Rural Roads in Cement Concrete: A Technique That Can Be Adapted to Developing Regions

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Interest in concrete roads exists for many reasons, especially in countries with adequate cement supplies. Concrete roads offer several advantages to other solutions from both technical and economic points of view. In Belgium, 50 percent of the rural road network of land reallocation regions consists of cement concrete. The concrete slabs are usually laid directly on the soil without the provision of a road base. The initial construction cost of these cement concrete roads is very competitive with that of other types of structures that comprise a bituminous pavement. Maintenance costs are very low or nonexistent, and the service life is estimated at more than 40 years. The construction of this large network of rural roads since 1960 has enabled the development of design and construction methods and specifications that are particularly well-adapted to this type of road. These methods can be transferred not only to other industrialized countries, but also to developing regions. The thickness of the concrete pavement varies from 16 to 20 cm, depending on the traffic volume and the modulus of the subgrade soil. The usual practice is to improve the subgrade only when the modulus of the soil is lower than 20 MPa (California bearing ratio value < 2). Slab length is limited to 5 m and the joints are made by inserting plastic strips into the fresh concrete. The concrete can be laid in several ways, ranging from labor-intensive methods to techniques that require specific equipment. In this respect, the use of slip-form pavers currently makes it possible to achieve daily productions of about 400 to 600 m with a reduced concreting team. Finally, an analysis is provided of the elements in the selection of concrete pavement technology for minor roads. The analysis is based on technical and economic criteria connected with each particular context, and on the availability of materials and labor.

Over the past few years, interest in the construction of cement concrete roads has revived in various countries for use in motorways and major roads, and for low-volume rural roads (Figure 1). This trend is especially apparent in countries with adequate cement supplies and in which the import of oil products is an additional drain on foreign exchange resources (*1, 2*).

Belgium has many years of experience in the construction of concrete roads, dating back virtually to the beginning of the century. Therefore, it is not surprising that the engineers entrusted with the design of the first rural land reallocation projects in the 1950s resorted to this technique for the construction of part of the rural road network (*3, 4*). This technique offers several specific advantages to other solutions, from both technical and economic points of view:

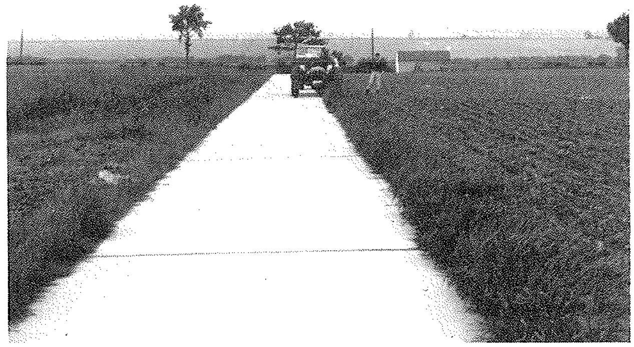

FIGURE 1 Cement concrete rural road.

- A good load distribution, which eliminates the need for thick and expensive bases;
- A great resistance to deformation and wear at any temperature;
- The degree of solidity is the same at the edges of the pavement as it is at its center; and
- An insensitivity to stagnant oil, clay, or fecal matter.

Concrete pavements also meet the following economic criteria:

- An estimated service life of more than 40 yrs,
- Virtually nonexistent operating and maintenance costs, and total construction costs that are generally lower than those of flexible pavements, and
- A competitive initial investment cost, as a result of an advanced laying technology.

The trend toward the use of concrete has become even more marked over the past 10 years as a result of the relative stability of the construction costs of concrete rural roads in regard to the consumer price index and the price index of the principal construction materials (Figure 2). In terms of initial investment costs, this stability has given concrete roads a clear advantage over flexible, bituminous pavement, as shown in Figure 3. In July 1985, the construction costs under Belgian conditions of structures a, b, and c in Figure 3 were in the ratio of 2.1: 1.5: 1; the unit costs per running meter of 3-m-wide rural roads were 2,650 BF/m, 1,887 BF/m, and 1,268 BF/m, respectively (1 \$ US ≈ 40 BF). The most recent methods for the design and construction of rural concrete roads are presented. The criteria for evaluating the adaptability of this technique to other

