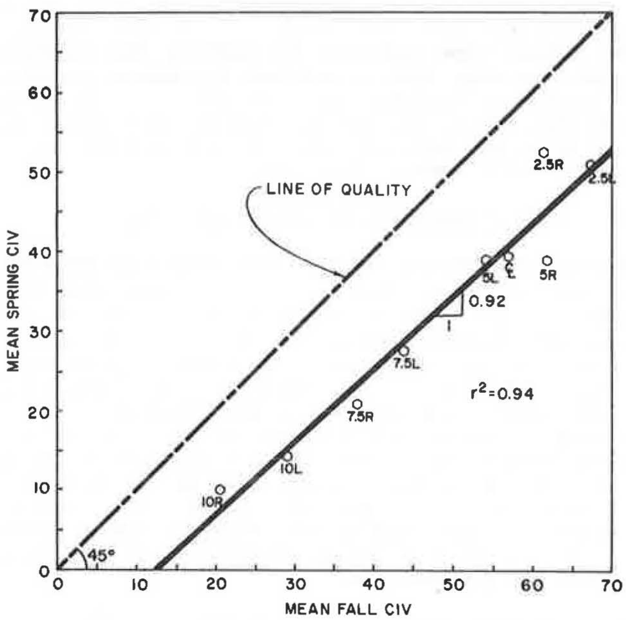
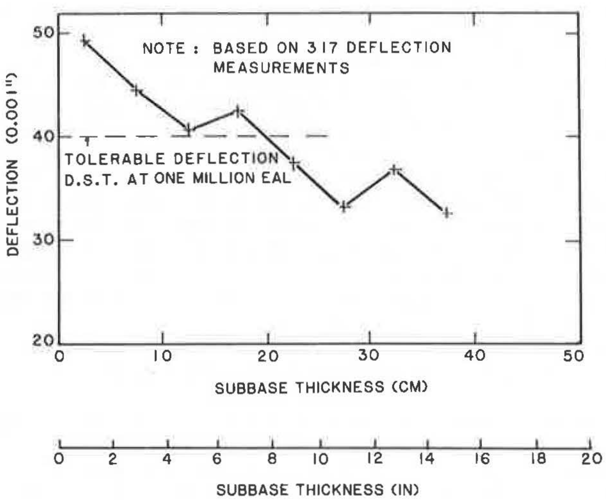


Figure 9. Deflection versus subbase thickness for a gravel road.



analysis, samples must be taken to the laboratory and tested, unless information is available relative to the material itself.

LOCATION AND SPACING OF TESTS ALONG ROADWAYS

The wearing surface and subgrade materials in unpaved county roads are subject to variations in depth and quality of base and variations in the nature of the native subgrade soils. Therefore, a sufficient number of field samples and tests must be made to develop a picture of the range of variations that exist in a given section or roadway.

The complete CIV-transverse section of the roadway should be evaluated at periodic intervals along the length of the road project. The number of tests required is about 10/mile, which sets the frequency of testing at about every 500 ft. One depth measurement and one subgrade CBR value should be taken at various points on each transverse section.

APPLICATION OF FIELD TEST RESULTS

The ultimate use of the field test is to design a road improvement. To accomplish this, it becomes necessary to fall back on standard methods of design of pavements by using documented methods commonly in use. The subgrade CBR will give a check on the required thickness of the finished pavement. The CIV of the wearing course will suggest the quality of the material and whether it should be upgraded by stabilization or whether it is satisfactory as it exists at the present time. For the project illustrated in Figures 5 and 6 the base material has a potential design CBR of >100 percent and it is considered satisfactory for this class of road. If very heavy traffic would be expected, this material should be stabilized or otherwise improved to a minimum CBR of 100 percent for the entire cross section.

Wearing surface materials that have a reasonably uniform in-place CBR value and a reasonably uniform width and depth can usually be incorporated directly into the new pavement design. However, for the illustrated case, additional depth and width of base material are necessary to upgrade the base to meet the pavement design.

For purposes of evaluation, the values in the wheel tracks should be used for redesign and determination of quality and those at the pavement edge should be used as indicators of added needed work that might be carried out at the pavement edge.

SUMMARY

One of the problems that faces the county highway systems in the United States is the time required to make a true evaluation of the road before decisions are made relative to surfacing. This paper presents conceptually the philosophy that, rather than spend a great deal of time on expensive tests at just several locations, it would be better to use simplified test procedures wherein a large amount of data can be obtained in a relatively short period of time. Techniques currently available, which are based on sound engineering principles, can be adopted for this purpose.

