The Development of Low-Volume Roads in India

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India faces the enormous task of providing all-weather road access to all of its nearly 600,000 villages. The Central Road Research Institute (CRRI) has been engaged in research work on a variety of aspects, some of which are discrete items. Reported in this paper are findings in regard to the study of the socioeconomic impact of road development in rural regions, network planning, pavement design, and efforts to evolve intermediate technologies. The study of socioeconomic aspects indicates that some parameters are more directly affected by road development, such as literacy, proportion of non-agricultural workers, unit agricultural yield, and unit fertilizer consumption. Other socioeconomic parameters on which road development has a more indirect effect are facilities for health, education, banking, and postal services. A new planning methodology that is based on graph theory is presented. In its present form, it provides a simple method for more rational decision-making, but it has certain limitations. Reported herein are findings from comprehensive work performed by CRRI on the design of pavement for low-volume roads to allow for such elements as traffic of solid-wheeled carts, varying subgrade moisture conditions, and minimum acceptable serviceability levels. Intermediate technologies that center around the use of agricultural tractors with agricultural implements and other towed equipment are also mentioned.

Most of India's population continues to live in about 600,000 villages that are scattered in various rural regions. From the standpoint of overall socioeconomic development, it is very important that the transportation network of the country reach out to these numerous population centers. Roads and road transport are preeminently suited to meet the transportation needs involved. A little over one-third of the villages have already been provided with all-weather road access.

Completion of this task calls for great financial outlays and, therefore, utmost thought is to be given to possible economies. The Central Road Research Institute (CRRI) has been devoting considerable effort toward the development of improved and more cost-effective techniques for the planning, design, construction and maintenance of low-volume roads. The CRRI had done work earlier on the approach to planning rural road networks that applied the concept of minimal spanning trees. The CRRI recently had the opportunity to review nine district-level studies that were undertaken in different parts of the country to assess the socioeconomic impact of road development in rural regions. The review was undertaken as a step toward further analysis, synthesis, and possible rationalization.

The development of techniques for the use of soils and other local materials in road construction has been a major concern. A number of small projects were arranged in different parts of the country in the form of test tracks and demonstration works. The feedback from these and other projects provided the basis for such aspects as the suitability of techniques for benefication of local materials available in different parts of the country, estimation of the highest subgrade moisture content, estimation of subgrade strength from index properties, deterioration of low-volume roads, and relationships to pavement design of different serviceability levels.

Road construction in India continues to have a high level of manual input. The CRRI has been working on the development of intermediate technologies appropriate to the small and scattered works of village roads. This work has consisted of technologies based on the use of agricultural implements, animal power, and the agricultural tractor as a prime mover. The CRRI has also developed new pavement systems for low-volume roads in different regions with certain special conditions.

A number of special programs have been launched from time to time to speed the socioeconomic development of rural communities. The construction of low-volume roads is an important component of these programs. The organizational structure has also been under review. A number of exercises have been undertaken in recent years in government circles and in the Indian Roads Congress to update the management of low-volume roads.

THE DEVELOPMENT OF ACCESS ROADS

When India launched its 5-year development plan in 1951, the total road length was about 400,000 km, nearly two-thirds of which was unsurfaced. Road development has been a notable component, both directly and indirectly, in the various 5-year plans that have launched since then. A number of programs were created with such objectives as area development, provision of minimum needs, and generation of employment that have contributed notably to the construction of low-volume roads.

The total number of villages in India are broken down according to population size and the percentage of villages that are connected by all-weather roads as of April 1, 1986, in the following table.

Population	*Total Number of Villages*	*Percent Connected With Roads*
1,500 and above	69,408	74
1,000 to 1,500	56,609	54
Less than 1,000	466,076	29
Total	592,093	37

It can be seen that a great majority of the villages have a population of less than 1,000. The percentage of the total number of villages that are connected by roads is 37. In order to connect all villages with roads, the length of the low-volume road network would have to be increased to 2.2 million km (Figure 1) (*1*).

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SOCIOECONOMIC ASPECTS

It is generally accepted that the provision of roads contributes notably to a variety of socioeconomic activities. If this contribution could be quantified, an assessment could be made of the priority to be placed on road development in an economy of highly competing needs. Some attempts have been made in the past to understand the interactive relationship between roads and development. Studies with similar objectives were launched under the aegis of the Indian Roads Congress in nine districts (Figure 2) that were typical in regard to such factors as the level of development already reached, the potential for development, the nature of the economic base, and the characteristics of the terrain. These studies were entrusted to separate agencies. It was soon realized that the data and findings from individual district studies would have to be further explored to place data on as uniform a base as possible, and to rationalize the differences and findings. This task was entrusted to the CRRI and some findings can be reported based on work performed thus far.

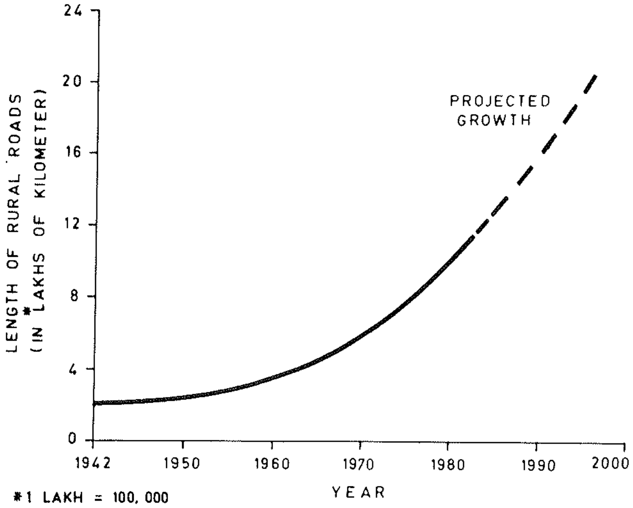


FIGURE 1 Growth of rural roads in India.

FIGURE 2 Locations of district-level studies on socioeconomic aspects of rural roads.

It can be anticipated that the existence of a road in the neighborhood of a rural community can contribute to development directly and indirectly. The effects of the availability of road access on socioeconomic activities frequently depend on the availability of other inputs. For example, the availability of road transport can contribute to the development of agriculture only if irrigation facilities, improved seeds, fertilizers, and bank loans are available. The nine district-level studies were performed by seven different agencies. Although these agencies were given common terms of reference, there have been variations in detail in regard to the collection and treatment of data.

When CRRI undertook the task of rationalization and synthesis, it was soon realized that a district with its own heterogeneity is too large a unit for the impact to be assessed. The districts were therefore divided into subdistricts according to terrain (plain, rolling, or hilly) and level of development (relatively undeveloped and relatively developed). Two districts also had a sizable tribal population.

The three road parameters studied were road length/unit area, road length/unit population, and level of road access, or distance between a village and the nearest road. Presented in Figures 3 to 10 are some of the plots that indicate the effect of the intensity of road development on certain socioeconomic parameters. These data are in regard to the subdistricts with plain or rolling terrain, but include both developed and undeveloped pockets. The following socioeconomic parameters are presented:

- Literacy level, or percent literate (Figure 3),
- Nonagricultural workers as a percentage of total workers (Figure 4),
- Agricultural yield in tonnes/hectare (Figure 5),
- Fertilizer consumption in tonnes/1000 hectares (Figure 6),
- Cooperative banks/100,000 persons (Figure 7),
- Primary schools/1,000 persons (Figure 8),
- Primary health care centers/100,000 persons (Figure 9), and
- Post offices/100,000 persons (Figure 10).