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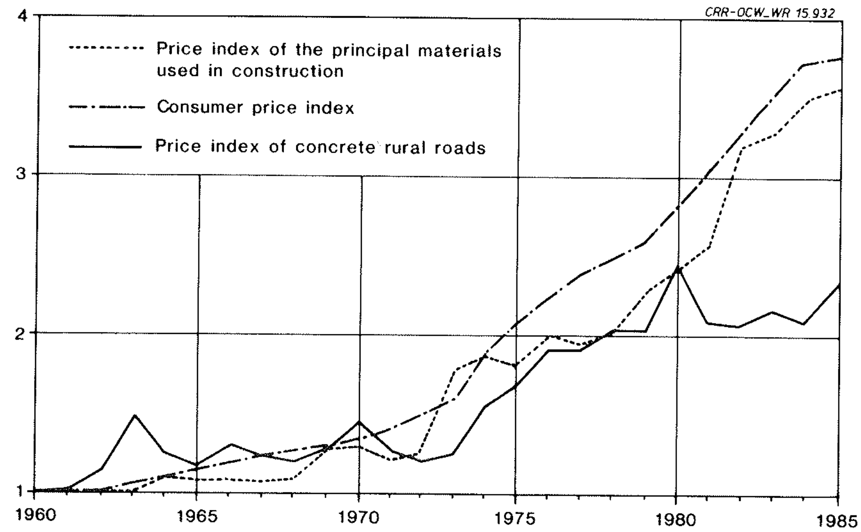

FIGURE 2 Evolution of the construction cost of concrete rural roads from 1960 to 1985.

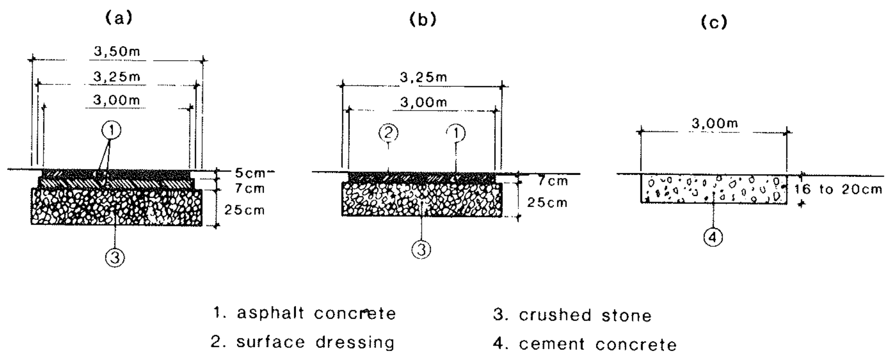

FIGURE 3 Typical structures of asphalt or cement concrete rural roads.

countries, particularly developing countries, are then analyzed on the basis of the technical environment and economic context of each particular case.

DEVELOPMENT OF THE CONSTRUCTION OF CONCRETE RURAL ROADS

Cement concrete pavements have comprised a major portion (50 percent) of the rural land reallocation projects in Belgium since 1958. The initial choice was based on the good performance of this type of pavement on state and secondary roads in the 1930s. The development of cement concrete and bituminous pavement construction from 1975 to 1985 is depicted in the histogram in Figure 4.

Although the percentage of concrete pavements remained stable at 46 to 54 percent between 1958 and 1975, it has increased since 1976, when the first effects of the oil crisis were felt. This percentage increased to an average of 57 percent between 1976 and 1980, and reached 79 percent during the next 5-yr period, with a maximum of 83 percent in 1982.

The histogram also shows a very marked reduction in road construction in rural land reallocation areas, from 400 km in 1977 to 120 km in 1984. This reduction is a result of drastic cuts in funds allocated by regional authorities for rural land reallocation projects.

THE DESIGN OF CONCRETE RURAL ROADS

Although a great many design methods exist, their application to rural roads leads to problems that mainly stem from the limited resources available to the designers and the relatively high study costs. It is also hazardous to extrapolate fatigue laws to low-stressed pavements (10^3 to 10^4 heavy vehicles in 40 years). Finally, most methods require considerable means to evaluate soil-bearing capacity and traffic.

