RECENT DEVELOPMENT IN THE DESIGN OF RIGID PAVEMENTS IN FRANCE. STUDY OF PERFORMANCE OF OLD PAVEMENTS AND CONSEQUENCES DRAWN FROM NEW HIGHWAY CONSTRUCTION

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Concrete was used for pavements in France even before 1900, but it was especially during the past 14 years that major superhighway construction projects made use of the Californian technique. There are presently about 500 kilometers of concrete-paved superhighways in France.

A very recent study of the performance of these superhighway pavements was conducted and this paper details the many investigations carried out. An assessment of the use of other concrete pavement construction techniques used throughout the world was also made and the reasons for the French choice are set out along with the latest modifications applied to French structural design. Finally, the research trends in France for the future are examined.

I. STUDY OF PERFORMANCE OF OLD PAVEMENTS

Since 1962, French highway engineers have used nonreinforced, short-slab (15'±) concrete pavements, without dowels, on subbases treated with hydraulic binders, and have witnessed premature signs of aging, with pumping, stair-stepping and sometimes even cracking.

An extensive study was consequently initiated jointly by the Concessionary Company of the Paris-Lyons Superhighway, the Laboratoire Central des Ponts et Chaussees and the Service d'Etude Technique des Routes et Autoroutes. The general analysis of 232 kilometers (144 miles) of 4 lane superhighway was refined by a more detailed study of 80 kilometers (49 miles) and five control sections of 0.5 to 1.5 kilometer (0.3-0.9 mile) each were tested using many measurements to allow closer investigation of the degradation phenomena involved. Out of these 232 kilometers (144 miles), 112 are in good or excellent condition, 57 are in poor condition or evolving, and 63 are in an intermediate condition, i.e. moderately or locally degraded.

These investigations involved the following tests:

- Measurement of vertical deformations at transverse joints by several apparatus with the recording of temperatures at different levels of the concrete.
- Measurement of the vertical displacement of slabs at transverse joints (right and left side of heavy-traffic lane) and at the longitudinal joint.
- Measurement of horizontal opening of joints.
- Measurement of joint permeability.
- Ten borings at edge of slab at the transverse joint side down to the subgrade, with description of materials encountered. Identification and determination of mechanical and geotechnical properties of these materials.
- Description of condition of each slab (cracking, and so on), of the adjacent shoulder (traces of pumping, ejections, degradation) and of surroundings (slopes, grades, cut or fill, proximity of highway structures, and so on).

- Sixty 16-cm (6.3 in) diameter core samples of the concrete and subbase (at middle of slab, at joints, and on either side of joints).

- Observation of the condition of materials, tensile testing at interface, cylinder splitting test on concrete, hardness of subbase.

- Characterization of crack form for core samples taken on joints.

- Observation of moisture at contact between courses with certain core samples drilled without water.

- Determination of water volume entering cavities as well as permeability of interfaces and courses.

Many investigations and research for correlation purposes accompanied these in-situ measurements and, since, some of these measurements have been performed on other superhighway sections located in other regions. Finally, considerable observations were made during a construction project involving the destruction of two lanes out of three on a section having withstood a traffic of 14 million commercial vehicles (in France, the authorized single axle is 13 metric tons (28,600 lbs), certain vehicles being overloaded).

The main conclusions which can be drawn from the study of these old pavements are:

a) The quality of the concrete is good, especially for sections having used limestone aggregates; the real thickness of the concrete layer is in general in conformity with plans, to within 1 centimeter (0.39 in). Insufficient local thickness led to significant cracking.

b) The inadequacy of subbase quality and thickness is the main reason for the most serious defects:

   - The surface of the cement- or slag-treated base exhibited rather low mechanical properties in several sections leading to erosion under the slab joint. This erosion can create a cavity under the leave slab end, in addition to the classification build-up of fines under the approach slab (see Figures 1.1 and 2.2).

   - The difficulties of adjusting the subgrade have led to highly variable thicknesses in the subbase: about 8 to 18 cm (3 to 7 in) for a theoretical value of 15 cm (6 in).