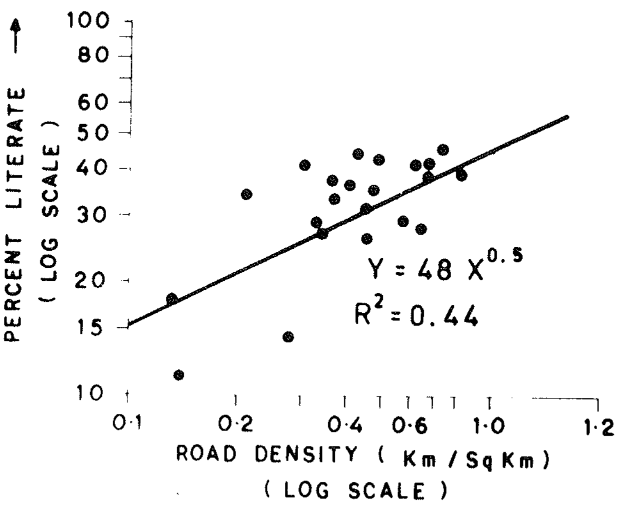


FIGURE 3 Percent literate versus road density.

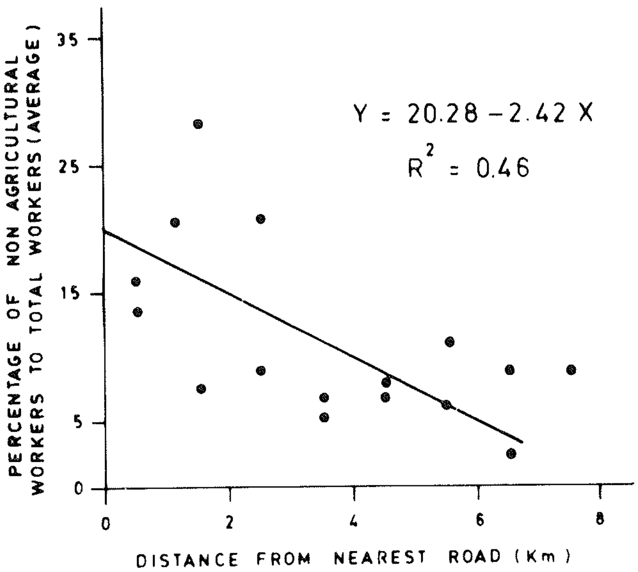


FIGURE 4 Nonagricultural workers versus distance from nearest road.

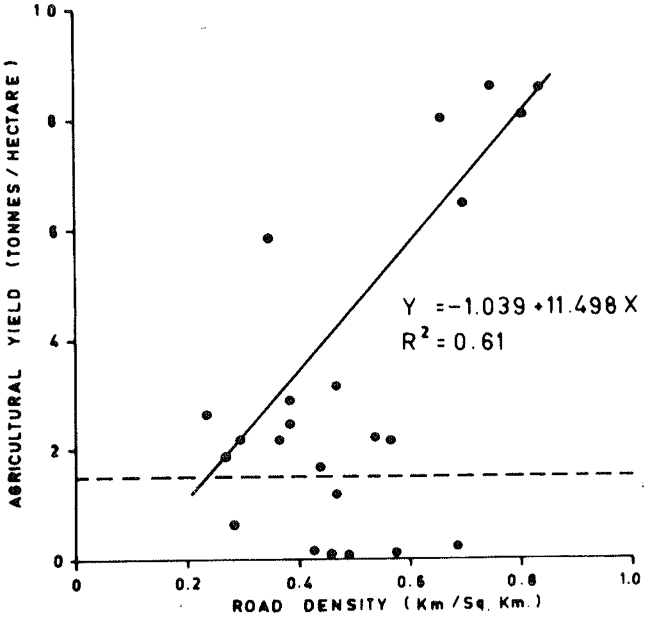


FIGURE 5 Agricultural yield versus road density.

It can be observed from the plots in these figures that there are pockets in which certain parameters had not been duly influenced by road development. It is believed that the function of the road could not be exploited in these cases for want of other needed inputs. The correlation and other coefficients were arrived at after excluding these pockets, as shown in Figures 5 to 9. The same also applies to the stray plots that deviated greatly from the general trend for various reasons.

The plots presented in Figures 3 to 10 can be divided into the following two groups: aspects in which the function of the road is more direct (Figures 3 to 6), and aspects in which the function of the road is indirect (Figures 7 to 10).

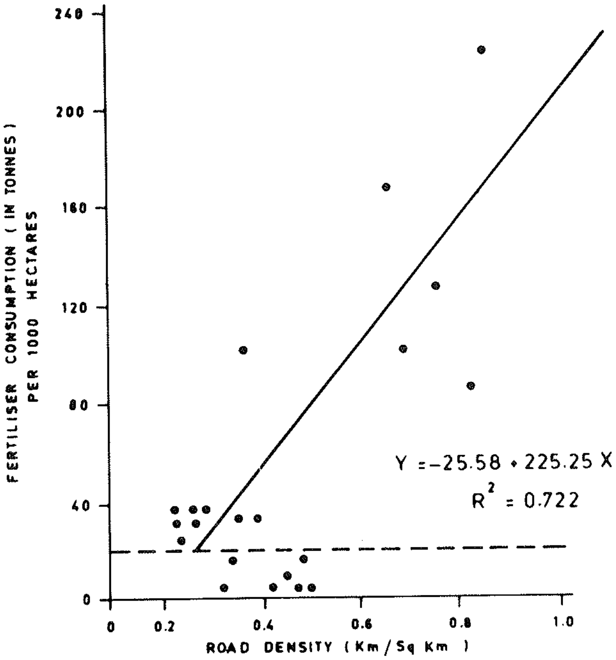


FIGURE 6 Fertilizer consumption versus road density.

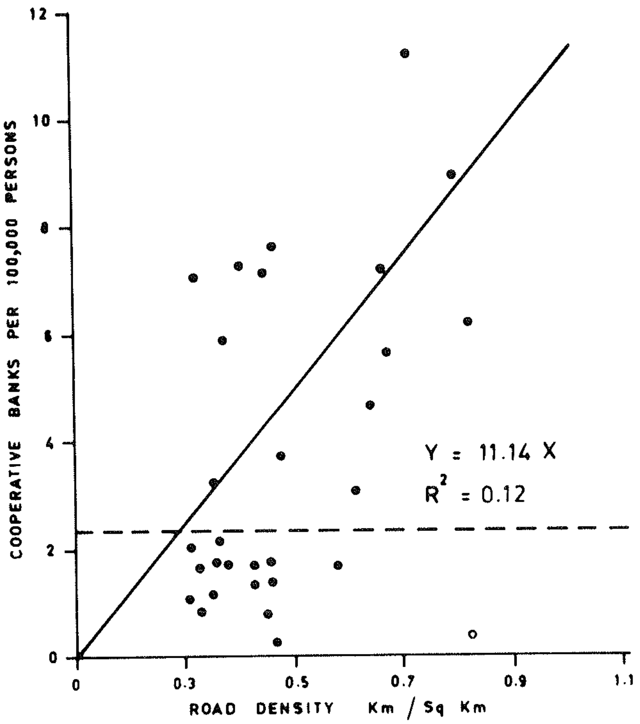


FIGURE 7 Cooperative banks versus road density.