A guide to the design of rural roads has been developed in Belgium to provide a functional classification of rural roads (*5*). For example, these roads may function as service roads, farm or forestry roads, roads intended for housing estates or tourism, or roads that are or are not used by public transport vehicles or heavy traffic. Roads were grouped into the following classifications:

- Primary rural roads serve villages and business centers, and link them to each other and to the state and provincial networks. The width of these roads is never below 5 m and they consist of two lanes.
- Secondary rural roads serve hamlets and housing estates, and link them to each other, to the villages, and sometimes to the state and provincial networks. Secondary roads consist of one or two lanes and their width may be 3 or 5 m.
- Tertiary rural roads essentially serve land parcels used for

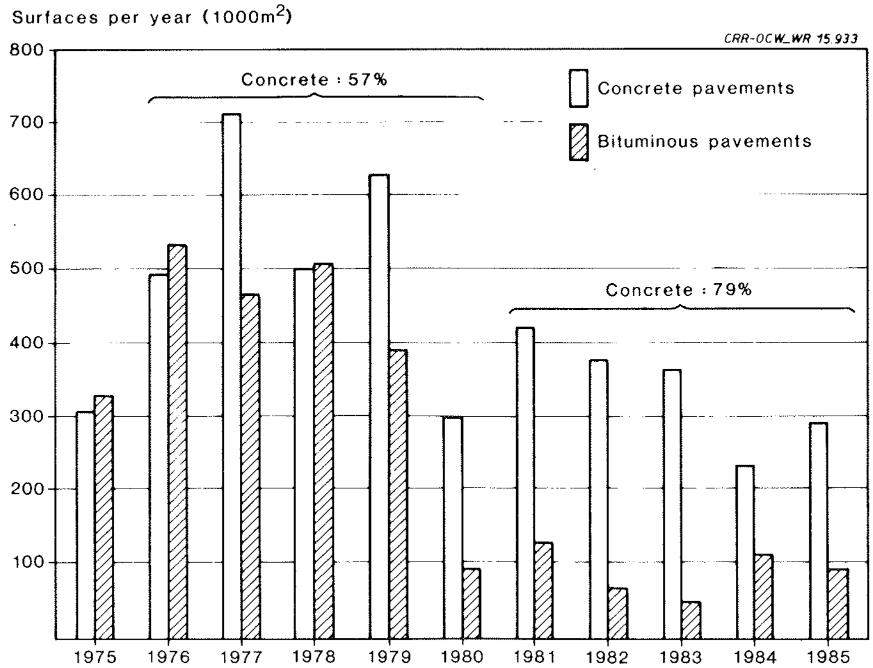

FIGURE 4 Construction of rural roads in land reallocation regions from 1975 to 1985.

farming or lumbering, and link them to the farms and other networks. They consist of one traffic lane and their width is generally 3 m. The daily number of vehicles of all categories traveling in both directions (V_{AC}) on each class of road is given in the following table.

Rural Road	V_{AC}	*Width*
Primary (two traffic lanes)	300-900	≧5 m
Secondary (one or two traffic lanes)	50-300	3-5 m
Tertiary (one traffic lane)	<50	3 m

Agricultural Traffic

Another subject addressed in the guide to the design of rural roads is the study of agricultural traffic. The traffic to be considered for the design calculation can be determined from the following equation:

$$N_R = V_{AC} \times 300 \times a \times c \times T$$

where

N_R = the equivalent number of standard axles;
300 = the number of days of the year, considering the decrease in traffic during weekends and public holidays;
a = the percentage of commercial vehicles (laden weight > 3.5 t), which depends on the type of farming;
c = the cumulative factor, which accounts for the foreseeable annual traffic growth during the service life of the road,

$$c = \frac{(1 + i)^d - 1}{i}$$

where

i = annual rate of traffic growth, and
d = service life estimated at 40 years for concrete pavements; and
T = the loads factor, which characterizes the deterioration mechanism of the road,

$$T = \bar{n} \Sigma f_i \left(\frac{P_i}{P} \right)^m$$

where

$\bar{n}$ = the average number of axles per commercial vehicle,
f_i = the proportion of axles with a load P_i, and
P = the standard axle load.

The standard axle considered in Belgium in the design of rigid structures is 13 t. The value of exponent m, which characterizes the damaging effect of axles, varies according to the authors and has been taken as equal to 14 (*6*). When no data are available on the number of vehicles of all categories (in the case of a new road), the evaluation of traffic is based on the type of farming and on the number of loads to be transported. The number of commercial vehicles is evaluated by accounting for the types of vehicles normally used in the region.