   - At certain places, the placing of a thin resurfacing layer in cement-treated material often poorly compacted, gave rise to significant disorders, even when the subbase was itself good (Fig. 2.3).

     According to measurements on core samples taken on many sections ranging in age from 6 to 10 years, adhesion between the concrete and the subbase is very frequent at the center of the slab (tensile strength of about 10 kg/cm^2) (Fig. 2.6) whereas it practically never arises on 50 cm (10 in) on either side of the joint. On the contrary, on certain sections, the deformation measurements in the concrete and subbase showed that, when the pavement was older than about 6 months, a discontinuity of the deformations appeared at the interface, suggesting a certain detachment. Thus, adhesion phenomena at the concrete-subbase contact are complex and call for in-depth research (Figures 2.4 and 2.5).

c) The treated base course of the shoulder created a water trap at the lower edge of the concrete slab leading to movement in the presence of water and to pumping, even long after rain had fallen.

   The difficulty of compacting this treated material against the side of the concrete slab on certain occasions gave rise to free fines near the joints, thereby accelerating the stair-stepping effect.

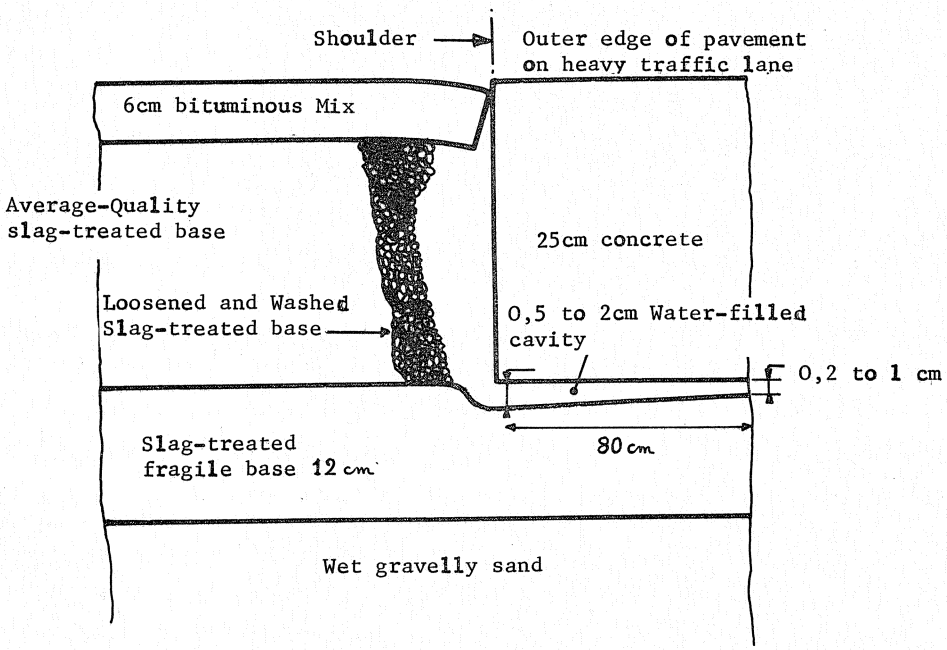
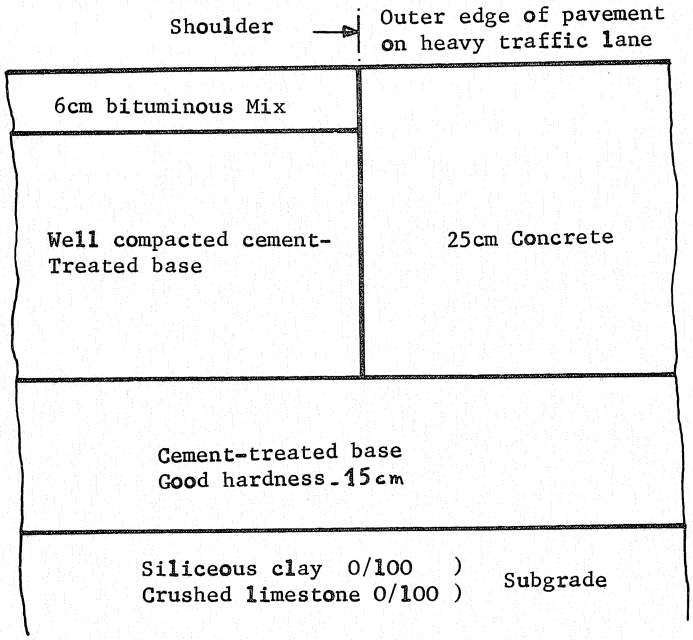