Direct Aspects

The literacy rate significantly increases with road density (Figure 3) according to the following relationship:

$$\text{Percent literate} = 48 \times (\text{road density in km/km}^2)^{0.5} \qquad (R^2 = 0.44)$$

It can be surmised that the provision of roads enables students to travel to more distant schools. However, it can also be

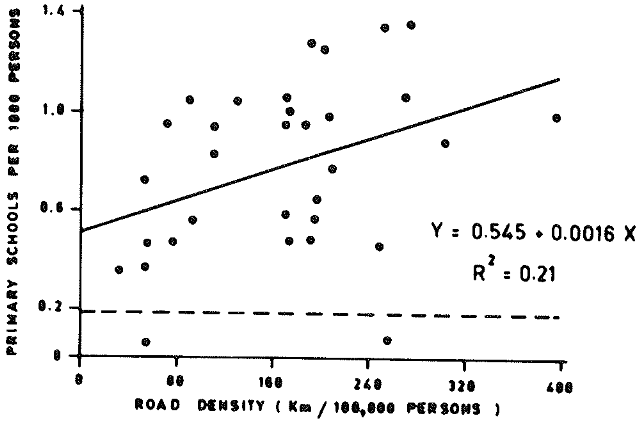


FIGURE 8 Primary schools versus road density.

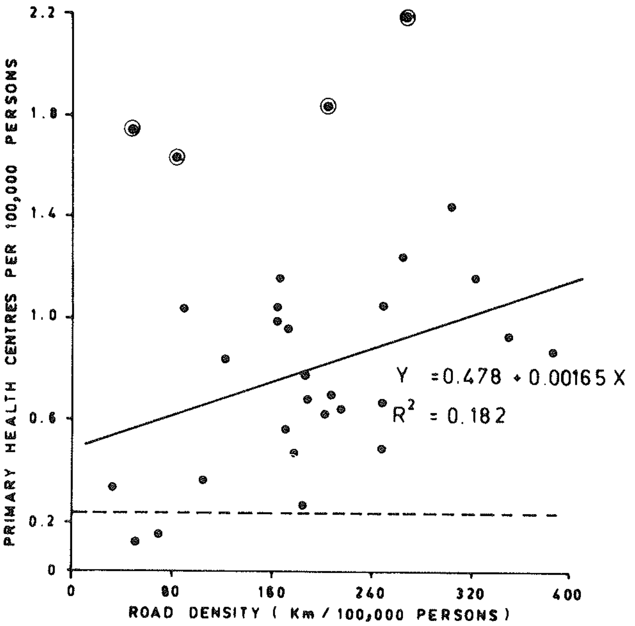


FIGURE 9 Primary health care centers versus road density.

surmised that the availability of teachers improves because they can travel to rural regions that were previously inaccessible.

The effect of roads on the extent to which the populace depends on agriculture is demonstrated in Figure 4. It can be seen that the percentage of nonagricultural workers is very low in pockets that are distant from roads, but that this percentage increases as road access improves according to the following relationship:

Percentage of nonagricultural workers to total workers = 20.28 - 2.42 (distance from nearest road in km)
(R^2 = 0.46)

This can be taken to mean that opportunities for employment and development of skills in nonagricultural activities improve with road access.

After the pockets with little or no road development are eliminated, it can be seen (Figure 5) that a fairly linear relationship exists between unit agricultural yield and road density, as follows:

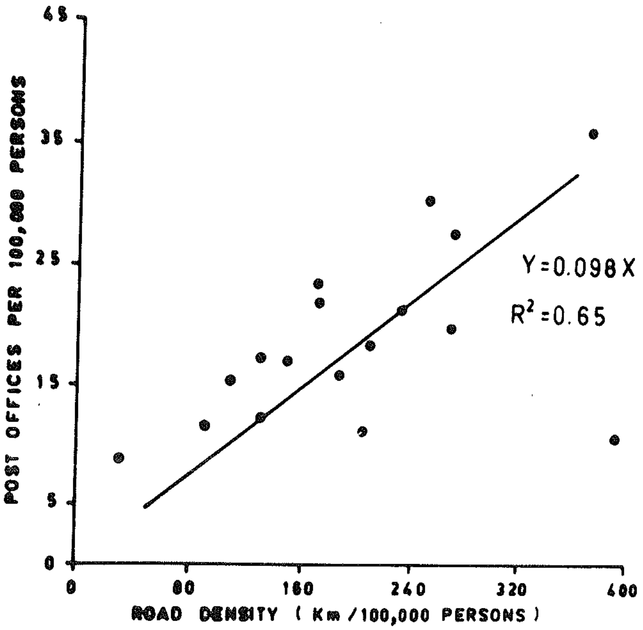


FIGURE 10 Post offices versus road density.

Agricultural yield in tonnes/hectare = 11.498 (road density in km/km^2) - 1.039
(R^2 = 0.61)

This can be taken to mean that road access enables a variety of contributions to be made to agricultural yield, such as an improvement in extension work to improve agricultural practices; better availability of inputs like improved seeds and fertilizers; better farmgate prices, which promote intensive agriculture; and other agricultural services.

Proof that road access improves the availability of farm inputs can be found in Figure 6, in which the unit consumption of fertilizer is related to an increase in road density, as follows:

Fertilizer consumption in tonnes/1000 hectares = 225.25 (road density in km/km^2) - 25.58
(R^2 = 0.722)

Fertilizer consumption increases significantly with an increase in road density.

Indirect Aspects

It can be seen in Figure 7 that a linear relationship exists between the availability of banking services and road density, as follows:

Cooperative banks per 100,000 persons
= 11.14 (road density in km/km^2)
(R^2 = 0.12)

It can be surmised that a greater demand for banking services exists, and banks find it easier to operate in rural regions, when roads are available.

Similar, though somewhat subdued, is the correlation obtained between the availability of primary schools and road density (Figure 8), as follows:

Primary schools/1,000 persons
= 0.0016 (road density in km/100,000 persons) + 0.545
(R^2 = 0.21)

The demand for primary education and the availability of teachers in primary schools can be taken to improve with the availability of road access. The decline in the sharpness of correlation trends may be a result of the fact that many villages tend to have their own primary schools. Similar trends are shown in Figures 9 and 10 of the effect of road density on the availability of primary health care centers and post offices. The relationships that emerge are as follows:

Primary health care centers/100,000 persons
= 0.00165 (road density in km/100,000 persons) + 0.478
(R^2 = 0.182)

Post offices/100,000 persons
= 0.098 (road density in km/100,000 persons)
(R^2 = 0.65)

The CRRI has undertaken the collection of further data in three selected subdistricts. Further analyses will be undertaken on the availability of supplementary data. In that regard, the above findings and correlations are not final.

PLANNING OF LOW-VOLUME ROADS

The planning of roads in rural regions can be said to center on the maximized socioeconomic benefit per unit of investment and the attainment of high connectivity. The element of distributive justice also exists. The decision to provide certain villages with road access is currently made on the basis of their population sizes; the linking modes are decided more or less subjectively. In order to prepare master plans at this stage of development, CRRI devised a simple methodology for more rational decision-making. In this methodology the flow of traffic in a rural road network can be considered analogous to the flow of electricity in a circuit (*2*). The road transportation system can be visualized with the following components:

- Market centers (high charge points) that are interconnected to form a grid that carries relatively high traffic volumes (high charge), and
- Villages of different sizes (that carry a charge proportionate to their population) that interact between themselves and with market centers.

