been 100 percent because the material would have been judged according to certain criteria whose influence on the assessment remained stable irrespective of the subjective approach of the engineer involved.

CONCLUSIONS

Although the project described in this paper was the first application of this scheme to a road project in South Africa, approximately $200 million of work incorporating the use of this or similar acceptance control schemes has since been let to contract. Unfortunately, however, it is not possible to gauge accurately the feelings of contractors about the scheme. Certain contractors—generally the more technologically advanced organizations—appear to welcome the approach, but others have expressed their doubts about it. The more dubious contractors generally do not appear to understand the principles involved nor to be able to explain their misgivings clearly.

A great deal of education in statistical principles thus appears to be required. This education, the collecting and processing of more and reliable information about the variability associated with construction control testing, and the relative variabilities contributed by the sampling and testing processes are regarded as the most important phases of this work to be done in the immediate future. It is hoped that the introduction of a quality assurance subsystem into the computerized data management system currently being implemented by the South Africa Department of Transport will help to some extent in obtaining more information about variability in materials and processes.

A study of the results of tests on asphaltic concrete showed clearly that, when a contractor makes a definite effort to produce a homogeneous or consistent product, there is no difficulty in fulfilling the requirements of the specification. The use of inconsistent material in the production of asphaltic concrete can only lead to trouble. Use of the statistical acceptance plan provides a client with an adequate means of judging the product.

The statistical acceptance control scheme should not be seen as another "big stick" with which the engineer may beat the contractor but as a scientific assessment of the contractor's capability to produce a uniform product. Ad hoc or biased judgments of the product are eliminated, and on-site arguments between the contractor and the resident engineer are reduced to a minimum. The contractor is encouraged to produce a uniform product, which is what the client desires, and the benefits that accrue to both contractor and client must eventually accrue to the construction industry as a whole.

The continued use of statistical acceptance control on road-work projects is therefore recommended. The ultimate aim of the major clients connected with the road construction industry in South Africa is to develop a standard statistical acceptance control specification based on the several specifications that are now being implemented throughout the country.

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Quality Criteria for Maintenance and Reinforcement of Pavements in the Netherlands

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In the next 10 years, population and traffic density will reach a maximum in the Netherlands and other industrial countries of Western Europe. The need for an adequate policy for spending the available (and decreasing) funds for roads necessitates the development and application of objective criteria for maintenance and reconstruction of the existing road network. These criteria deal mainly with road-surface characteristics (safety and riding comfort), bearing capacity (strength) and durability of the pavement, and traffic safety. Quality criteria relating to road-surface characteristics and the condition of the pavement as a bearing layer are examined. In the Netherlands, such criteria are gradually being more systematically applied in judging priorities and making decisions on maintenance and strengthening of pavements. These criteria have been developed on the basis of measurements and research on the national road system carried out by the State Road Laboratory, especially during the past 25 years. An explanation is given of the methods of measurement, the interpretation of the results of testing and visual inspection of roads, and the way the data are used in developing and applying a system of rational pavement management practice.

In a number of Western European countries, and particularly in the densely populated Netherlands, the planned road networks required to provide an effective infrastructure are nearing completion. Figure 1 shows the 1968 state highway plan for the Netherlands; after some necessary correction, the greater part of this plan will be completed in the next 10 years. In the past 15 to 20 years, a number of new main roads, primarily motorways, have been built. These roads linked large industrial and residential areas but also frequently bypassed those centers of population. As a result, a degree of saturation will be reached in the next 5 to 10 years. This trend is being accentuated by increasing resistance on the part of certain groups to further extension of the road network, the resulting loss of areas of open country, and the continued damage to the environment caused by the increasing volume of road traffic. The result is, of course, that road builders and highway authorities are turning their attention more and more to methods of maintaining, strengthening, and reconstructing existing roads instead of building new ones.

MANAGEMENT SYSTEM FOR ROADS

For several years, the aim in the Netherlands has been to achieve greater rationalization in the determination of objective criteria for pavement maintenance, reinforcement, and reconstruction with the object of making the best use of financial resources. Since 1973, the results of measurements and the criteria developed have been more systematically applied to objective decisions on the maintenance and reinforcement of existing primary roads. To decide whether maintenance and reinforcement measures are needed, the following objective criteria are applied:

1. The surface characteristics of the pavement, i.e., skidding resistance, evenness, rutting, and surface texture;
2. The condition of the pavement as a bearing layer, i.e., cracking, disintegration of materials, and deformation; and
3. Factors of traffic safety, i.e., location of the road, roadway width, and crossfall for drainage.