This paper has presented concepts for using simple instruments for evaluating gravel surfaces. The utility of these devices lies in their portability and the ability of the investigator to make a large number of tests on which to base conclusions. A word of caution, however, is presented in that a sufficient number of quality tests must be made relative to grain size distribution and plasticity of the base before a solution is arrived at.

The need for providing for adequate drainage and other environmental factors cannot be overstated and it is axiomatic that these be included in the evaluation. It is believed that the use of rapid testing techniques in the field offers the opportunity for the engineer to arrive at an economic redesign of existing gravel surfaces. Testing of the type outlined will suggest alternatives such as application of an asphalt surface, stabilization of the existing base, recompaction and reshaping, or other alternatives that are at the engineer's disposal.

ACKNOWLEDGMENT

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Surfacings for Low-Volume Roads in the Third World

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This paper is a review of planning criteria for use in deciding when to provide low-volume roads with permanent surfacings and appropriate techniques for asphalt surfacings on such roads in the third world. Planning criteria involve benefit/cost studies, changes in road user costs (mainly in vehicle operating costs) balanced with the costs of the road improvement, and subsequent changes in road maintenance costs. Pavement deterioration under traffic is influenced considerably by climate, by the road-making materials and methods employed, and by the care taken in pavement maintenance. The choice of bituminous surfacing technique has a considerable influence and the thesis developed is that the pursuit of high stability and good load distribution properties, both desirable in bituminous mixtures on heavily trafficked roads and airfields, has militated against the flexibility that is a prime requirement for asphalt surfacings on low-volume roads. Types of surfacing with this property of flexibility are reviewed.

As the building of main road networks of Third World countries is moving toward completion, emphasis in their road-building programs is changing toward the construction, improvement, and maintenance of secondary and feeder roads that are being built as an essential component of agricultural development schemes. Most of these feeder roads carry very light traffic and are built of earth and gravel. The secondary roads often make up more than half of the total network and generally carry traffic within the range 30-500 vehicles/day. Most of these secondary roads also have surfacings of earth or gravel and there are great pressures to provide them with permanent bituminous surfacings. These pressures are generated by the desire to maintain a free and unencumbered passage for vehicles in wet weather and to remove the nuisances of dust and corrugated bumpy surfacings in dry weather. They are often exacerbated by the incapacity of local road maintenance organizations to provide even minimum routine maintenance on the earth and gravel roads. This paper has two objectives; one is to review criteria for deciding when it is desirable to provide such roads with permanent surfacings of asphalt or concrete and the other is to consider appropriate techniques for bituminous surfacings on such roads.

CRITERIA FOR PROVIDING ROADS WITH PERMANENT SURFACINGS

To the transport economist the criterion for providing roads with permanent surfacings is that of minimizing total transportation costs. Vehicle operating costs are normally reduced substantially following the provision of a permanent surface and the calculation is usually undertaken as a benefit/cost study, with the benefits expressed as a rate of return on the investment necessary to upgrade the road. To the politician the criterion may lie at least partly in the perceived gratitude of constituents. Between them there is the uneasy seat of those charged with allotting scarce capital resources among all the different heads of government expenditure. Our stand must be with the transport economist, and in taking this stand we are not functioning as lobbyists--we are seeking to provide a factual basis for making wise decisions on what resources should be devoted to road works and how these resources should be most effectively used.

The basis for benefit/cost calculations concerning the upgrading of roads from earth or gravel to bituminous-surfaced is well established. The basic information required for such calculations consists of data on traffic flow and predictions of likely future growth on costs of the various procedures of road construction and maintenance, on pavement deterioration under the combined effects of traffic and weather, and on the influence of road conditions, particularly of pavement roughness on vehicle operating costs. Typically, in open African savannah such calculations will indicate that rates of return exceed the opportunity costs of capital with present traffic flow between 150 and 400 vehicles/day. Somewhat lower traffic thresholds are to be expected in hilly country and in wet climates. It is always desirable to make sure that local circumstances have been fully considered in assembling the data and in the assumptions that have to be made. Some of the pitfalls are indicated briefly below.

The data on traffic flow must include a realistic estimate of the spectra of vehicle and axle loading. Enforcement of vehicle-loading regulations is generally weak in Third World countries. Overloading beyond the rated capacity of trucks is commonplace and the axle loading spectra are frequently heavier than on main roads in industrialized countries (Figure 1). There is evidence that the fourth power law derived from the American Association of State Highway Officials (AASHO) Road Test--that damage to a pavement is proportional to the fourth power of the wheel load--applies at least approximately on lightly constructed bituminous pavements. Designs on the assumption that legal loading limits are not exceeded can lead to pavement deterioration 10 times more rapid than was intended.

Construction costs will vary from one locality to another. At one locality they will be affected