High charges at market centers and along main roads attract the smaller charges that are situated at various villages around them. Village roads are assigned weightage in direct proportion to the force of attraction exerted and in inverse proportion to the connecting road length. By using these weightages, the final optimized rural road network can be generated by way of the concept of minimal spanning trees. The rural road network emerges as several minimal spanning trees in which the roots are situated either on main roads or directly at the market centers. The various steps involved in generating the rural road network are described in the following paragraphs and shown in Figures 11*a* and 11*b*.

In the first step, a plan is prepared that shows the location of various villages, market centers, and main roads.

In the second step, the market centers, main roads, and villages of various population levels are assigned the following magnitudes of electric charge:

- Individual village—population is divided by 100 units subject to a maximum of 100,
- Market centers—100 units, and
- Main roads—80 units.

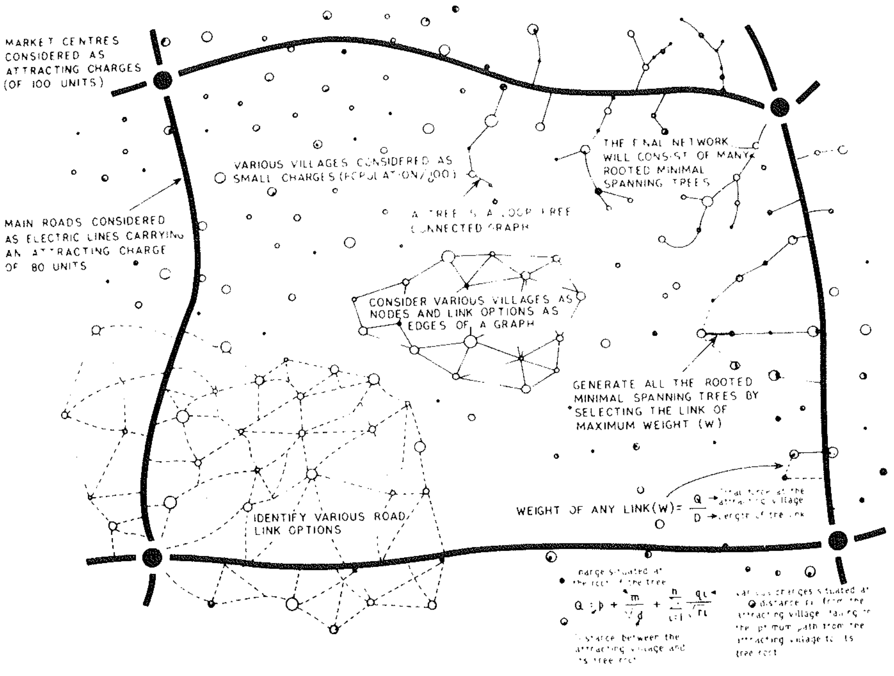
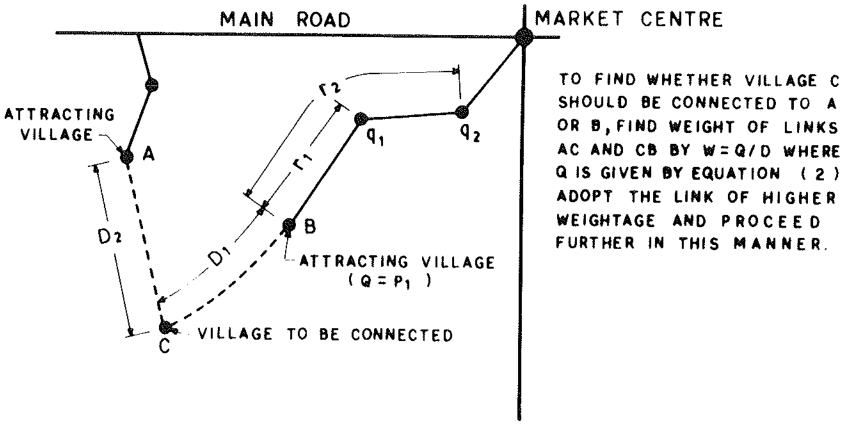


FIGURE 11a A systems approach to rural road network development.



TO FIND WHETHER VILLAGE C SHOULD BE CONNECTED TO A OR B, FIND WEIGHT OF LINKS AC AND CB BY W = Q/D WHERE Q IS GIVEN BY EQUATION (2) ADOPT THE LINK OF HIGHER WEIGHTAGE AND PROCEED FURTHER IN THIS MANNER.

FIGURE 11b Procedure for determining the road links.

In the third step, the villages closest to the market centers and main roads are connected, proceeding toward the interior, depending on the weight (W) of the road length. This weight is given by the following equation:

$$W = Q/D \qquad (1)$$

where

D = length of the link option, and
Q = total traffic-attracting force situated at the market center, main road, or village already connected, as the case may be.

The variable Q is equal to 100 or 80 if the village is to be directly connected to the market center or main road, respectively. When a village under consideration is to be connected to a village already connected by a rooted tree, this village is called an attracting village. The variable Q is calculated from the following equation:

$$Q = p + \frac{m}{\sqrt{d}} + \sum_{i=1}^{n} \frac{q_i}{\sqrt{r_i}} \qquad (2)$$

where

p = self-charge of the attracting village,
m = charge situated at the tree root (market center or main road),
d = distance of the attracting village from the tree root, and
q_i = charge (population divided by 100) of the i^{th} village that is already planned to be connected, situated at distance r_i from the attracting village.

This procedure is depicted in Figure 11b.

The generation of various rooted, minimal spanning trees will start from their roots. In order to identify the various tree roots, the villages that are closest to the market centers and main roads are connected by selecting the links of maximum weight (W) calculated from Equation 1. All possible roots can be identified in this manner. The various minimal spanning trees are generated side by side by adding links of maximum weight (W) and connecting village to village. The procedure is continued until all villages are connected.

The system thus developed is an idealized one in which the existing rural roads are not considered. In order to make use of the existing road network to the maximum extent possible, the generated network is superimposed on the existing one. Modifications are then made in the planned network by considering the existing roads to have maximum weight. Another refinement is required in cases in which a proposed road link must cross a wide waterway or ridge, which involves a great expenditure. In such cases, it is necessary to examine the proposed links in light of field conditions, and make necessary modifications and adjustments to keep the cost as low as possible. This is similar to cases in which the link options have marginal differences in weightage.

Because the different stretches of a village road that form the branches of a minimal spanning tree have different traffic volumes and composition, it is necessary to classify village roads and sections to determine standards of design and construction. Three different types of village roads are proposed, as follows:

- Type A—village roads that form the main stem of minimal spanning trees and connect a large number of villages, either directly to the market center or through the main road. Such roads should be designed according to CRRI design curves for Category I rural roads, which are discussed in a later section.
- Type B—village roads that form auxiliary branches of minimal spanning trees. These roads could be designed according to CRRI design curves for Category II rural roads.
- Type C—village roads that interconnect the smaller isolated villages. These roads could be designed similar to Type B or developed as earth roads in the first stage.