A final judgment on the condition and the quality of the pavement can only be made after data on the age and the structure of the pavement and the traffic load are considered and a visual inspection is made.

In the Netherlands, the State Road Laboratory performs such measurements and inspections. The results and the judgment made based on the results and on pavement data, traffic volumes, and road situations are sent to the authorities concerned. The executive authorities can then determine a draft working scheme and draft specifications. At this stage, the State Road Laboratory may be asked to give general advice.

Figure 1. 1968 state highway plan for the Netherlands.

Figure 2. Skid-resistance tester.

CRITERIA FOR DETERMINING MAINTENANCE AND REINFORCEMENT NEEDS

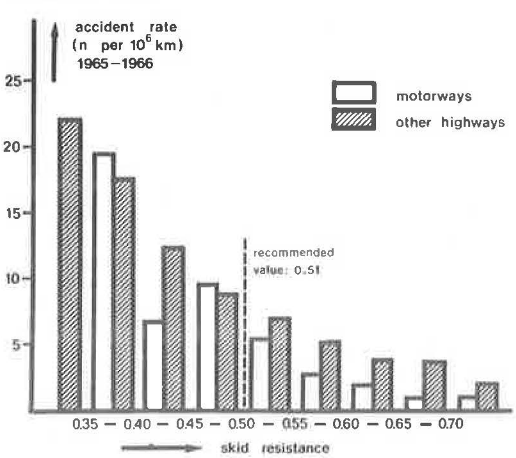
Skid Resistance

The main characteristics that determine skid resistance, other than traffic density, are the texture of the road surface and the resistance of the aggregates to polishing. A considerable amount of research has been done on this subject in the Netherlands in the past few years.

The complete network of existing primary roads (national highways) in the Netherlands totals about 4000 km. It has been fully checked for skid resistance every year since 1953 by using 100-m test sections that are representative of road sections several kilometers in length and that have the same pavement type and traffic history. A standard test vehicle with a retarded wheel (86 percent slip) is used (Figure 2) on a wet road surface at a speed of 50 km/h, usually in the right-hand lane. In some cases, especially if the depth of the pavement texture is low, measurements are carried out at a speed of 70 km/h because of the possibility of a greater than usual decrease in skid resistance at increasing speeds.

The annual testing of national highways takes place

Figure 3. Relation between skid resistance and accident rate (1965-1966).



from August to November. During this period, skid resistance may reach minimum values because of summer temperatures and polishing (in winter, skid resistance is improved by erosion). Because this seasonal influence largely determines the condition of the road surface, it must be taken into account in the interpretation of test results.

This systematic examination involves only random measurements. The measurements made in connection with working plans are much more extensive, particularly at junctions, slopes, overtaking lanes, and "black spots."

To establish the relation between skid resistance and accident risk on a wet road surface, data were collected on all accidents that occurred on national highways in the Netherlands in 1965 and 1966 (Figure 3). These data can be used not only for the determination of maintenance priorities or for comparisons with a model but also for budgetary purposes.

In the classification adopted by the Netherlands State Road Laboratory, a coefficient of friction (f) of 0.51 measured at a speed of 50 km/h is regarded as a minimum value for national highways. Values lower than 0.51 are considered insufficient and indicate that measures should be taken to improve skid resistance. However, the State Road Laboratory does not always recommend immediate measures for improvement or traffic restrictions. This depends strongly on factors such as the length of the road section in question, the date the measurements were taken, the situation of the road, the cause of the low skid resistance, the traffic volume, the condition of the pavement, and any strengthening operations already planned.

If skid-resistance values below 0.46 are found, immediate action—such as the placing of SLIPPERY ROAD signs—is recommended regardless of the length or the location of the road section. If necessary, other measures such as restrictions on speed are also taken. At the same time, measures to improve skid resistance are prepared.

In summary, it can be stated that the following directives regarding the friction coefficient (f) are applied in practice: If $f < 0.46$, the pavement must always be repaired; if $f = 0.46$ to 0.51, the need for repair depends mainly on road traffic conditions; and if $f \geq 0.51$, pavement repair is generally not undertaken.

