J. J. Troon for the extensive use of his reference material, Mrs. J. Owen for typing the manuscript, and all other members of the County staff for their practical help over the years.

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# Road Network, Materials, and Evaluation in Jordan

TAISIR S. KHEDAYWI, EGONS TONS, AND S. BINDRA

**The economic activity in Jordan during the last 10 years has caused a substantial increase in traffic, which in turn has affected the condition of pavements, especially those designed for lower traffic volumes. Many stretches of roads will have to be improved or reconstructed earlier than expected. Although the increase in traffic is assumed to be the major factor in road deterioration, other factors such as the effect of materials, design methods, and construction procedures cannot be overlooked. An appraisal of the Jordanian environment, road traffic, and road-making materials is presented. Problems with materials and construction are discussed and some typical pavement failures and their probable causes are described. Case histories that dealt with the evaluation of asphalt pavement deterioration in several roadway sections in the Irbid area of Jordan are discussed. This evaluation involved the physical sampling of components, condition surveys by 40 people who rated the roads, and the mechanistic measurements of a Present Serviceability Index. Some present and future studies on pavement components are also included.**

The Hashemite Kingdom of Jordan occupies a strategic geographic position in the Middle East. Its road network system is more extensive than other transport systems and it provides a distribution base for national and international markets. Almost all of the paved roads in Jordan have a surface that contains bitumen. Because of the rapid development of

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economic activity in Jordan in the last 10 years, many road projects have been planned, designed, and constructed. This road construction has been accompanied by a substantial growth in both population and motor vehicle registration (Table 1). The government of Jordan is taking actions to foster further economic expansion through development strategies that would enhance the potential of the Kingdom's resources and minerals (primarily phosphate, potash, and building materials), agricultural products, and skilled manpower. The increase in Jordan's road transportation during the last decade is likely to continue for many more years.

The road development program envisaged for the country involves large amounts of money, manpower, and materials and will concern not only the building of new roads, but also the improvement of the existing network. Many stretches of the older roads will have to be reconstructed sooner than had been expected because they were designed for low traffic volumes.

Although the increase in traffic volume has been a major reason for the premature failure of roads, it is clear that there is a need for careful consideration of such factors as the choice of materials, design methods, and construction techniques so that newly designed or rehabilitated pavements will last for their full design life. The needed research efforts and priorities for optimal utilization of resources, however, have to be directed from an integrated approach that has evolved from such considerations as conservation, economy, performance, ease of construction, and ease and cost of maintenance. A brief appraisal of the main parameters of geography and environment, road network, traffic, and the material resources to develop an understanding of the highway problems in Jordan is given in the following section with an emphasis on low-volume roads.

## THE ROAD NETWORK IN JORDAN

The existing road network in Jordan is 6332 km long. Of the total network 76 percent is paved and 24 percent is unpaved. The local rural roads that serve small villages and agricultural areas account for about 3500 km of the network, of which 2400 km are paved. The secondary road system, on which long trips are made by low traffic volumes, is 825 km long. The paved, higher-volume roads account for about 2000 km. The general traffic distribution of these roads is shown in Figure 1. Therefore, about 75 percent of all low-volume roads in Jordan have some kind of asphalt-treated surface.

The Jordan Government's future development plans will require the modernization and extension of the existing road system. The intention of the plans is to develop sources of income through development strategies that enhance the potential of the Kingdom's natural, industrial, and human resources.

## ROAD TRAFFIC IN JORDAN

Road freight traffic and passenger transport have both grown rapidly in the recent past. According to present data, motor vehicle registration doubled in the 6-yr period from 1979 to 1985. Ownership rates for passenger vehicles grew from 8.7 per 1,000 people in 1970 to 118.4 per 1,000 people in 1986. Private automobile ownership increased from about 30,000 in 1976 to 221,454 by 1985 and is expected to reach more than 387,000 by the end of the century.

The maximum legal load limit for single-axle commercial vehicles is 13.5 tons. This limit has been recently increased to 20 tons on certain strategic routes. Wide traffic variations exist in terms of weight and volume. In a recent pilot study of the axle load spectrum it was observed that the equivalent number of standard axles of 8200 kg per 100 commercial vehicles could be as high as 500.