PAVEMENT DETERIORATION UNDER RURAL TRAFFIC

The rural traffic in India is generally a mix of animal-drawn carts (many of them solid-wheeled), light, pneumatic-tired vehicles such as tractor-trolleys and other intermediate vehicles, and a few heavy vehicles such as buses and trucks. The solid-wheeled, animal-drawn carts impose low wheel loads but very high contact stresses (Figure 12). The repeated operation of these solid-wheeled carts causes deep rutting in the pavement (Figure 13) (*3*). Studies were performed at the Central Road

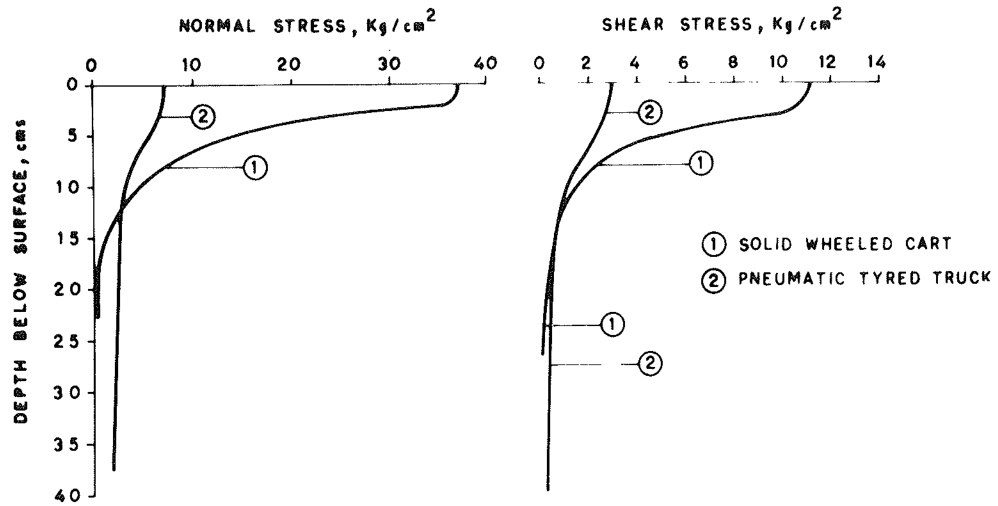


FIGURE 12 Typical variations of normal and shear stress with depth.

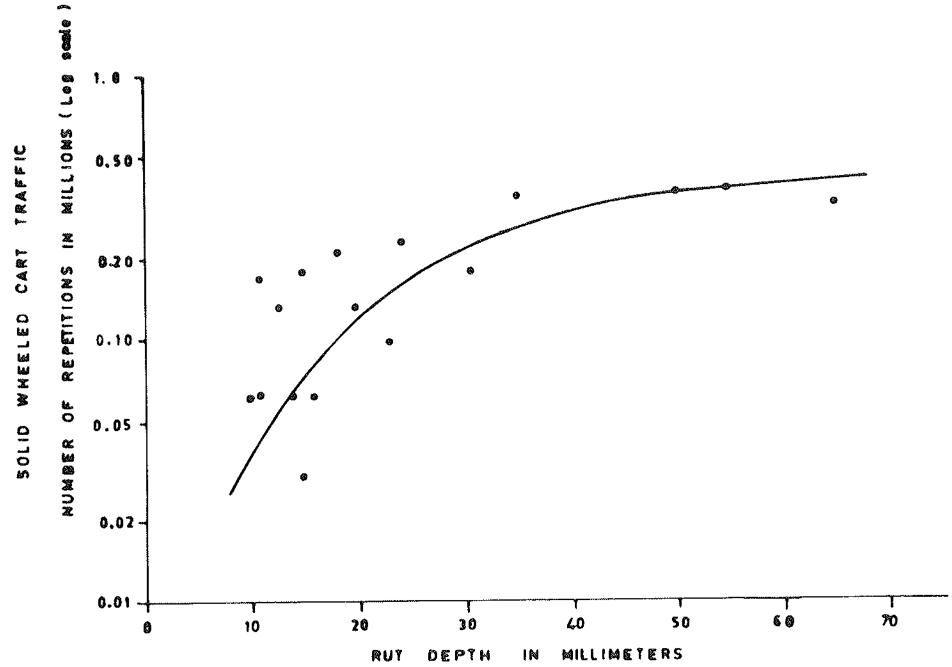


FIGURE 13 Relationship between depth of rutting and repetitions of solid-wheeled cart.

Research Institute on the relative effects of damage caused by different types of rural vehicles (*4*). These studies indicated that solid-wheeled carts caused twice as much damage as the heavy, pneumatic-tired commercial vehicles and five times as much damage as the light, pneumatic-tired vehicles (Figure 14). It was therefore considered appropriate to adopt a composite traffic index that incorporated all three types of vehicles in proportion to the relative effects of their damage for purposes of pavement design. The CRRI is working on field trials of a hub insert developed to improve the contact between the solid wheel and the traveled surface.

In order to control and regulate the evenness of pavement layers and road surfaces, the CRRI has developed a range of devices (*5*). One such device is an unevenness indicator, which essentially is a traveling straight edge with datum wheels fixed at 3 m and a probing wheel in the middle. As the unit is moved at walking speed, it indicates the magnitude of bumps and depressions. Then, according to preset tolerance limits, it marks the nonconforming high and low spots by throwing paint on the surface and sounding a buzzer. The device is shown in Figure 15.

Another device is a profilograph, which consists of a rectangular steel frame supported on a wheel base of 3 m with a central probing wheel. The relative movement of the probing wheel is plotted on a paper recorder, which produces a continuous record of the profile in regard to the moving datum. The device is shown in Figure 16.

PAVEMENT DESIGN CURVES

The low-volume rural roads are short in length. The year-round passability on these roads is more important than the speed of travel. The CRRI developed a set of pavement design curves for

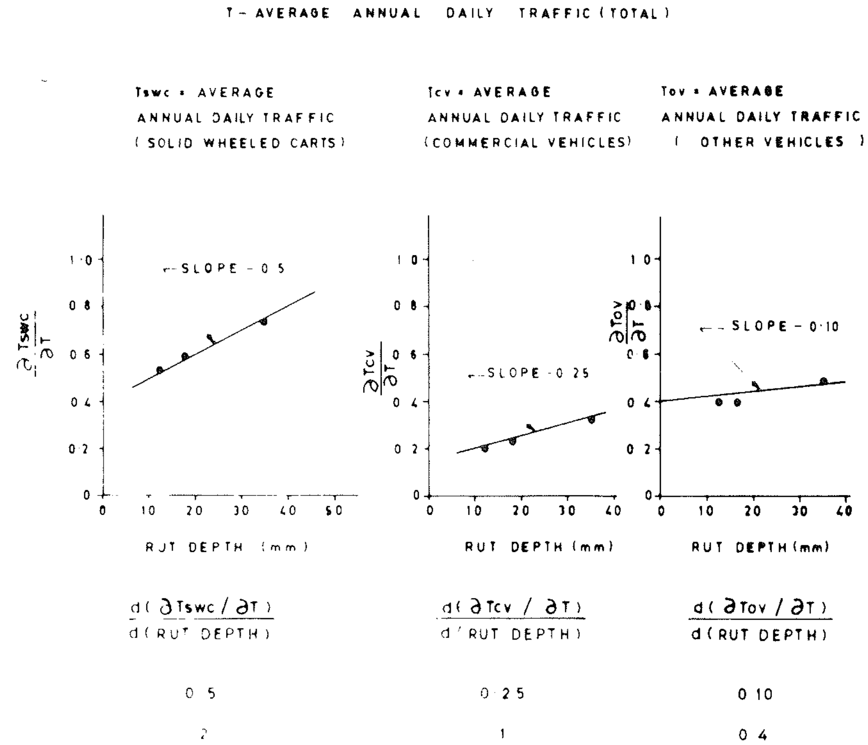


FIGURE 14 Evaluation of the relative damaging effects of solid-wheeled carts, commercial vehicles, and other vehicles on rural roads.