FIGURE : 1.1 TYPICAL FINDINGS ON MOST DEGRADED SECTIONS

CROSS-SECTION AT INTERSECTION BETWEEN LONGITUDINAL AND TRANSVERSAL JOINTS

FIGURE 1.2 TYPICAL FINDINGS ON GOOD SECTIONS
Cross-section



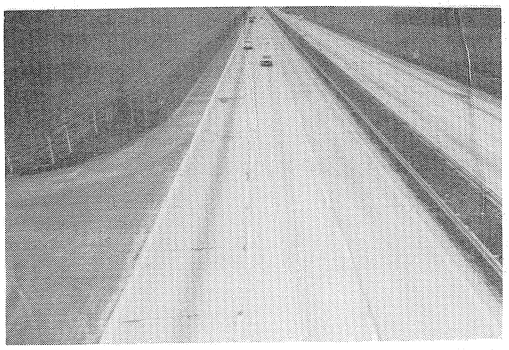


Figure 2-1 : Old section with some shoulder damage pumping and stepping



Figure 2-2 : Approach and leave slab corners lifted
Left : Deterioration of shoulder
Center: Water and buildup on CTB

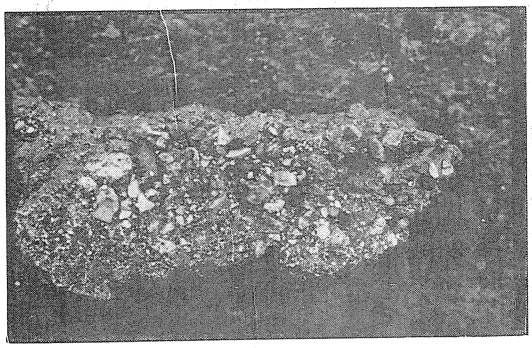


Figure 2.3 : Eroded surface of subbase under leave slab of an old, heavy traffic superhighway



Figure 2-4 : Longitudinal section showing bond between concrete and CTB especially When CTB is not thick enough

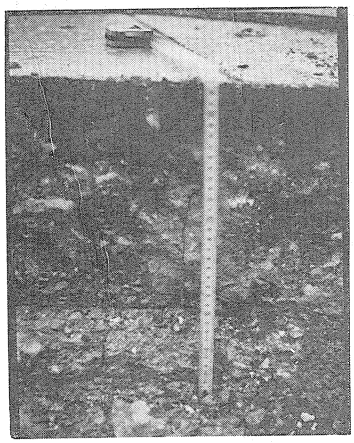


Figure 2-5 : Longitudinal section at a joint showing possibility of a crack in CTB under concrete joint

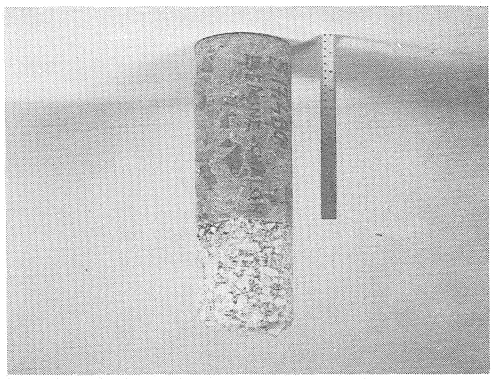


Figure 2-6 : Core sample of concrete bonded to slag treated base at center of slab