## GEOGRAPHY AND ENVIRONMENT

The terrain of Jordan has a variety of different landscapes and climates. The eastern desert area is a semiarid steppe that receives little rainfall. The central spine of the country, the highland plateau and hill region, runs from north to south. To the west, the Great Rift valley runs the entire length of the country, and includes the Jordan valley; the Dead Sea, which is the lowest spot on earth, at 400 m below sea level; the Wadi Araba; and the Aqaba area around the Gulf of Aqaba and the Red Sea. A map of Jordan is shown in Figure 1.

Jordan enjoys a mild and comfortable eastern Mediterranean climate. Average temperature ranges from 8.5°C in January to 25°C in August. The rainy season is from December to March in winter. The rainfall of each month is between 80 and 110 mm.

TABLE 1 POPULATION AND VEHICLE OWNERSHIP CHANGES

| Year | Population | Index | No. of Vehicles | Index | Vehicles per Person |
|---|---|---|---|---|---|
| 1970 | 1,508,200 | 100 | 24,279 | 100 | 0.016 |
| 1971 | 1,562,000 | 104 | 26,380 | 109 | 0.017 |
| 1972 | 1,617,500 | 107 | 26,698 | 110 | 0.017 |
| 1973 | 1,675,100 | 111 | 30,814 | 127 | 0.018 |
| 1974 | 1,735,000 | 115 | 37,131 | 153 | 0.021 |
| 1975 | 1,810,500 | 120 | 47,243 | 195 | 0.026 |
| 1976 | 1,889,300 | 125 | 60,455 | 249 | 0.032 |
| 1977 | 1,971,600 | 131 | 79,493 | 327 | 0.040 |
| 1978 | 2,057,500 | 136 | 97,402 | 401 | 0.047 |
| 1979 | 2,147,600 | 142 | 117,250 | 483 | 0.055 |
| 1980 | 2,233,000 | 148 | 135,271 | 557 | 0.060 |
| 1981 | 2,322,300 | 154 | 156,924 | 646 | 0.068 |
| 1982 | 2,415,200 | 160 | 177,849 | 733 | 0.074 |
| 1983 | 2,495,300 | 165 | 197,783 | 815 | 0.079 |

