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THE NON-DESTRUCTIVE TESTING OF PAVEMENTS IN THE CONTEXT OF MAINTENANCE AND OVERLAY PROJECTS TRANSPOSITION TO DEVELOPING COUNTRIES

by

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THE NON-DESTRUCTIVE TESTING OF PAVEMENTS IN THE CONTEXT OF MAINTENANCE AND OVERLAY PROJECTS. TRANSPOSITION TO DEVELOPING COUNTRIES

Studies carried out in connection with pavement maintenance and overlaying are somewhat different from those concerned with the construction of pavements for completely new roads, in the sense that at the stage of the feasibility study the economic criteria involved must be analysed in the light of the national road system as a whole, and not in the light of a single itinerary.

FEASIBILITY STUDY :

An economic criterion of profitability can only be determined in the context of an overall policy of management of the road system. The analysis is a comparative approach which requires that a policy of road management has been previously established on the basis of a transportation plan, or – which amounts to much the same thing – on the basis of a master plan leading to the establishment of a programme of work covering a number of years. It is never a question of deciding whether a given pavement should be maintained or not, but rather of selecting from among all the itineraries of the road system those which have to be maintained and those which have to be overlaid, and of working out the corresponding budgetary allocation and consequently, in the light of the annual maintenance and overlaying budgets, selecting priorities. From the technical point of view, which is the one we adopt here, the feasibility study corresponds to the evaluation of the quality of the road system.

THE PRELIMINARY DESIGN STUDY :

The preliminary design study (APS in French) relates to the itineraries scheduled under the programme of work laid down in the course of the preceding phase. It consists of making a complete pathological analysis of an itinerary, specifying the localisation, nature and cost of the work involved. It is necessarily carried out very shortly prior to the performance of this work, because the condition of the pavement is evolutive, and the solutions proposed soon become outdated (in three or four years for roads carrying heavy traffic and for pavements in a poor condition). The APS phase may in certain cases be complemented by a study of the modernization or modification of certain sections (widening, rectification of the longitudinal profile or of the plane alignment, etc.). In the latter case, a comparison must be made between the economic advantages of the two possibilities : maintenance or overlaying without rectification of the alignment, and total or partial modernization of the itinerary.

There is another important point concerning the choice between progressive overlaying and immediate heavy overlaying; this arises more at the stage of the feasibility study rather than at the APS stage, because it is a question of general policy affecting the whole road system much more than the individual itinerary which is the subject of the APS.

THE FINAL DESIGN STUDY PROJECT :

The final design study (APD in French) consists of establishing the actual work to be performed. At this level, all non-destructive testing must be practically completed; there may possibly remain some points in the APS to be settled in order to make the different solutions adopted coherent. Hence the technical studies relate mainly to the techniques and materials adopted, including quarries if this point has not already been dealt with, and the wording of the technical terms and conditions for the performance of the work.

So we see that in most cases technical studies carried out in connection with pavement maintenance and overlaying consist of :

– An overall evaluation of the road system (feasibility).

– A pathological analysis of a given itinerary (APS plus APD).

The examples which we shall cite in what follows correspond to these two phases : the examples of Mali and Algeria for the first phase, and the examples of Iran and Tunisia for the second.

OVERALL EVALUATION OF ROAD SYSTEM :

The reasons for which maintenance or overlay work is undertaken are generally the following :

a) Inadequate bearing capacity of the pavement.

b) Unacceptable serviceability.

c) Unacceptable degree of deterioration.

d) Unacceptable level of safety.

e) Unacceptable cost for road users.

f) Unacceptable maintenance cost.

In what follows, we shall exclude the surface characteristics of the pavement (riding quality, skid resistance) because doubtless this is not yet the prime concern of developing countries, at least on the scale of their road networks as a whole. We shall also exclude the «cost for the road user» because on the one hand this point largely exceeds the scope of surfaced pavements, the cost depending much more on the presence or absence of a surfacing and on geometric characteristics (gradients and bends) than on the structural quality of the pavement; and secondly it would lead us into an economic analysis forming the basis of a study which does not come within the scope of the present communication.