Figure 4 shows the frequency distribution of skid-resistance values for various lengths of national roads measured in 1970 by means of systematic investigations. (Because of the effort required to determine this distribution, it has not been done since 1970, but evidence indicates that the distribution has not greatly changed since that time.)

Figure 5 shows the percentage length of the national highway system that had a friction coefficient lower than the recommended minimum value as measured during the period from 1954 to 1974. Figure 6 shows the frequency distribution of 1975 skid-resistance values determined in relation to 1976 work plans for maintenance and reinforcement of highways.

Figure 4. 1970 frequency distribution of skid-resistance values.

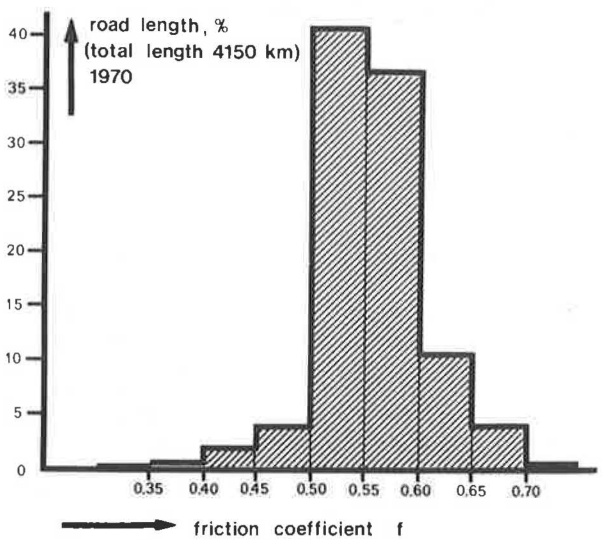


Figure 5. Percentage length of roads from 1954 to 1974 with a friction coefficient below 0.51.

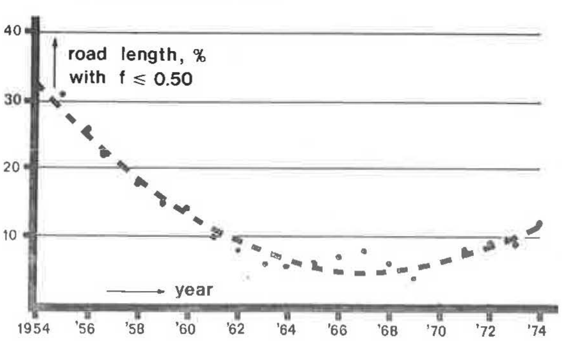


Figure 6. 1975 frequency distribution of skid-resistance values measured in relation to 1976 work plans for maintenance and reinforcement.

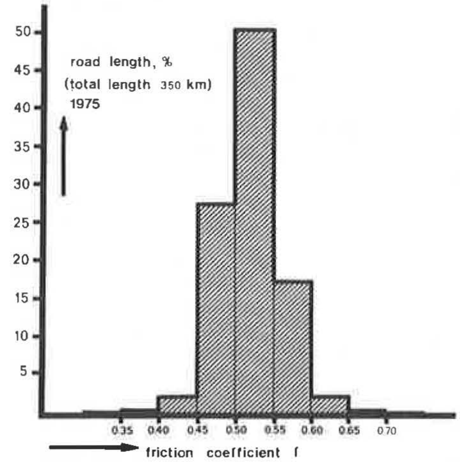


Figure 7. Roughometer.

Roughness

The present serviceability index criterion (PSI), developed in the United States in connection with the AASHO Road Test, is used in many countries. It consists primarily of results obtained from measurements of longitudinal roughness, rut depth, cracking, and repaired surface. But in the Netherlands this combination is frequently not very meaningful. Regarding PSI as an exclusive figure indicating the residual value of the pavement ignores two other important parameters for pavement quality—skid resistance and bearing capacity. If PSI is regarded as a figure for assessing roughness or riding comfort, the cracking index has little significance. For this reason, separate criteria are used in the Netherlands for longitudinal and transverse roughness.

Longitudinal

To obtain an idea of riding comfort on roads in the Netherlands since 1953, the roughness of the road surface was determined by using the so-called roughometer designed by the U.S. Bureau of Public Roads and manufactured by the U.K. Transport and Road Research Laboratory (Figure 7). The relative displacement of the wheel axle in a single direction with reference to the frame of a one-wheel, mass-spring system (trailer) was measured and totaled over 500- to 1000-m stretches of road. Measurements were made at a test speed of 50 km/h.