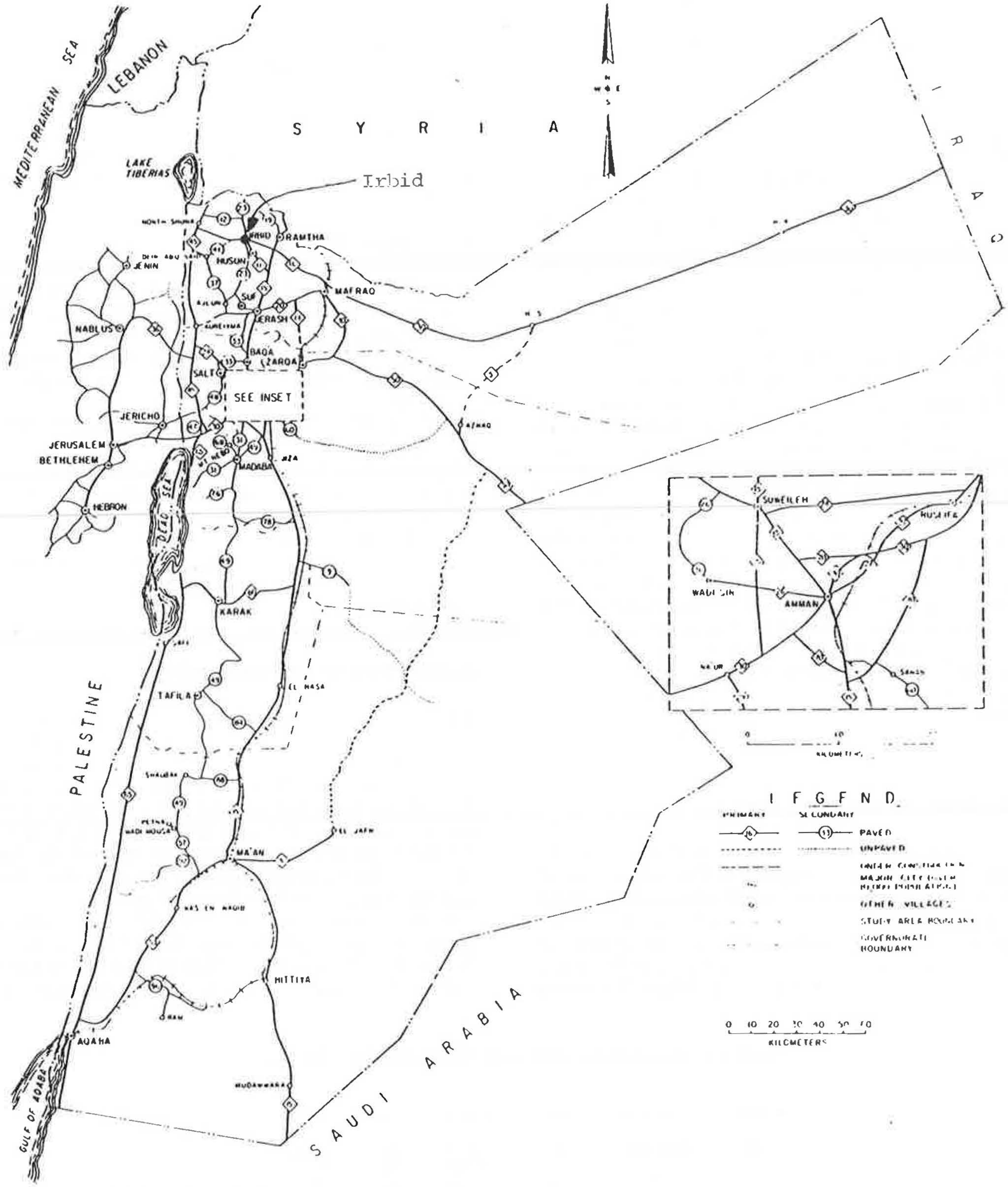

**FIGURE 1 Existing routes in Jordan.**

## ROAD MATERIAL RESOURCES

Jordan is fortunate to have abundant supplies of cheap building materials in most parts of the country. The granular material that is commonly used in road construction in Jordan consists of natural sands, gravel, and crushed rock. There are about 275 quarries in Jordan from which crushed aggregate is produced. In addition, there are 16 sand pits and 72 other rock sources from which road materials can be obtained. The regional distribution of aggregate quarries reveals that Amman has 155; Balqa 14; Irbid 56; Zarqa 14; Karak 5; Mafraq 8; Madaba 4; and Aqaba, Tafila, and Ma'an have 14 (Figure 1). The kinds of aggregates that are available in Jordan are briefly described as follows.

The valley aggregates were formed by rocks that were swept away from the mountains, followed by sedimentation in the valleys or low regions. This kind of aggregate has good gradation, high specific gravity, low water absorption, and good resistance to wear by attrition or abrasion.

Granite aggregates of several colors are found in Algatam, Aqaba, and south of Ma'an. These aggregates have good resistance to wear.

Volcanic stones are found in Mafraq and Wadi Dulail. These aggregates have low resistance to abrasion and attrition, and a low specific gravity.

Hard basalt aggregates that are dark in color are found in Mafraq and in the Jordanian and Iraq border area. They have a high specific gravity and low water absorption.

Limestone aggregates are found in many regions and they differ widely in their properties.

Fine aggregates are found in mountains, the desert, and river beds. They are also obtained from crushing plants.

Gravels in Jordan are available in large quantities in many places, such as stream bottoms or terraces adjacent to streams, outwash plains, and fans adjacent to mountains. Marine or lacustrine beach and delta deposits are also present in some places. In most instances, the gravel aggregates are strong and durable, and satisfy the general physical requirements of road aggregates. It would therefore be economical to use them when crushed stones are not available or have to be brought in from a considerable distance.