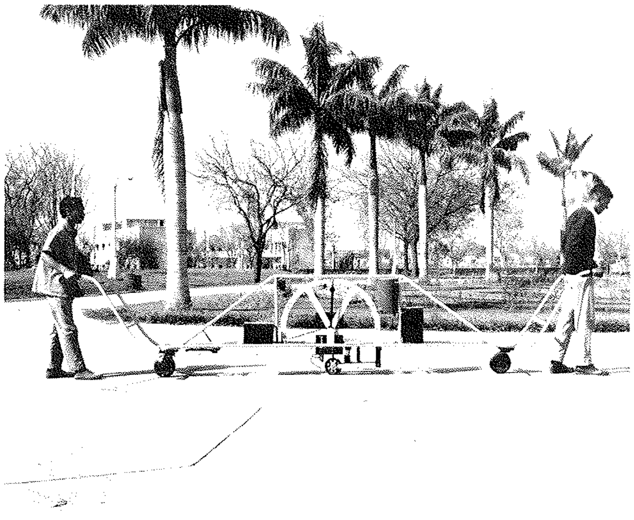


FIGURE 15 Unevenness indicator.

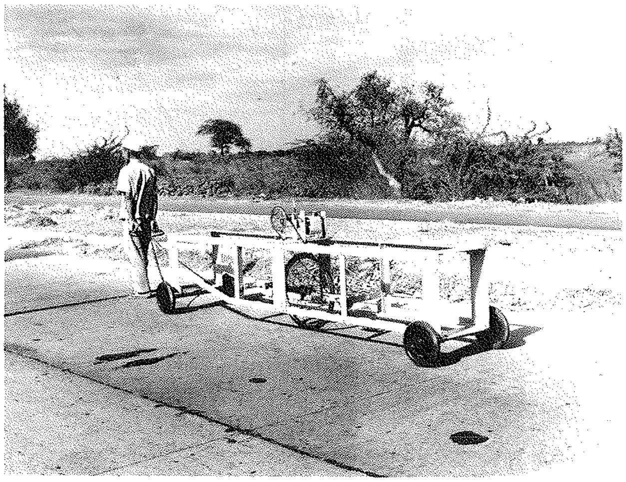


FIGURE 16 Profilograph.

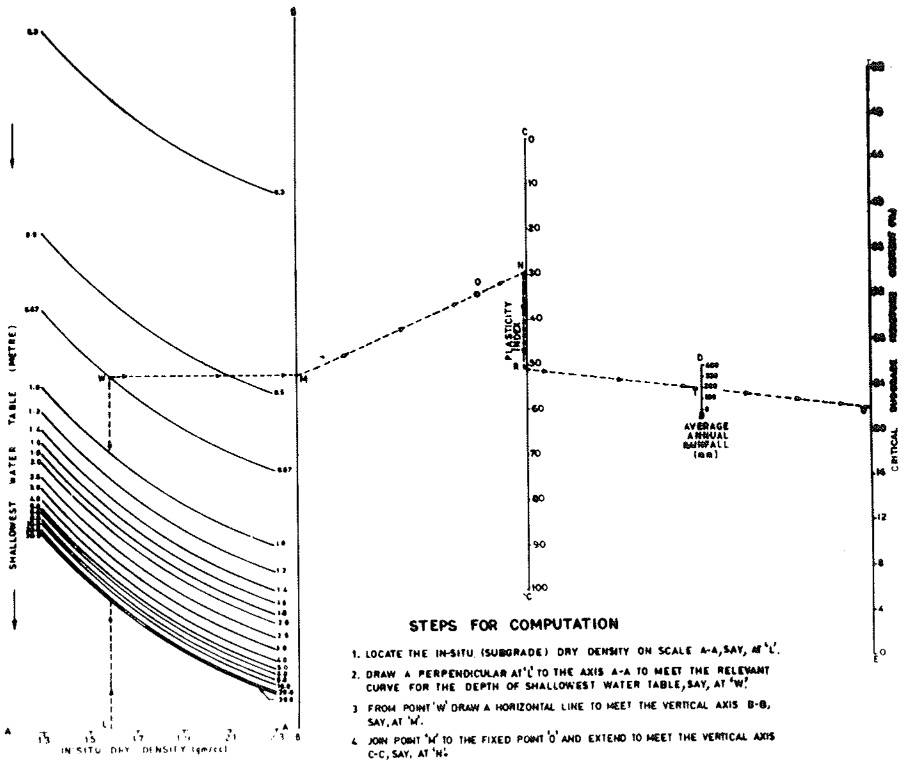
these roads according to two appropriate levels of serviceability. The design moisture content needed to evaluate the subgrade strength greatly influences pavement thickness requirements. A comprehensive survey of a large number of existing roads in different parts of the country was therefore undertaken to develop a simple method of estimating the critical subgrade moisture content. Based on the analysis of data obtained from this survey, the following statistical relationship was developed (*6*).

$$\text{Critical moisture content} = 0.023X_1 + 0.011X_2 + 0.045X_3 + 0.31X_4 + 10.70X_5 + 3.37X_6 + 0.02X_7 - 4.76$$

where

X_1 = percent retained on ISS 2.36-mm sieve,
X_2 = percent fraction passing ISS 2.36-mm sieve and retained on ISS 75 micron,
X_3 = percent fraction passing ISS 75 micron,
X_4 = plasticity index,
X_5 = 1/in situ dry density in gm/cc,
X_6 = 1/shallowest water table (m), and
X_7 = average annual rainfall in cms.

A ready-to-use nomograph that can be used to estimate critical subgrade moisture content is given in Figure 17.



STEPS FOR COMPUTATION

1. LOCATE THE IN-SITU (SUBGRADE) DRY DENSITY ON SCALE A-A, SAY, AT 'L'.
2. DRAW A PERPENDICULAR AT 'L' TO THE AXIS A-A TO MEET THE RELEVANT CURVE FOR THE DEPTH OF SHALLOWEST WATER TABLE, SAY, AT 'W'.
3. FROM POINT 'W' DRAW A HORIZONTAL LINE TO MEET THE VERTICAL AXIS B-B, SAY, AT 'M'.
4. JOIN POINT 'M' TO THE FIXED POINT 'O' AND EXTEND TO MEET THE VERTICAL AXIS C-C, SAY, AT 'N'.
5. ALONG THE VERTICAL AXIS C-C, ADD THE PLASTICITY INDEX OF THE SOIL FROM 'N', SAY, UPTO 'R' (WHERE, NR = PLASTICITY INDEX).
6. JOIN POINT 'R' WITH THE AVERAGE ANNUAL RAINFALL AXIS D-D, SAY, AT 'T' AND EXTEND TO MEET THE AXIS E-E AT THE POINT, SAY, 'U' WHICH FINALLY READS THE CRITICAL SUBGRADE MOISTURE CONTENT (%).

FIGURE 17 Nomograph for the computation of critical subgrade moisture content.