The following rating has been developed and adopted as a criterion for riding comfort (expressed as the roughometer value): <1.4 = good, 2.4 to 3.4 = moderate, 1.4 to 2.3 = adequate, and ≥3.5 = poor. This rating agrees fairly well with standards adopted in other countries for the interpretation of roughometer results.

In some countries, roughometer results are used as an absolute standard for maintenance. In the Netherlands, however, roughometer values are used for classifying stretches of road in order of evenness. The results, including those from comparative measurements, have indicated a good correlation between roughometer readings and PSI. A roughometer value (R) between 2.5 and 3.5 is approximately equivalent to a PSI between 2.5 and 1.5 (Figure 8); that is, R = 5 - PSI.

The roughness of one-third of the length of all highways is measured every year, and thus the whole national road system is checked for roughness every 3 years. The condition of a given section of road can therefore be compared with the overall condition of the state road network. Figure 9 shows the frequency distribution of roughometer values of national roads measured in 1975 in relation to work plans for maintenance and reinforcement of highways to be carried out in 1976. This distribution does not differ essentially from the overall frequency distribution of these values for all roads except in the percentage of roads classified as poor, which is much greater.

As a rule, improvement of evenness will definitely be necessary if the roughometer rating is poor. If the rating is moderate, factors such as the condition, rut depth, crossfall, and skid resistance of the road will generally play a part in the decision on what measures should be taken.

Transverse (Rut Depth)

Deformation of the pavement in the wheel tracks caused by traffic may result in rutting. The main causes are insufficient stability of the asphalt and high levels of traffic density. Research carried out on test sections of roads in the Netherlands shows that serious rut formation is usually caused by only a few heavy vehicles with high tire pressures on no more than a few very hot days a year.

Although deep ruts impair the steerability and roadholding capability of vehicles, a more serious drawback is that the ruts can fill with water, even at low rainfall intensities. Thick layers of water on roads can greatly decrease skid resistance at higher vehicle speeds. In extreme conditions, hydroplaning may occur. In addition, vehicles moving on water-covered road surfaces will produce a strong water spray that is both annoying and dangerous to other road users.

A normal straightedge can be used in rut measurement. In 1974, however, the State Road Laboratory developed a measuring device known as the rut meter (Figures 10 and 11), which continually registers maximum rut depth. The result is expressed as the mean rut depth per 100 m of road length. The measuring speed is 50 km/h.

The thickness of the water layer in a rut depends on rut depth, transverse and longitudinal slope of the roadway, traffic volume, and rainfall intensity. Investigations are being made into the degree of rutting that is just admissible; the incidence and the prevention of accidents are important factors in this research. Although the investigations have not yet been completed, a tentative mean rut depth of 20 mm per 100 m of road length has been adopted in the Netherlands as a limit beyond which corrective measures are needed. The depth of the right-hand rut is considered the determining factor. The decision on what improvement measures should be recommended depends on the age and the vertical structure of the pavement as well as crossfall, skidding resistance, longitudinal roughness, and possibly other factors.

Figure 12 shows the frequency distribution of rut depths measured in 1975 in relation to work plans for maintenance and reinforcement of highways to be carried out in 1976.