The Jordan Petroleum Refinery company produces an asphalt cement of 60/70 and 80/100 penetration grade and liquid asphalt MC-70, RC 250, and RC 800, which are used in both low- and high-volume roads.

## AN APPRAISAL OF DESIGN, MATERIALS, AND CONSTRUCTION IN JORDAN

Asphaltic road surfaces in Jordan are generally classified in three groups: thin, medium, and thick. Thin flexible pavements have a bituminous surface that is 25 mm thick on a granular base course. Medium pavements are frequently comprised of a bituminous surface with a bituminous penetrated base that has a combined thickness of less than 180 mm. Most designs were made by different consultants of various countries worldwide, who had used their own standards without specifically considering Jordan's particular soil and climatic conditions. These designs invariably neglected the peculiar winter conditions in Jordan, which not only show a drop in temperature but also cause a high soil saturation from winter rains and snow.

In traditional WBM construction in Jordan, layers of single-sized stones 38-63 mm in size are laid down, followed by nonplastic fines 6 mm and less in size that are rolled and watered into the surface to produce a dense material. This form of construction serves as a satisfactory riding surface when plastic soil is added to the surface. However, the plastic soil becomes a source of weakness if it is not properly removed before a bituminous surfacing is added.

A wet-mix graded material that is 39 to 53 mm and less in size has been tried. It was produced by direct crusher run or by recombining the different sizes of material. Experience has shown that such materials tend to separate and their handling and compaction characteristics are very sensitive to changes in moisture content.

Economics demand that the production of unbound aggregates should essentially be on a continuous crushed run basis. It has been observed that different aggregates crush in different ways. For instance, softer limestones generate a high dust content and hard igneous rocks tend to produce flaky aggregates that are short of fines. A need exists to provide more latitude in specifications to allow the use of more local materials.

Limestone is generally found to make a good road base. Some very hard and fine-grained igneous rocks are difficult to use because they cannot readily be compacted to form a dense, interlocking mass. Decomposed or badly weathered gravels and rocks produce clay, particularly when their parent rock is of a basic igneous type like basalt. Such decomposition cannot be generally diagnosed by the naked eye and may be discovered only by mineralogical examination.

The commonly used bituminous macadam base and binder course consists of a single course of 50 to 75 mm of compacted crushed aggregates that are premixed with bituminus binder that is laid immediately after it is mixed on a prepared base. The current specifications for gradings and the physical and mechanical properties of aggregates in bituminous layers are derived from AASHTO and BS specifications.

Asphaltic concrete, semi-dense carpet, premix carpet, and surface dressing are some of the wearing surfaces commonly used in Jordan. A survey of the bituminous surfaces that was performed by the Royal Scientific Society has revealed that the quantity of binder used in Jordan is normally more than that specified in the BS or AASHTO specifications (*1*).

## COMMON MODES OF FAILURE

It is apparent that many of the road failures that have occurred in Jordan in recent years might have been avoided by using better traffic predictions and designs with thicker layers of bitumen-bound materials. The following are the most common modes of failure on Jordanian roads.

### Rutting

Rutting problems occur in the form of permanent deformation in the wheelpath of the pavement wearing surface. Rutting problems reflect the consolidation or displacement of the underlying pavement material or the consolidation or displacement of the asphaltic surface itself. This problem becomes more critical during the unusually hot summer season.

### Slippage Cracks

Slippage cracks are the crescent-shaped fractures of the pavement wearing surface that usually point in the same direction as the thrust of wheels and show the lack of a bond between the surface layer and underlying course. Investigation of these cracks has shown that a contributing factor to this problem is a high deflection in the saturated unbound base material. This could be rectified by replacing unbound material with bituminous bound material.

### Collapse Resulting From Saturated Unbound Granular Materials

Investigation of the problem of road collapse has shown that subbases have been wet and were mixed with the wet clayey subgrade. A highly efficient drainage system or stronger waterproof material foundations are required to rectify this problem.

### Ravelling, Fretting, and Stripping

These problems result in the dislodgement of the aggregates from the surfacings. Fretting is mainly caused by poor compaction, thin layers, low bitumen content, and laying in cold wet weather. Stripping is mainly caused by the aging of bitumen and the use of hydrophilic aggregates. The solutions to these problems are careful quality control and adequate design.