-3- TABLE OF MAIN RESULTS OF FINE ANALYSIS OF 5 ZONES

Construction date	Cumulative truck traffic end 1974 (in 10^6)	Stair-stepping (mm)	Slab-end differential deflection values (in 10^{-2})	Pumping	- Aggregates - Cement - Concrete thickness	Nature + thickness of subbase + performance CTB = Cement-treated base STB = Slag-treated base	Subgrade
Zone 1: 1.1 km December 1963	4.6	5 to 8	High or medium 40 to 70 20 to 40	Moderate at present but very poor condition of slab-shoulder joint. Ejection of fine sand and pumping pits.	-Silico-calcareous -15% slag Portland cement -21-25 cm 24 cm (9.5 in) average	CTB 9 to 16 cm ≃ 12 cm (4.75 in) aver. Clear deficiency of cohesion on 2 core samples out of 12. One deficiency is on an end. Absence of bond between concrete and CTB.	Fine sand 0-0.5 mm MC_{nat} = 10.5% Sand equivalent: 28
Zone 2: 0.5 km July-Aug. 1966	3.8	1 to 3	Low 10 to 30	Small (water slightly colored by subgrade clay)	-Limestone -15% flyash Portland cement -24-27.5 cm 26 cm (10 in) average	CTB 12 to 19 cm 16 cm (6.3 in) average Clear deficiency of cohesion on 3 core samples out of 14. Fragile cores were on ends. Weakness or absence of concrete-CTB bond appears.	Siliceous clay 0/100 MC_{nat} = 8% Atterberg limits: LL = 34 PL = 14 PI = 20 19% passing 80 μ 56% passing 20 mm
Zone 3 0.5 km Apr.-May 1969	3.8	1 to 3	Low 10 to 15	Small (beginning of shoulder cracking near joints)	-Porphyry -Portland cement -26 to 27 > 26 cm (10 in) aver.	STB 11 to 18 cm 14 cm (5.5 in) average STB more fragile under ends. Tendency toward lack of concrete-STB bond under ends.	0/100 crushed limestone, fairly dry and compact. MC_{nat} = 5.6% LL = 34 PL = 17 PI = 17 12% passing 80 μ 30% passing 2 mm 60% passing 20 mm

MC_{nat} = natural moisture content

Zone 4: 1.1 km Apr.-June 1970	4.5	1 to 3	- Medium, 20 - High, 50 - Low, 15 (scattered values)	Significant and localized to medium (traces of clayey ejections from subgrade)	- Porphyry - 15% flyash Portland cement - 24 to 26 cm 25 cm (9.8 in) average	STB 5 to 14 cm 10 cm (4 in) average Good behavior on 50% of core samples. Fragile on 25% of samples. Concrete-STB bond is quite frequent in slab center.	Crude, heterogeneous and polluted alluvial gravel (clumps of clay) MC_{nat} = 6 to 8.7% Atterberg limits: LL = 20 to 33 PL = 16 to 19 PI = 4 to 14
Zone 5: 1.5 km June-July 1970	4.5	3 to 7	- Medium, 20-40 - High, 30-50 - Low, 10-20 (scattered values)	Moderate at present time. Poor condition of slab-shoulder joint (pumping pits). Stage of pumping under concrete doubtless over.	- Porphyry - 15% slag Portland cement - 23 to 26 cm 25 cm (9.8 in) average	STB 6 to 25 cm 13.5 cm (5.3 in) average Good performance on 75% of cores. Fragile on 25% of cores, except in case of fragility of STB. Concrete-STB bond is quite frequent in slab center.	Sandy alluvial gravel (fine sand + some elements) MC_{nat} = 7.5 to 8% LL = 20 PL = 16 PI = 4 Sand equivalent: 23 to 25

MC_{nat} = natural moisture content

d) The nature of the subgrade is not at the very origin of the disorders noted since a section of good general performance had, for example, a subbase with 20 percent of the material passing an 80 μ sieve; however, when a pavement exhibits subbase defects, a fine-sand subgrade or one having a high proportion of very fine particles within a granular skeleton, can significantly accelerate the rate of degradation.

e) The qualitative stair-stepping phenomenon is widespread on the heavy traffic lane but its intensity there is often negligible. On the light-traffic lane, no degradation is ever observed even when there are major subbase defects. For the zones of the heavy-traffic lanes in which the displacements are great (4 to 8 mm), there is no perfect correlation with a parameter taken separately from among those mentioned above (a to d). However, with the pumping phenomenon, stair-stepping depends essentially on the simultaneous occurrence of significant slab-end deflection, water at the concrete-subbase-shoulder contact point, and free fines (Table 3).

f) The first joints to open remain, with time, the ones most widely opened. They then exhibit more deflection and their stepping increases faster than that of the others. Obtaining the best joint crack opening is a guarantee of durability especially when certain parameters (nature of aggregates, concrete placing period) allow the joints to be open only during relatively short cold periods.