Soil Bearing Capacity

The bearing capacity of the subgrade soil is one of the most difficult factors to assess. Many existing methods also require the use of equipment that designers do not possess. Therefore, an original approach to the evaluation of soil bearing capacity has been tried in Belgium since 1976. This approach consists of interpreting soil maps (*7*). Although pedology is a science that aims at the classification of soils for agricultural purposes, it has been observed that a certain relationship exists between the first two pedological indices and soil bearing capacity.

The first index actually defines the morphological characteristics of the soil, such as silt, sand, and clay. The second index, which pedologists call the drainage class, is actually a precious piece of information about the presence or absence of a permanent or temporary water table. The remaining indices are not directly useful in the determination of bearing capacity, although they provide some information. This evaluation is of course only a rough estimate, but it has a great advantage; it is quick and does not require expensive investments. Furthermore, these values make it possible to avoid the most frequent major errors in the design of low-traffic roads.

The triangular diagram that is used by pedologists to determine the first pedological index is shown in Figure 5. The estimated values of the soil modulus as a function of the two pedological indices are given in Table 1. Improved subgrades and stony embankments are characterized by an 80-MPa modulus.

The relationships between pedological indices and bearing capacity were established on the basis of a large number of measurements with the light percussion sounding apparatus of the Belgian Road Research Center (*8*). These measurements enabled the California bearing ratio (CBR) and the soil modulus to be determined on the basis of the following relation: E_s (MPa) = 10 × CBR. Although the constant in this relation is subject to criticism, it appears that it can be applied to Belgian soils without the risk of a major error (*9*).

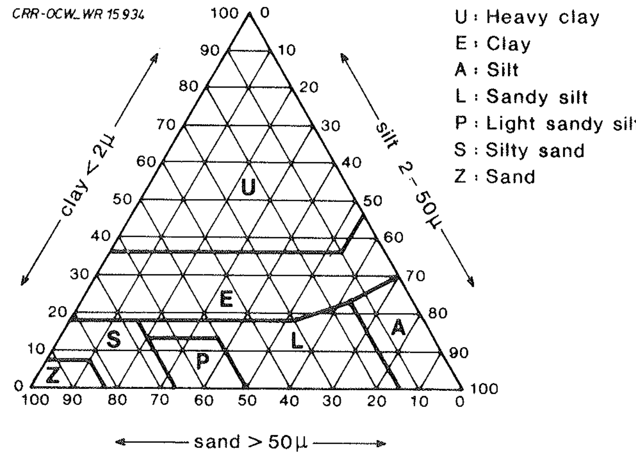

FIGURE 5 Triangular diagram of the grading of soils.

Characteristics of the Concrete Used for Agricultural Roads

The average composition of concrete used for agricultural roads is as follows:

Aggregates	70 percent
Sand	30 percent (by weight)
Cement (Class 30)	300 kg/m^3
Average compressive strength after 90 days	45 MPa (6,390 psi)
Average tensile strength	6 MPa (852 psi)
Modulus of elasticity	30,000 MPa (4,260,000 psi)

Design Chart

A design chart has been developed (Figure 6). It shows the thickness to be adopted for the pavement depending on the number of equivalent axles of 13 t and the subgrade modulus expressed in MPa. This chart resulted from the application of a model based on layered elastic slab theory. Stresses that result from the effect of temperature gradients have not been accounted for because the length of the slabs has been limited to 5 m. However, a risk factor has been accounted for by assuming a 2.5 percent cracking in the slabs, which can be tolerated by roads in a rural environment.

The subgrade has to be improved in cases in which the value of the modulus is lower than 20 MPa. This can be done by stabilizing the natural soil with lime or cement, or by providing a subbase. The thicknesses found by using the guide are the same as those usually adopted for agricultural roads.