### Slipperiness

This problem is primarily found in chip seal coats in the form of a loss of frictional resistance because of loss of aggregate from the seal surface and upward movement of bitumen under repeated traffic loading.

### Tender Mixes

A tender or slow-setting asphalt mix in a pavement has a low resistance to deformation by punching loads. Such a pavement scuffs under horizontally applied shearing loads after compaction has been completed. Tender mixes generally pose the following problems:

- The mix is difficult to roll,
- The specified density cannot be achieved,
- The pavement ruts soon after construction is completed,
- The pavement is soft after completion and will displace under the heel of a shoe,
- The pavement shoves under traffic,
- The pavement slips under traffic soon after construction, and
- The pavement indents under a punching load.

## PAVEMENT PERFORMANCE EVALUATION STUDIES IN JORDAN

In order to evaluate the construction practice and performance of pavements in Jordan, a study was performed for all the different low-volume roads in and around the Irbid region (Figure 1). A number of test lengths of 100 m were randomly selected to measure layer thickness. Cores were taken on the surface of each construction layer at a spacing along a line 1.0 m from the nearside edge of the nearside lane. A convenient temporary benchmark was used at each site when cores were taken from subsequent layers and it also provided a means of relating measurements when the cores were taken at a new position.

The proportion of thickness of individual layers, which were expected to range within the tolerances given in the following table, varied from 61 to 92 percent. Ten percent of the thicknesses were below the lower limit requirement for surface courses.

| *Surface* | *Level Tolerances (mm)* |
|---|---|
| Wearing course | ± 6 |
| Base course | ± 6 |
| Road base | ± 15 |
| Subbase | ± 10 |

Pavement evaluation helps to plan and assess the need for maintenance and strengthening. The frequently used Present Serviceability Rating (PSR) method of pavement evaluation is subjective and is based on the evaluation of the riding quality by a panel of persons that represents the road user.

The term serviceability index used in the PSR method of pavement evaluation is taken as a measure of the pavement's ability to service mixed traffic as indicated on a scale of 0 to 5 with 0 to 1 being very poor, 1 to 2 poor, 2 to 3 fair, 3 to 4 good, and 4 to 5 very good.

The Irbid road network was arranged by routes that had similar conditions to perform the study. This was done after a careful review of existing road project reports and all pertinent publications. All available data were assembled and analyzed for each route and a survey program was designed to provide the supplementary data required. The program included not only a determination of the structural condition of pavement components but a field condition survey that included measurements of cracking, patching, and rut depth.

After routes with similar conditions were identified, typical sample test routes with defined test sections were selected on which to perform a detailed PSR survey. A panel of 40 road raters were driven in a test vehicle at a defined speed and trained to rate a pilot test route on a 0 to 5 scale. These trained road raters were then asked to rate the actual test routes.

Individual PSR ratings were compared to the mean panel rating. The typical relationship is shown in Figure 2. The PSR