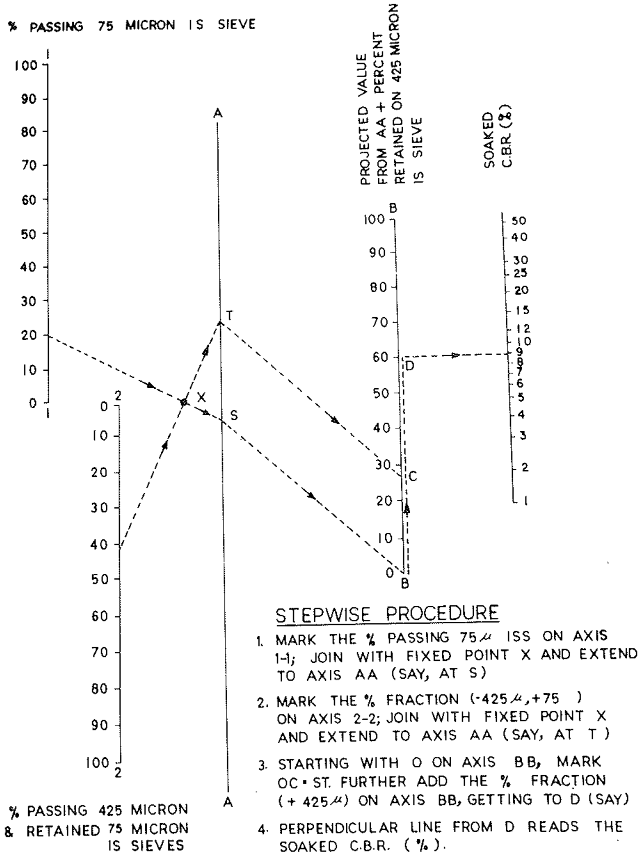
However, in regions of high rainfall and water-logged regions, 4-day soaked CBR values should be taken for design purposes. The nomograph shown in Figure 18 can be used to quickly estimate the soaked subgrade CBR values at Proctor density, based on particle size analysis. The following statistical expression relates the soaked CBR values of moorums (soil-gravel) with simple index properties (*7*).

$$\text{Soaked CBR} = 44.0A - 0.2B - 0.59C + 0.22D - 44.71$$

where

A = dry density at standard Proctor compaction (gm/cm^3),
B = percent by weight of fraction retained on IS 2.36-mm sieve,
C = percent by weight of fraction passing IS 75 micron sieve, and
D = plasticity index.

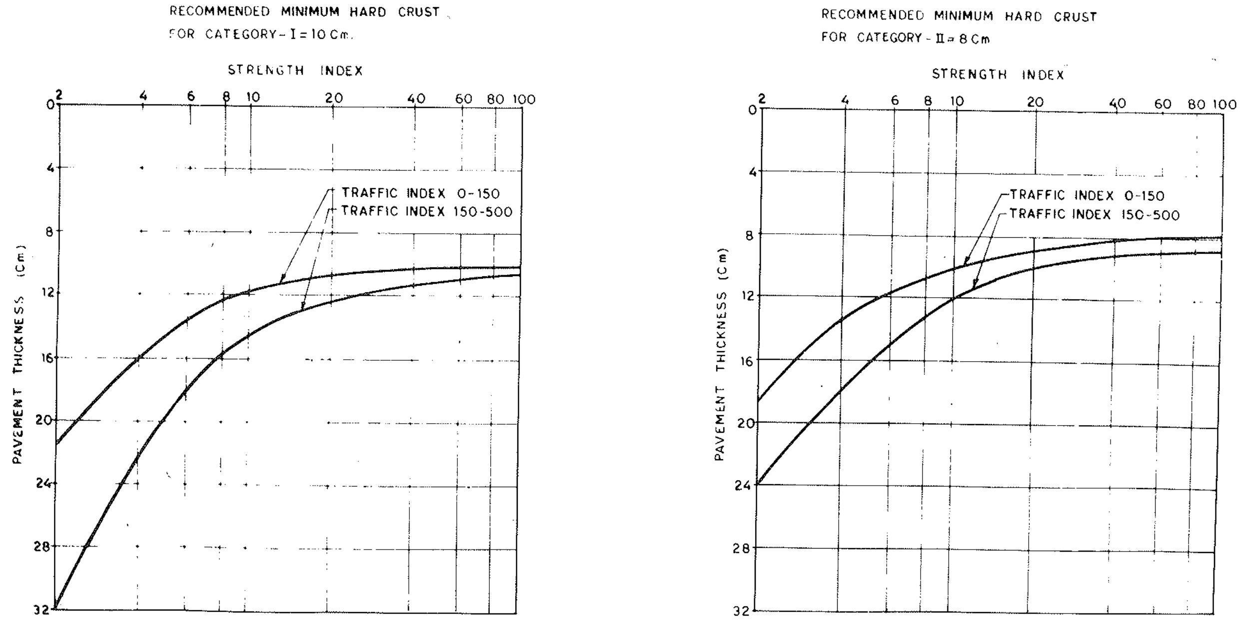
A comprehensive survey of over 200 existing rural roads (after about 5 years of service) was undertaken in regard to the traffic volume and composition, pavement thickness and composition, subgrade and climatic conditions, and serviceability level. The data collected from this survey were analyzed. Then, based on the parameters of the traffic index and the subgrade strength index (correlated with CBR), two sets of pavement design curves (Figure 19) were developed for two categories of rural roads. The design curves depended on the following minimum levels of acceptable serviceability. The depth of rutting and transverse slope variance are 5 to 15 mm and 5 to 20, respectively, for a Category 1 road, and 10 to 40 mm and 20 to 25, respectively, for a Category 2 road.



STEPWISE PROCEDURE

1. MARK THE % PASSING 75μ ISS ON AXIS 1-1; JOIN WITH FIXED POINT X AND EXTEND TO AXIS AA (SAY, AT S)
2. MARK THE % FRACTION (-425μ,+75) ON AXIS 2-2; JOIN WITH FIXED POINT X AND EXTEND TO AXIS AA (SAY, AT T)
3. STARTING WITH O ON AXIS BB, MARK OC = ST. FURTHER ADD THE % FRACTION (+425μ) ON AXIS BB, GETTING TO D (SAY)
4. PERPENDICULAR LINE FROM D READS THE SOAKED C.B.R. (%).

FIGURE 18 Nomograph for the computation of soaked CBR value from sieve analysis data.



DESIGN CURVES FOR RURAL ROADS CATEGORY-I

DESIGN CURVES FOR RURAL ROADS CATEGORY-II

FIGURE 19 Pavement design curves for rural roads.

Category I roads are associated with relatively high speeds and traffic volume. This is to be expected on roads that connect large villages to market and growth centers, and roads that carry a relatively high percentage of pneumatic-tired commercial vehicles. Category 2 roads are associated with relatively low traffic volumes and slow-moving traffic, generally with a high percentage of animal-drawn carts. These roads connect small villages and hamlets.

SPECIAL PAVEMENT SYSTEM FOR SANDY REGIONS

Conventional road construction materials are not locally available in regions of sandy terrain such as in western Rajasthan in India, and have to be brought over long leads. The local soil is very fine and poorly graded sand. Dhandla, which is a softer variety of a calcareous aggregate, is available in pockets here and there. Water is generally very scarce. In view of the scant population and other related factors, the traffic generally is not heavy. Work was undertaken at the CRRI to determine if a special pavement system could be developed to suit such conditions (*8*). This work led to the development of a new pavement system that is composed of interconnected precast blocks.