LAYING THE CONCRETE PAVEMENT

Cement concrete can easily be laid in several ways, ranging from the simplest labor-intensive methods (Figure 7) to highly

TABLE 1 EVALUATION OF THE SOIL MODULUS

Soil (Basic symbols cf. figure 5)	Drainage class: dry to very dry soil good drainage	moderate and imperfect drainage	wet soil with permanent or temporary water table	very wet to extremely wet soil with permanent water table
Z, S, P, L	40	40	20	≤ 10
A, E	40	20	≤ 10	≤ 10
U	20	≤ 10	≤ 10	≤ 10

Note: 1 MPa = 142 psi.

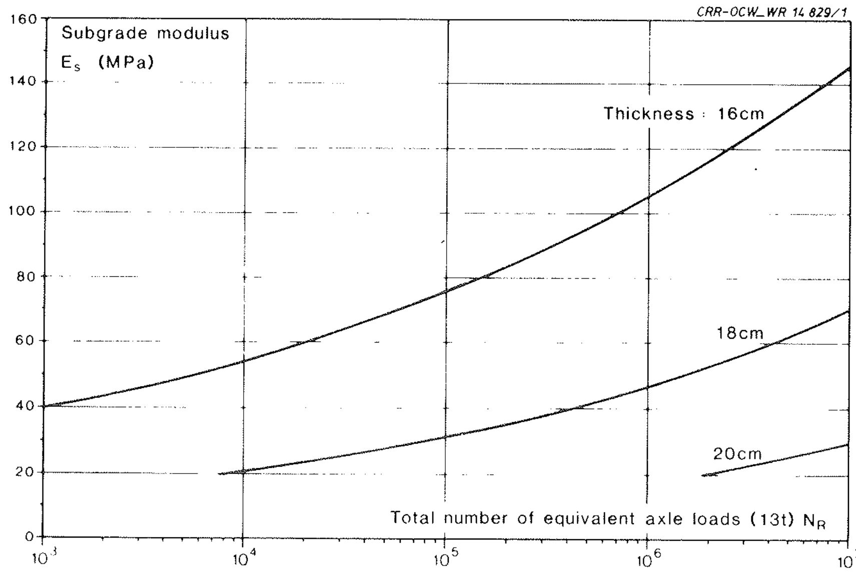

FIGURE 6 Design chart for concrete rural roads.

productive methods that require specific equipment. The choice of one construction method over another depends mainly on the availability and qualifications of labor, the available equipment, the amount of work to be performed, and the desired rate of construction of the planned network. In this respect, although experience has shown that it is possible to construct small concrete roads of a high quality with reduced equipment, it appears that the development of a concrete road network at a reasonable rate inevitably requires the use of specific laying machines.

Until about 1960, concrete rural roads were laid in Belgium with so-called conventional machines that rolled on fixed form work. The concreting train generally consisted of several machines; the first distributed the concrete, the second compacted the concrete by vibration, and the third created the crack inducer of the joints in the fresh concrete (Figure 8).

Lightly modified asphalt finishing machines were used since 1965 to lay concrete pavements (Figure 9). Small slip-form pavers that were developed from machines used on large motorway construction sites were used in the 1970s to lay widths of 3 to 5 m with an average daily production of about 400 m (Figure 10). The various laying methods for concrete rural roads with a width of 3 m are compared in Table 2.

Construction of the Joints

The joints are generally created by inserting a plastic strip in the fresh concrete to a depth of one-third of the thickness of the pavement. Joints are made 5 m apart and are neither dowelled nor sealed. The machine has to stop when a joint is created in the fresh concrete and this reduces productivity. Some contractors saw the joints in the hardened concrete and indicated that the sawing cost is compensated by the increase in daily production.

It is difficult to compare the two joint construction methods because daily production can be influenced by many other factors, such as the production capacity of the concrete mixing plant, the distance between the plant and the construction site, the number of lorries assigned to the transport, the access facilities to the construction site and the length of the roads to be concreted.

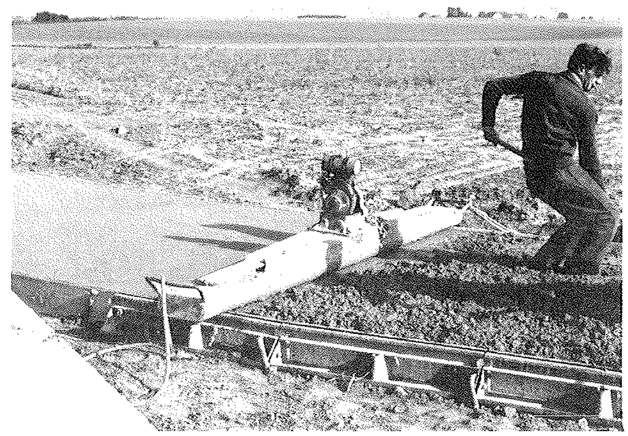

FIGURE 7 Manual application of concrete by means of a vibrating beam.