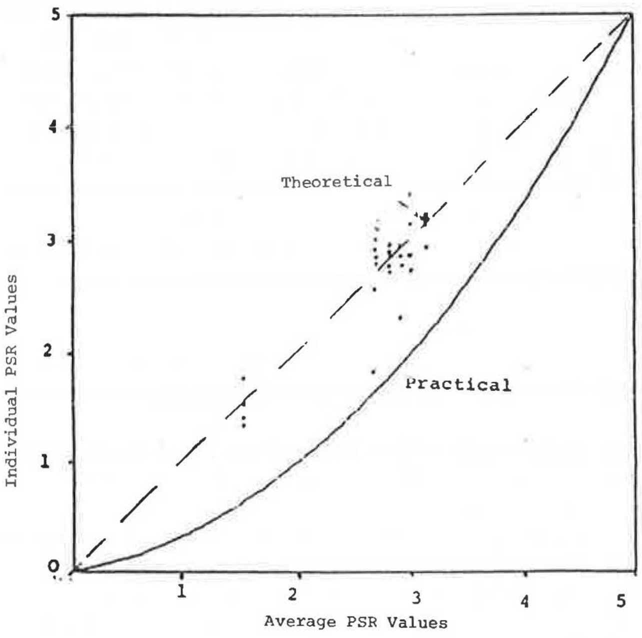

**FIGURE 2 Relationship between individual and average PSR using 35 data points.**

ratings were also compared to the Present Serviceability Index (PSI) that was determined by the procedure specified by AASHTO. This procedure involved the determination of the pavement condition survey data of cracking, patching, rut depth, and slope variance. The regression equation that related PSR ($Y$) and PSI ($X$) was of the form $Y = 0.068\ X^2 + 0.046\ Y + 2.10$ with a correlation coefficient of 0.81. The plot that indicates the variability is shown in Figure 3.

It is shown that the PSI appears to be capable of establishing relationships between objective pavement measurements and the subjective ratings of the road user. This relation also helps to get some measure of the degree of rutting, cracking, and patching. The method permits measurements to be obtained at various times and the establishment of a parameter that defines pavement condition, which shows that histories of pavement performance can be related to changes with time.

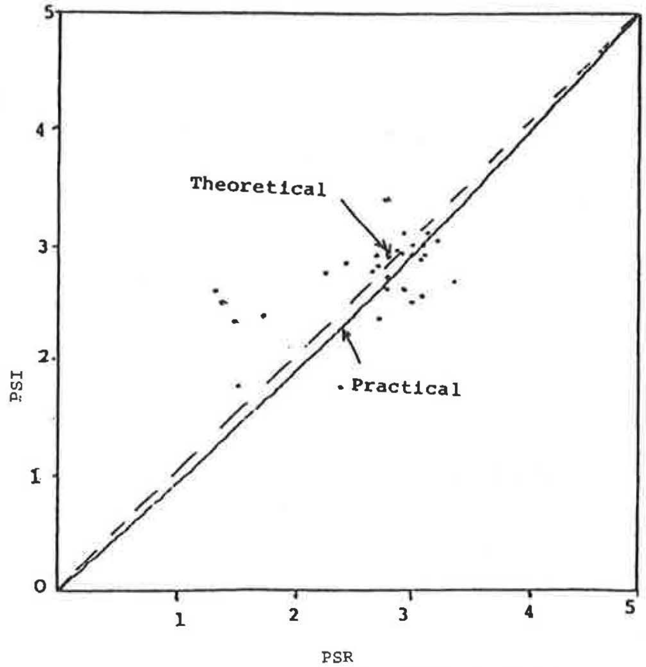

**FIGURE 3 Relationship between PSR and PSI using 30 data points.**

## SELECTED STUDIES OF SUBGRADE AND BASES

The results of a study on expansive subgrade soils in Jordan show that it is possible to obtain a reliable estimate of the in situ permanent deformation by using the results of the constant swell pressure tests and consolidation tests in conjunction with a probable moisture content profile during dry and wet seasons. The prediction equation that relates initial water content in percent ($W$) and the swell pressure in kg/cm$^2$ ($SP$) can be expressed as $\log (SP) = A + B \log (W)$. The magnitude of the constants $A$ and $B$ for Amman soil are 7.845 and -5.623 and for Irbid soil, 5.076 and -3.488, respectively.

The linear volumetric change due to the increase in moisture content can be determined by assuming that the rebound or swell takes place from an initial swelling pressure ($SP_i$) corresponding to dry season water content ($W_i$) to the final swelling pressure ($SP_f$) corresponding to wet season water content ($W_f$).

$$D = H \frac{(C_s)}{1 + e_o} \log \frac{(SP_f - SP_i)}{SP_f}$$

where

$H$ = the thickness of the subgrade soil concerned,
$C_s$ = the coefficient of swell, and
$e_o$ = the initial void ratio.

The coefficient of swell, $C_s$, and the initial void ratio, $e_o$, are obtained from consolidation tests. The average $C_s$ and $e_o$ values for Amman soil were found to be 0.34 and 0.69 and for Irbid soil, 0.070 and 0.84, respectively. After some of the roads in the Irbid area were investigated, it was found that final swelling pressures are invariably greater than overburden pressures (especially for low-volume pavements). The permanent deformations that were computed using the previously mentioned equation were compared with the deformations that were actually observed in the field using a straight edge. A good degree of agreement was obtained, as shown in Figure 4.