Deflection

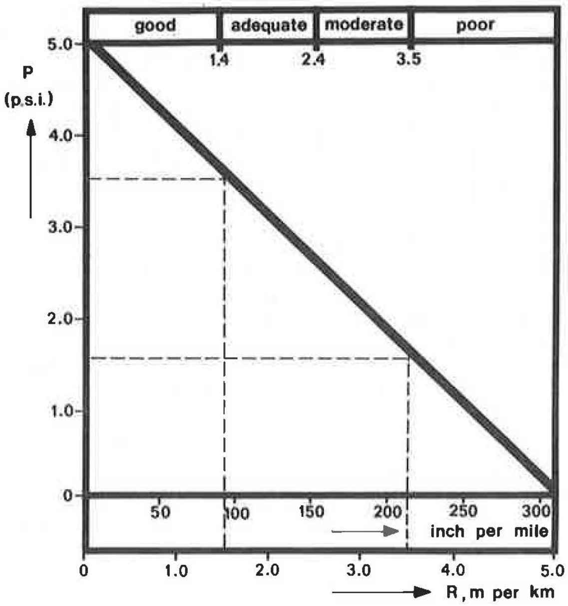
Maximum pavement deflections (vertical displacements of the pavement surface) are measured by using the Lacroix deflectometer at intervals of about 4 m, at a measuring speed of about 3 km/h, and under a load of 9 Mg (Figure 13). About 25 measurements are made per 100 m of road length between the left-hand and right-hand dual wheels of a heavy truck. The deflection values, which are not corrected for temperature variations, are classified, and a frequency distribution is recorded for each 100 m of road length. Influence curves (deflection as a function of the distance to the wheels) are determined. It is possible by means of the Lacroix deflectometer to determine the deflection values of rather long stretches of road in a fairly short time. The deflection-related homogeneity of a pavement structure can thus be determined. By using the frequency distribution per 100 m of road length and theory about expected deflection values, any weak spots in the structure can often be clearly discerned. Existing design methods are mainly based on Benkelman beam measurements; the State Road Laboratory (and others) have established the correlation between the two measuring methods.

Recommendations concerning the need for pavement strengthening are based on several deflection-related factors, which are discussed below.

Seasonal Influence

Deflection values are influenced by temperature and humidity. Measurements must be made under comparable

Figure 8. Relation between present serviceability index (P) and bump integrator value (R).



conditions to reflect this dependence. The measurements are therefore carried out only in spring and autumn, those seasons in which variations are the smallest and thus reliable corrections can be made.

Figure 9. 1975 frequency distribution of roughometer values measured in relation to 1976 work plans for maintenance and reinforcement.

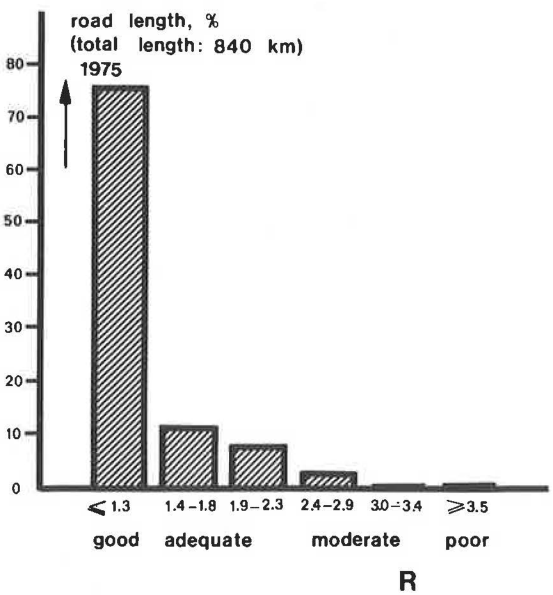


Figure 10. Diagram of rut meter.

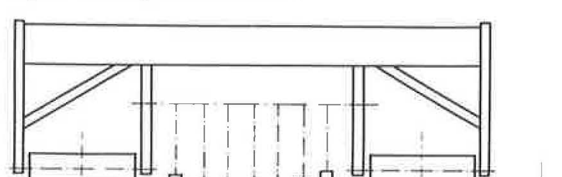


Figure 11. Rut meter.

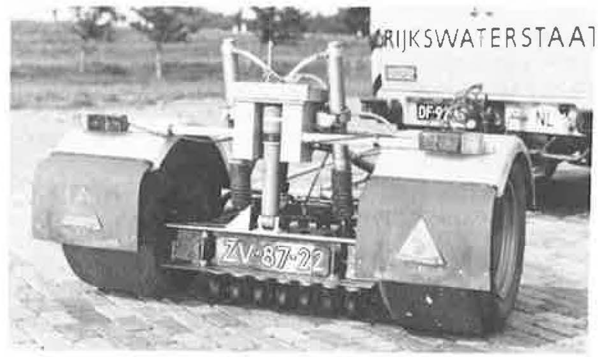


Figure 12. 1975 frequency distribution of rut depth measured in relation to 1976 work plans for maintenance and reinforcement.