Along with the systematic measurements carried out on large surfaces, finer measurements were made on some joints (Fig. 4). In particular, very precise recordings of the vertical deformations of the slabs of fairly degraded sections made it possible to arrive at the following conclusions for the adopted experimental conditions:

- There is no rocking of slabs upon passage of heavy axles.

- The degree of stepping (from 0 to 10 mm)(0.39 in) practically has no influence on the values of the maximum vertical deformations of the slab ends (dynamic effect not substantial).

- The influence of axle load varies depending on the extent of the cavities under the slab; an axle of 13 metric tons (28,600 lbs) creates deformations two to three times greater than those of a 6.5-ton (14,300 lb) axle.

- Thermal deformations have the greatest influence on the deformations through crack opening. Depending on this opening, temperatures allowing excellent load transfer vary from 20 to 30°C.

Thus, in concluding this study of the performance of old pavements, it is possible to set forth the following three points:

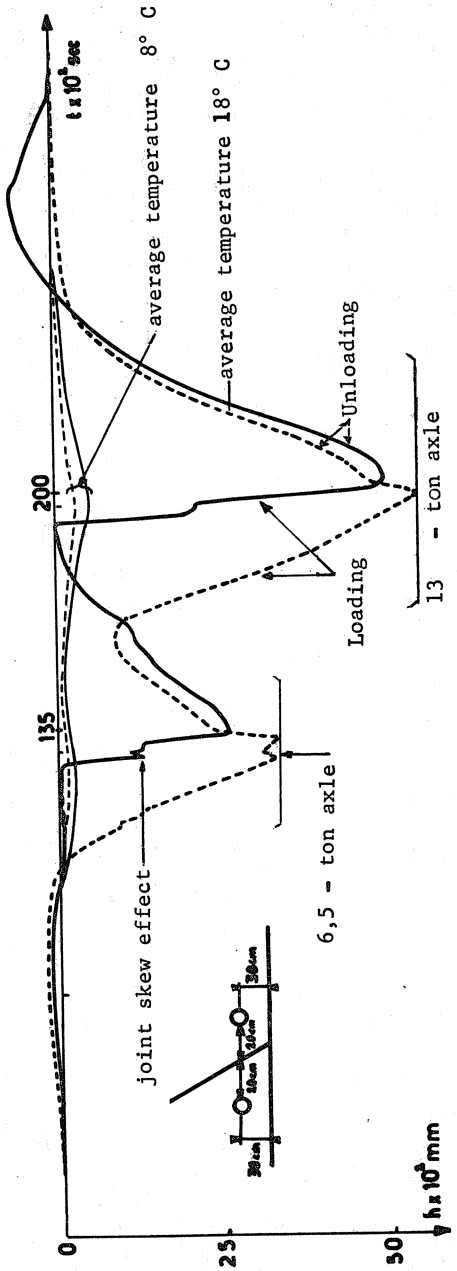
- The disorders encountered are due to a great extent to construction defects, in particular in the subbase.

- The required design improvements relate to drainage, the longitudinal joint between the slab and the shoulder and the hardness of the subbase surface.

- Properly constructed sections stand up very well after 5 to 15 million commercial vehicles, in spite of the absence of dowels.

FIGURE 4 : VERTICAL DEFORMATION OF SLAB
CORNERS UPON PASSAGE OF A TRUCK

Speed : 30 km/h



Approach slab deformation recording : ----------

Leave slab deformation recording : ——————

II. COMPARATIVE ASSESSMENT OF CONCRETE PAVEMENT TECHNIQUES THROUGHOUT THE WORLD

Along with the preceding study, an in-depth investigation was conducted to compare the different designs of concrete pavements existing throughout the world and to analyse the possibilities of their use in France.