It has been observed in recent pavement deflection surveys conducted by the Ministry of Public Works in some parts of the country using the Benkelman Beam that sections with treated subbases (lime or cement) generally had lower deflections and larger radii of curvature than those with untreated subbases. The condition survey on some roads in the Irbid and Amman areas also revealed that sections with untreated subbases generally exhibited more map cracking in the surfacing than those with lime- or cement-stabilized subbases.

## ESSENTIAL PROPERTIES AND ACCEPTANCE TESTING FOR BITUMINOUS MIXES

Because about 75 percent of low-volume roads and all higher-volume roads in Jordan have some bituminous treatment, an understanding of mix behavior is needed. Most failures on existing Jordanian bituminous-surface roads have been related to underestimating traffic, saturation of granular materials, and problems in construction and compaction. In order to ensure that available materials are used in the most economic manner, the essential properties must be considered so that a long life span can be obtained economically. A flexible, durable, and highly stabilized mix that is impermeable, of a relatively high modulus, and made with relatively cheap, locally available aggregate is needed for the surface layer. A good riding quality, safety, and nonpolishing and abrasion-resistant characteristics are also required for the wearing surface. The mix requirements and the effects of mix composition on the requirements are summarized in Table 2 to illustrate the requirements just mentioned. It is shown in Table 2 that there is considerable conflict between the various requirements and that some compromise must be reached for any given situation.

The failure criteria of bituminous bound layers, which are of concern in Jordan in evolving design and maintenance strategies, involve the estimation of excessive permanent deformation and cracking. The mechanical characteristics required for the prediction of behavior in terms of primary response (stress and strain), limiting response (permanent deformation or rut depth), and functional response (surface profile) are the dynamic stiffness or resilient modulus, fatigue strength, and resistance to permanent deformation.