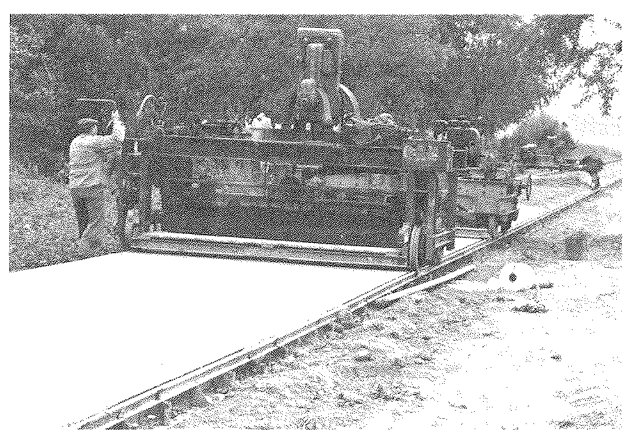

FIGURE 8 Concreting train on fixed form work.

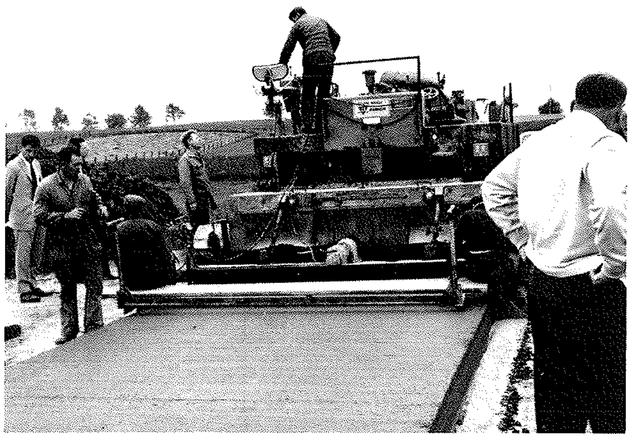

FIGURE 9 Modified asphalt finishing machine for laying concrete pavement.

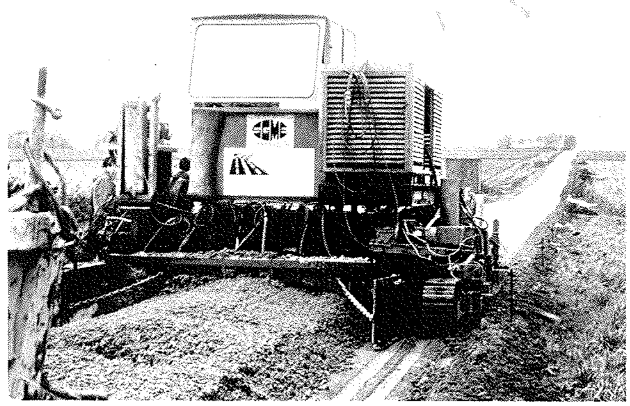

FIGURE 10 Small slip-form paver for roads 3- to 5-m wide.

ELEMENTS IN THE SELECTION OF CONCRETE RURAL ROADS

The selection of a road construction technique should be based on criteria that are associated with both the technical environment and economic context of the country or region concerned. These criteria include possible sources of materials (aggregates and binders) and supply conditions, financial and energy savings, environmental protection and equilibrium in the balance of payments.

The circumstances under which concrete pavements are able to compete with other techniques in the construction of rural roads are examined on the basis of Belgian experience. These circumstances can then be quantitatively assessed in each particular context, on the basis of a technical and economic feasibility study.