Trips to the United States, Belgium, Great Britain, Germany and Spain made it possible to better characterize the specific aspects of each technique. The study of the possibilities of applying these techniques in France led to the following conclusions:

a) Continuously reinforced concrete cannot be adopted in France as a standard concrete pavement construction technique even in the near future, for the following reasons:

   - It is a rather difficult technique. Countries using it are those that have a large proportion of concrete pavements for their superhighways. Contractors are hence familiar with the concrete technique. Moreover, even in certain of these countries, incidents which are sometimes serious and involving long lengths of highway have occurred during construction.

   - The cost of execution would, under conditions in France, be 25 to 50 percent higher than the other techniques.

   - The cost, time and effectiveness of local repairs make maintenance very difficult and costly when pavement construction quality has been inadequate.

   - For urban expressways, the many bridges and other structures is a handicap for this technique.

   - The problems of corrosion and poor compacting on the concrete under the reinforcements are not yet solved in a sufficiently economic and dependable manner for regions using large amounts of de-icing salt.

b) Long, reinforced and doweled slabs do not constitute a technico-economic optimum between continuously reinforced concrete and short doweled and nonreinforced slabs.

c) Short doweled and nonreinforced slabs represent a technique with unquestionable advantages: good performance under intense and heavy traffic without stair-stepping and good adaptation to a wet climate without requiring a highly erosion-resistant subbase.

However, under conditions in France, the following drawbacks were noted:

- Cost higher than that of the technique without dowels: from 8 to 20 percent depending on specifications covering dowels and the installation method adopted.

- In the present state of world research, there is no machinery compatible with slipform pavers for placing dowels by vibration in fresh concrete and actually providing every guarantee regarding the final positioning of the dowels and the evenness of the pavement.

- Greater sensitivity of dowel technique to construction defects and fairly high cost of crack repairs.

For these reasons, and considering the possibility of remedying defects observed when dowels are not used, the use of dowels in France has not been adopted at the present time.

Hence, the three main concrete pavement construction techniques used abroad and with which France has no direct extensive experience involve, compared with the California technique, higher costs for construction and for local repairs as well as greater sensitivity in the construction phase. Moreover, as certain sections using the technique without dowels exhibit excellent performance, it was decided not to change the French procedure for current construction, but to introduce certain improvements.

III. IMPROVEMENTS ADOPTED IN FRANCE FOR THE CALIFORNIAN TECHNIQUE

The design shortcomings investigated and the insufficient construction quality encountered have led to the proposal and the implementation of the following modifications: (Figures 5.1 and 5.2).

a) The cement-treated base is replaced by a compact lean concrete having the same mechanical and dimensional characteristics, thereby eliminating the risk of erosion at the joints of the concrete and better guaranteeing the thicknesses by spreading with a slipform machine (Fig. 5.2).

   The first construction site using lean concrete in the subbase had a concrete formula with 160 kg (352 lbs) of cement and 70 kg (154 lbs) of flyash yielding 7-day bending strengths of 25 kg/cm^2 (356 psi). Use was also made of aggregates obtained by the crushing of concrete from an old pavement.

   This modification makes it possible to use the same production and spreading machines as for the pavement, to avoid the need for a compacting plant and to take advantage of local aggregate resources which could not have been used on a cement-treated base.

b) The cement-treated base of the shoulder is replaced by a porous lean concrete in order to minimize the time during which the slab-subbase-shoulder contact works in the presence of water. Horizontal drainage away from the pavement was preferred to vertical drainage through a porous subbase in order to maintain good compactness of all layers under heavy traffic and to select a porous layer where traffic is very light. Laboratory and field tests were carried out. Concrete formulas of the type comprising 150 kg (330 lbs) of cement, 300 kg (660 lbs) of sand, and 1300 kg (2860 lbs) of 4/25 crushed material make it possible to obtain excellent permeability and strength values comparable to those of the cement-treated bases previously used. Placement by means of a side-discharge spreading machine moving on the pavement, followed by compacting with a powerful vibrating screed, allow an output of more than 1 km/day. An emulsion serves as a curing product and as a bond for the 4 cm upper bituminous concrete.