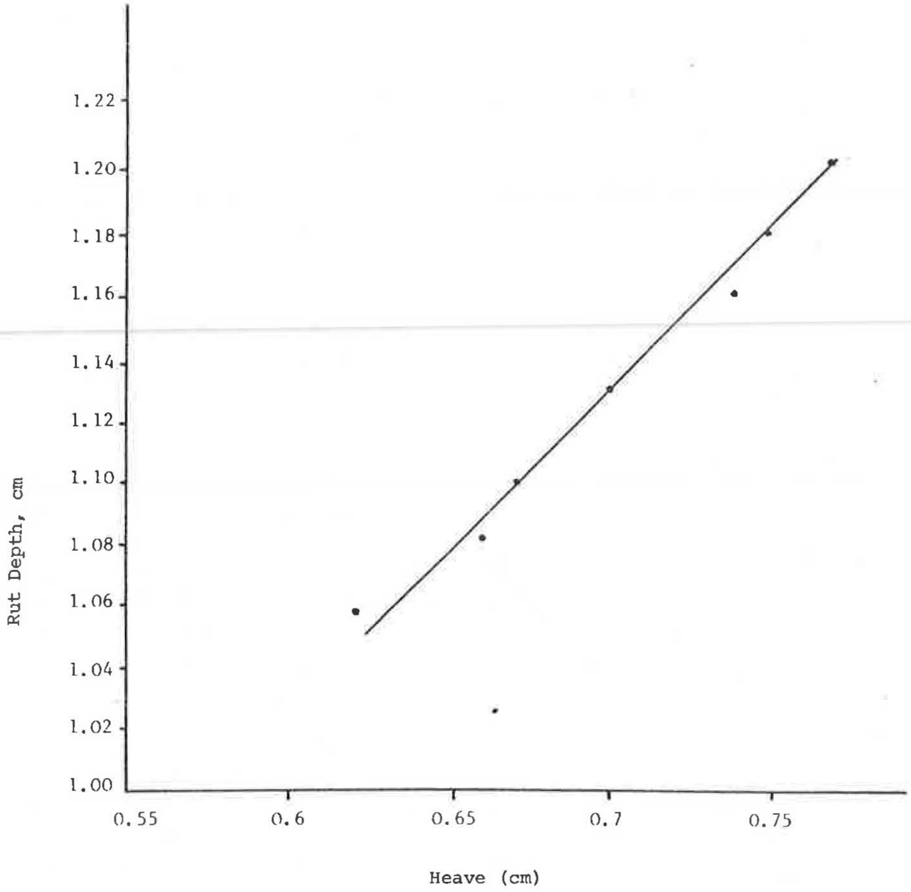

**FIGURE 4 Relationship between rut depth and heave on expansive soil in and around Irbid area.**

**TABLE 2 DESIRABLE MIX REQUIREMENTS AND COMPOSITIONS**

| Desirable Characteristics | Obtained By Aggregate Properties | Bitumen Characteristics Grade | Bitumen Characteristics Content |
|---|---|---|---|
| Stability | Dense grading<br>Rough texture | Hard | Low |
| Flexibility (resistance to fracture) | Dense grading | Soft or hard | Low |
| Durability | Dense grading | - | High |
| Workability | Rounded | Soft | High |
| Safety | | | |
| Skid resistance | Rough texture | - | Low |
| Fretting and ravelling | - | Soft | High |
| Impermeability | Dense grading | - | High |
| Stiffness | Dense grading | Hard | Low |

The resilient modulus is the ratio of applied stress to the resulting recoverable strain. The small permanent strain in bituminous materials for moving loads can be ignored. The resilient modulus can therefore be considered analogous to a time (rate of loading) and the temperature-dependent Young's modulus.

The resistance of a bituminous mix to cracking depends on its fatigue strength and is expressed as a relationship between maximum tensile strain and the number of load applications.

## NEEDED RESEARCH AND PRIORITIES

The empirical design approach for low- or high-volume roads is unsatisfactory because new situations arise, such as heavier axle loadings, shortage of high-quality aggregates, atypical environmental conditions, and changes in compaction techniques, that are at variance with the experience upon which the specifications were based. The development of a rational and scientific approach to deal with varying situations requires a sound understanding of the fundamental behavior of the pavement structure and its constituent materials. This has led to the need for analytically based structural design procedures that use suitable and representative material properties (*2, 3*). The application of these methods to Jordan's environment is under consideration.

Gradings that approximate the Fuller maximum density curve generally appear to work well. However, it has been found that these gradings do not always give the true maximum density because of variations caused by the roughness and shape of the aggregate particles (*4*). These findings will be investigated.

It appears that in situ performance of any material cannot be determined simply on the basis of laboratory tests. The actual behavior of the road material depends on the details of the pavement's structure as a whole together with the loading and environmental conditions. The effect of changing a particular mix parameter on the life of a pavement can only be assessed when the pavement is analyzed under all relevant conditions. Several differences exist between the stress-controlled, laboratory-repeated load test and the in situ road situation. In the latter, traffic loads vary in such a way that strain pulses are of variable magnitude, and rest periods occur between strain pulses. This area will be studied further.

Another problem that arises in the application of laboratory findings to practice is the influence of the lateral distribution of wheel loads. If all wheels do not pass exactly over the most heavily trafficked part of the pavement, a corresponding extension of fatigue life may occur (*2*).

Much needs to be done to understand asphalt technology for pavement surfaces and bases. This can only be achieved by considering conservation, economy, performance, ease of construction, and ease and cost of maintenance in the decision-making process. This will require future forward planning to avoid premature failure, optimize materials and methods, rationalize specifications, develop new and improved techniques, and plan useful investment.

## CONCLUSION

A brief appraisal of Jordanian road traffic, highway network, road-making materials, and performance under local conditions was presented in this paper. The results of some failure investigations have shown that poor-quality construction is often the cause of these failures.

Most surfaces of low- and higher-volume roads contain bitumen. Data have been collected that classified the types of failures and present serviceability ratings have been established for a limited number of highways. Work is continuing with an emphasis on the collection of background technical data on low- and higher-volume roads.

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