This pavement system involves the use of two sets of blocks. Hexagonal blocks are used for the interior of the road and pentagonal blocks are used at the edges to obtain lanes of a uniform width. The blocks are ribbed and provided with a special dowel-sleeve arrangement for interconnection and load transfer. The blocks are precast at a local site, cured, and either stored or used immediately.

The blocks are placed directly on the prepared formation and subgrade of local dune sand. No other pavement component exists. The blocks are tightly seated next to each other with as few gaps as possible on a properly densified formation such as is used in conventional road construction. Although sand can be filled from the top through the holes that were provided for this purpose, it is best to use light vibratory compaction for seating. Each interior and edge block weighs about 210 kg and can be readily placed by three persons. A light, truck-mounted crane can also be used to place the blocks.

After the blocks are placed and properly seated, the sleeves are moved forward with a small hand tool to interconnect dowels in adjacent blocks. The small hollows over the sleeves can be left as they are or can be filled with lean concrete. Individual blocks can be replaced whenever necessary. The whole pavement section can also be dismantled and used elsewhere.

The pavement system was tested in the laboratory under both static and repetitive loading, using a specially prepared sand bed (Figure 20). The results confirmed the high structural efficiency that was built into the system for the conditions of its use. A design traffic intensity of 200 heavy vehicles a day has

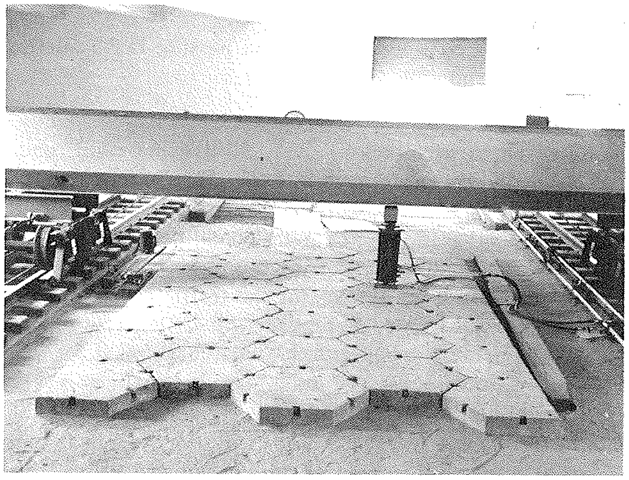


FIGURE 20 Assembly of precast blocks.

been assigned to the system for the time being. The system is also conceptually valid for other load intensities, and adjusted sections can be prepared for different loadings.

In terms of initial cost only, the new pavement system is slightly more expensive than a comparable flexible pavement with only a thin bituminous surfacing and is cheaper than conventional concrete pavements. Two road demonstration sections were recently constructed with this pavement system (Figure 21).

INTERMEDIATE TECHNOLOGIES

The road work in India continues to be performed with a relatively large degree of manual input (Figure 22). This is especially the case in the construction of low-volume roads, which is sometimes handled by agencies that are not well-equipped with expertise and infrastructure. It is recognized that road work continues to generate considerable employment, although it involves the use of some processes that are not so amenable to manual methods. There is also the question of added quality variations. Until large-scale mechanization is possible, technologies that constitute a good compromise between manual inputs and the quality and rate of production must be used.

Few, scattered jobs are created in the construction of low-volume roads. One important trend is the employment of agricultural implements that are readily available. Disc harrows (Figure 23) and moldboard plows that are towed behind a tractor are used for digging and pulverization. The mechanical power unit available in the form of tractors in rural regions provides for the use of several other low-cost items, such as the Rotavator or Rotiller (Figure 24) as mixers, towed rollers, and water bowsers.

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FIGURE 21 A demonstration stretch in which a special pavement system was adopted for sandy areas.

FIGURE 23 Disc harrows for pulverization of soil clods.

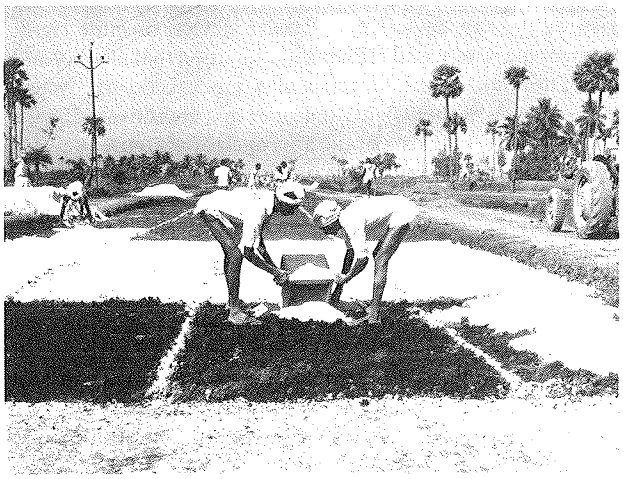

FIGURE 22 Manual methods in soil stabilization work.

FIGURE 24 Tractor-towed Rotiller for mixing soil with stabilizer.

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Physical and Operational Characteristics of Rail-Highway Grade Crossings on Low-Volume Roads

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The National Rail-Highway Crossing Inventory and Federal Railroad Administration accident files were analyzed to compare low-volume road grade crossing characteristics with those of their higher-volume counterparts. Other objectives included the determination of accident rates, accident proportions, and effectiveness factors for low-volume road grade crossings and the comparison of these with other grade crossings. Results generally confirmed the hypothesis that low-volume road grade crossing characteristics are significantly different from those of higher-volume road grade crossings. The differences were more evident for physical characteristics than for operational characteristics. Accident rates, in which exposure was incorporated, at low-volume road grade crossings were much higher than those at higher-volume road grade crossings. There were also significant differences in accident proportions between low-volume road and higher-volume road grade crossings. Effectiveness factors for low-volume road grade crossing upgrades were different from those used in the U.S. Department of Transportation Resource Allocation Model. Flashing lights to gates upgrades were more effective for higher-volume road grade crossings (70 percent) than for low-volume road grade crossings (51 percent). However, upgrades from no signs or crossbucks to stop signs were more effective at low-volume road grade crossings (73 percent) than at higher-volume road grade crossings (59 percent).

Potential conflicts can arise in the intersections of any traffic streams. However, the potential for conflicts at rail-highway grade crossings is unique. Because of the size of the train, significant changes in speed through deceleration or acceleration are not possible. Its travel path is limited to the rails. However, automobiles, trucks, and buses can stop, accelerate, decelerate, or turn in reasonable distances. Trains therefore must be given the right-of-way at grade crossings. It is the traffic engineer's responsibility to inform the motorist that a grade crossing exists and to alert drivers to the presence of trains so that drivers can take appropriate action.

Grade crossing warning devices include signs and signals on or adjacent to the highway approach to a rail-highway grade crossing. These traffic control devices can be classified as either active or passive devices (*1*). Passive devices include signs, pavement markings, and crossing illumination that identify and direct attention to the location of a grade crossing. Active devices include flashing lights and gates that are activated by the train to inform motorists of the approach or presence of trains on grade crossings. Gates have proven to be the most effective warning device in use because they provide a visible, if not physical, barrier between motor vehicles and the tracks.

The traffic engineer's job is to select the appropriate warning device for a given situation. Obviously, the ideal solution would be to install gates at all rail-highway grade crossings. However, because budget limitations make this impractical, the use of gates is usually reserved for the most dangerous crossings, and less effective devices are installed at other locations.

Between 1974 and 1985, approximately $900 million in federal aid safety funds were spent to provide active warning devices at nearly 22,000 crossings (*2*). Today, many of the most

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