c) In-situ treated or draining subgrade layers are to be preferred to clayey or sandy layers, in particular for exceptionally intense traffic. However, the quality of the subbase and compliance with its thickness should make it possible, for medium traffic, to use materials containing fine particles in the subgrade, especially if side drainage is effective.

d) The concrete slab extends 75 cm (29.5 in) into the shoulder. This modification, introduced in 1973 in France, enables a considerable reduction in deformations under load along the longitudinal joint and in particular at transverse joints. It moreover prevents deterioration of the edge of the shoulder by trucks drifting off to the right. Finally, this system keeps water and fines infiltrating the longitudinal joint away from the vertical of the truck wheels.

e) Concrete thickness varies in the cross-section (from 22 cm (8.6 in) on the light vehicle side to 28 cm (11 in) in the truck lane, for a heavily traveled road on a poor soil for example). This allows thicknesses to be adapted to the different heavy traffic intensities in the lanes.

These modifications, certain of which were implemented in 1973 and others in 1976, appear to provide effective control of the degradation phenomena encountered. They are aimed essentially at maintaining optimum conditions for slab bearing on the subbase to ensure structural durability and riding comfort.

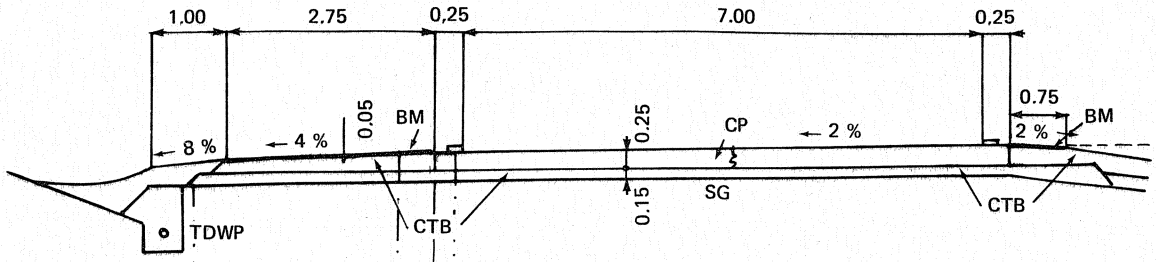


FIGURE 5.1

TYPICAL CROSS SECTION OF CONCRETE STRUCTURE

before 1973

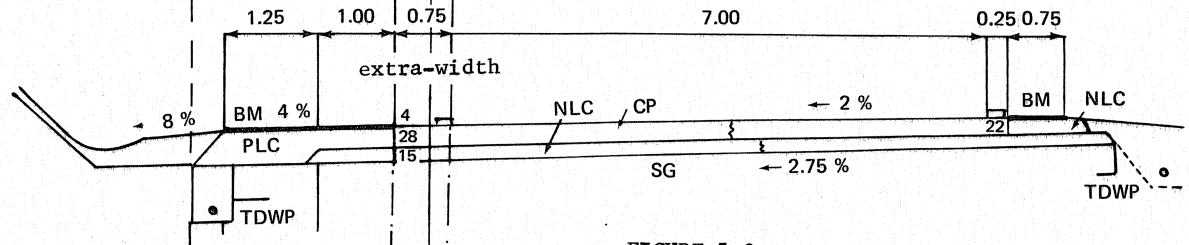


FIGURE 5.2

CROSS SECTION AFTER 1976

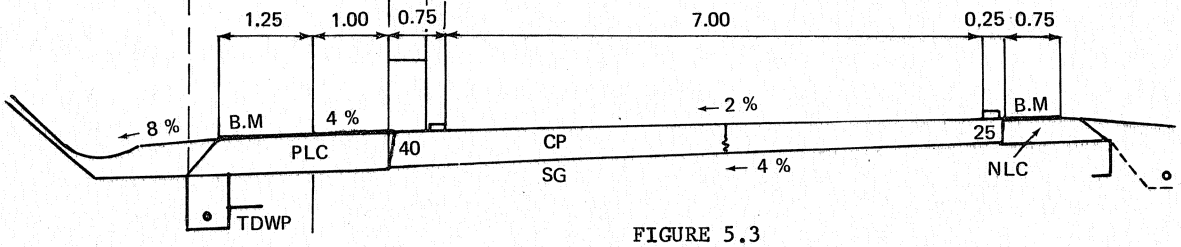


FIGURE 5.3

EXPERIMENTAL CROSS SECTION
EXTRA THICK SLAB

CP = Concrete pavement

CTB = Cement treated base

NLC = Normal lean concrete

PLC = Porous lean concrete

TDWP = Trench drain with pipe

BM = Bituminous mix

SG = Subgrade

IV. STUDY OF A NEW STRUCTURE

Two major projects recently completed in the United States with a thick concrete slab lying directly on a subgrade have generated considerable interest in France.

A cost study showed that this approach could cost from 10 to 15 percent less than the conventional technique, in particular for highly-traveled facilities. In addition, construction times are much shorter.

This technique can be especially effective associated with the use of a surface dressing one year after construction. In fact, it would be thus possible to overcome constraints relative to skid resistance of concrete materials, thereby allowing the use of limestone aggregates which moreover offer many advantages for concrete pavement construction.

Cement content and characteristics can be optimized according to these new data: clinker content[1] can be reduced:

- owing to larger aggregate size
- by the absence of surface wearing problems
- by the major reduction in slab fatigue risks
- by the possibility of adding fine particles (active particles such as flyash or inactive particles such as fillers in the sand).