Technical Aspect

The construction of concrete roads first requires the availability of adequate cement and water supplies. Apart from that, concrete can tolerate the use of various types of aggregate or sand fairly well, as long as these materials meet certain criteria, such as grading and cleanliness criteria. In regions where hard aggregates are scarce, concrete pavements can be advantageous because they require fewer aggregates and in most cases allow the use of local aggregates that are less hard. In regard to soil conditions, concrete pavements can tolerate a certain local loss of bearing capacity during a thaw or in case of flooding, for example, and are consequently less sensitive to the underlying soil and climatic conditions. It should be noted that it is generally on soils with a low bearing capacity that concrete is competitive (because of its great ability to distribute loads), provided the soil does not lead to differential settlements by its compressibility and heterogeneity. Concrete stands up better to severe climatic conditions than flexible materials, especially in hot climates (no risk of rutting) and in regions where flooding is likely to occur.

In the case of seasonal agricultural traffic, the stiffness of the pavement is an advantage in regions where the heaviest loads travel during the wet season. However, it should be remembered that concrete pavements are very sensitive to underdesign and overloads that are not specifically considered in the design calculations. The addition of a slight thickness guards against possible overloads. In densely populated regions where traffic cannot be diverted, 2 to 3 days must be allowed for the necessary curing process of the concrete (*10*).

Economic Aspect

The decisive criterion for the selection of a construction technique is the total cost of the structure, calculated over a long period. The total cost includes the construction and maintenance costs, and possibly user costs. This calculation should also account for the parts of foreign exchange and local currency, and the impact of the adopted strategy on the economy of the region (use of home materials, balance of payments, etc.).

Apart from this criterion, the selection of the type of pavement can also be influenced by the way construction projects are subsidized. In this regard, the selection of concrete structures is favored by financing structures that subsidize all or a portion of the investment costs for pavements except maintenance, which is often the responsibility of local organizations. However, the use of flexible structures is advantageous in cases in which financial resources are limited or the discount rate is high. This is because a time-staged construction strategy can be applied to the use of flexible pavements. This strategy of construction, maintenance, and strengthening nevertheless requires, even for low-volume roads, that the necessary maintenance funds be available in time to keep the pavement at an acceptable level of service.

However, experience has shown that even when the construction cost of concrete pavements was slightly higher than that of flexible structures, the absence of maintenance has amply confirmed the advantage of a higher initial investment, even if it is 10 percent higher. Moreover, user costs are reduced by the maintenance of a high level of service during the entire life of concrete roads.

CONCLUSIONS

Most rural roads in Belgium are now constructed in cement concrete. The use of high-production laying techniques has led to construction costs that are lower than those of equivalent flexible structures. The performance of rural roads in concrete has also proved to be excellent in the long term, because they require virtually no maintenance.

TABLE 2 COMPARISON OF THE LAYING METHODS OF 3-m-WIDE CONCRETE RURAL ROADS

	Conventional concreting train on fixed formwork	Modified asphalt finishing machine	Slip-form paver
- Formwork	yes	-	-
- Subgrade finish	important under the formwork	important on the track rolling paths	wire-guided
- Extra width necessary	0.50 m	0.75 to 1 m	1.40 to 1.60 m
- Number of machines	1, 2 or 3	1	1
- Concrete composition	no particular restriction	continuous grading	continuous grading
- Slump	0 to 1 cm	2 to 3 cm	2 to 3 cm
- Vibration mode	vibrating beam	vibrating beam	internal vibrators
- Vibrating frequency	50 to 66 Hz	adjustable from 0 to 66 Hz	adjustable from 100 to 200 Hz
- Theoretical maximum working speed	0.60 m/min	1.8 m/min	2.8 m/min
- Theoretical maximum production (8 hours of work)	288 m	864 m	1344 m
- Average practical daily production	125 m	225 m	400 m
- Production capacity of the concrete mixing plant	10 to 15 m^3/h	20 to 30 m^3/h	60 m^3/h
- Concrete transport	0.5 lorry/km	1 lorry/km	2 lorries/km
- Labour (Men x Days)	72 MD/km	30 MD/km	18 MD/km

These construction techniques are also suitable for developing countries that have plentiful cement supplies, but often limited maintenance funds (*11*). Rural roads in concrete can be constructed by local contractors using either very simple labor-intensive equipment or special equipment, depending on the circumstances. In this regard, the existence of a training policy for contractors and personnel is essential to the development of any new technique. The development of this training policy should preferably involve consultation with a country where the technique is used in the form of seminars, training periods, and monitoring of works in progress.

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