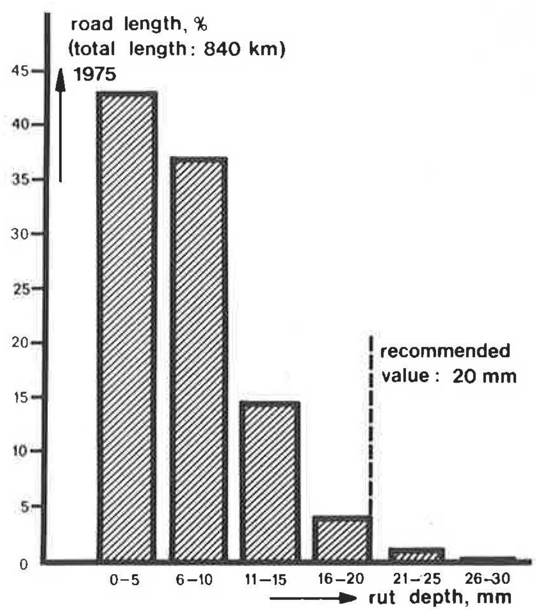


Figure 13. Lacroix deflectometer.

Cracking and Disintegration

Deflection measurements aid in the estimation of the theoretical service life of a pavement. Visual examination of the road surface and reporting of deformation and raveling and the degree and type of cracking make it possible to estimate the point at which strengthening will have to be recommended.

Structural Data

Data about the structure of the pavement are important because the theoretical service life and therefore the deflection values to be expected strongly depend on the materials and layer thicknesses of the structure. Moreover, differences in the behavior of the various materials must be considered.

Age of Pavement Structure

The age of the various parts of the structure is especially important in connection with the total traffic load that has acted on the pavement; such data make it possible to determine that part of the fatigue life of the structure that has been "consumed."

Truck Traffic Volume and Axle-Load Distribution

It appears from the AASHO Road Test that the decline in serviceability of a pavement depends on traffic volume and axle loads. Therefore, truck traffic volume is important in the calculation of the total traffic load. This calculation is based on data for axle-load distribution and on the assumption of a rate of growth in truck traffic of about 4 percent a year.

Additional Data From Test Cores

If data about the structure as a whole or about its parts are unknown or unreliable, more data may be obtained by boring cores. Cores should be taken especially from the right-hand wheel track. If it is believed that the thickness or the material of the structure varies across the road section, this should be verified by taking cores from other parts of the pavement cross section. The number of cores should be adequate to enable the structure of the pavement to be accurately determined. The number of cores taken also depends on the road manager's knowledge of a particular pavement section. In this respect, data on the behavior of the structure and the type of cracking are important.

MEASUREMENT METHODS

The type of measuring equipment used to define the quality of existing pavements is not of critical importance provided that what is measured is sufficiently closely related to the principal road characteristics—safety, riding comfort, and durability. Quality control by means of measurements at the site, the results of which are related to objective criteria, is one of the most significant procedures for maintaining the desired quality level. To ensure that the quality criteria used are reliable and effective, it is most important to use test methods that are quick, reproducible, and, if possible, continuous.

Final and effective decisions on the maintenance and reinforcement measures to be taken in a given road and traffic situation can only be made by combining the results of measurements, by visual inspection at the site, and by thorough deliberation involving an expert team of specialists and the site engineer. This method of road management can only be complete and adequate, however, when pavement maintenance and strengthening activities form part of a total, rational system of management in which other relevant factors (e.g., maintenance of verges and traffic control measures), especially those that have economic consequences, are also weighed.

CONCLUSIONS

The completion of the national road network in the Netherlands calls for much stronger attention to adequate methods of maintenance, strengthening, and reconstruction of existing pavements. Objective standards of quality and maintenance criteria for pavements are essential elements in a total system of pavement management and are necessary for fixing priorities in connection with the appropriation of funds. In the Netherlands, especially in the last 10 years, such objective criteria have been developed, mainly for skid resistance and longitudinal and transverse roughness. The criteria are based on a vast number of results of systematic measurements on main roads (most of them made during the past 20 years) and on long experience in road inspection. Longitudinal friction coefficient (f), roughometer value (R), and maximum rut depth value measured by a rut meter are used in obtaining the results. The results of deflection measurements made by using a Lacroix deflectometer are recorded by an expert inspection team of pavement specialists and are related to pavement and traffic history and data on cracking and disintegration of the surface. Deflection measurements are an essential factor in determining priorities and in making decisions on the maintenance and reinforcement of pavements.

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