This content should, furthermore, be lowered if hydration, thermal and hydraulic shrinkage is to be minimized in order to obtain the smallest crack openings. A cement with a very progressive hydration due, for example, to the pozzolanic effect of flyash between 28 and 90 days is particularly well suited to such a structure.

A study by the finite-element method showed that tensile stresses in the supporting soil around the slabs could be very high because of the great slab rigidity. Another question which must be clarified by experience is stair-stepping since the surface of the subgrade can be relatively erodable in the presence of water. To eliminate stair-stepping, the shoulder base must be made up of a porous lean concrete. The use of a treated subgrade, often necessary for certain construction conditions, or the use of a draining granular layer can avoid the occurrence of free fines and stair-stepping.

These considerations, and the interest roused in France by this new technique, have led to the construction of a 1200 m (1312 yds) test section on a highly-traveled road. The thickness of the concrete slab ranges from 30 to 36 cm (12-14 in) in the cross-section. The subgrade has variable dimensional and mechanical properties allowing optimum specifications to be laid down for it. A sheet of polyethylene under the slab and in the shoulder was provided to isolate the flow of water from the possible movement of fines. Gauges placed in the concrete enable deformation measurements, so that it will be possible to determine the real behavior of the structure.

Further experimentation is planned in the Spring of 1977 on a stretch of 2000 m (2180 yds) in order to define production and placing conditions. Its main characteristics are the following: cross-section varying in thickness from 25 to 40 cm (10-15 in); subgrade in draining gravel; concrete with 300 kg (661 lb) of cement and 40 kg of flyash per cu m (including a test with 250 kg (550 lb) of cement and 70 kg (154 lb) of flyash per cu m). Large aggregates of 60 mm (2.3 in) (also testing 80-mm aggregate) (Fig. 5.3).

Another experiment to be conducted in October 1976 will seek to adapt such a structure to the optimum use of local aggregate resources: subgrade in local sand, concrete in local silex or in limestone normally not utilizable for road construction because of their low strength.

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[1]Cements currently used for road building in France often contain 10 to 20 percent hydraulic or pozzolanic products (slag, flyash, pozzolan), in addition to clinker.

Thus, in France the thick slab technique is presently spurring research which should soon tell whether its performance holds the same promise as its very low construction cost.

Concluding, under present conditions in France, the simplest and surest solution making it possible to avoid the defects encountered on certain sections in the past has been found to be the technique of short slabs without dowels, on a compact lean subbase, with a variable cross-section and extending into the shoulder which itself has a porous lean concrete base.