Studies intended to define the major options of a maintenance and overlay programme depend on the road policy adopted, and on the time and resources which can be devoted to it. The decision-making parameters are : the management policy adopted, the traffic, and the state of the pavement. Where the state of the pavement is concerned, must it be thoroughly known ? True, this would be preferable, but we must consider the following points :

- The lengths to be tested non-destructively are often considerable, and the time and resources necessary for exhaustively testing the while of the road system are not always available.
- The problem we are faced with is to define priorities, and the overall work to be performed; so we cannot attempt to deal with it by statistical sampling.

Hence several methodologies emerge, their principle being the utilisation of one or more parameters believed to be in close correlation with the reply to the question posed.

I. – METHOD USING A SINGLE PARAMETER

a) French example :

The method employed in France in the course of the systematic non-destructive testing programme carried out in 1965-1966 was as follows :

Non-destructive testing was confined to that part of the road system which it was essential, for economic, political or social reasons, to maintain at an adequate level of serviceability (this is what we call the *master plan,* covering 30,000 km of roads).

On this priority network, we use a single non-destructive testing parameter : the measurement of deflexion at the level of the pavement.

Because, whatever criticism may be levelled at this from the theoretical point of view, *continuously measured* deflexion constitutes an excellent indication of poor quality. For a given type of pavement, (e.g. flexible pavements in the strict sense of the term, which account for the road network as a whole requiring overlaying) a substantial deflexion is always a sign of a major weakness in the road structure (the contrary is not necessarily true).

And because, with the Lacroix deflectograph, we have a rapid and efficient means of measuring deflexion.

Despite the high rate at which the deflectograph performs measurements, it was not possible to test the whole of the road system scheduled during the short period of the year during which the underlying soil conditions are unfavourable from the point of view of water content.

We therefore adopted a sampling technique, testing sections 2 kilometres long, every 10 or 15 km. These pilot sections were either regularly distributed along an itinerary, or determined after rapid visual examination in such a way as to be as representative as possible of a 10-km section.

The critical deflexion (average plus 2 standard deviations) over 2 km was compared with the admissible limit of deflexion, defined in the light of daily traffic.

These values, adopted in 1965, and valid only for conventional pavements featuring no rigid courses, were as follows :

Traffic* in number of vehicles per day	Limit of deflexion in 1/100 mm
> 6,000	100
from 3,000 to 6,000	125
from 1,500 to 3,000	150
from 750 to 1,500	200
(for two or possibly three lanes)	

* With 10% of heavy vehicles and a maximum single axle weight of 13 T.

We were thus able to classify the sections tested in four categories, in the light of traffic, on a map representing the itineraries tested :

– (In yellow) satisfactory sections, no overlaying considered necessary.
– (In green) sections requiring light overlaying, category 1.
– (In blue) medium overlaying, category 2.
– (In red) heavy overlaying, category 3.

This revealed those itineraries which were in satisfactory condition and those which were seriously deteriorated. This map has been the technical basis of the co-ordinated overlaying programme since 1968.

The task was complemented by continuous non-destructive testing of the same itineraries between 1967 and 1969; this was made possible by the number of deflectographs in service (13 in 1965, 25 in 1969).

b) Belgian example

For many years, the Ministry of Public Works has been determining the simplified PSI(*) (i.e. uniquely through the measurement of the RI(**) using the Bump Integrator). This PSI is determined for each section 500 m long. 63,000 km have already been examined in this manner (the same itineraries have been gone over several times).

A map has been prepared, representing the itineraries tested and assigning colours to them :

– Blue	:	very good	$5 > PSI \geqslant 3.5$
– Green	:	good	$3.5 > PSI \geqslant 2.5$
– Yellow	:	mediocre	$2.5 > PSI \geqslant 1.5$
– Red	:	poor	$1.5 > PSI$

If the PSI is less than 1.5, the section in question must be rebuilt or overlaid.

c) Advantages and drawbacks

These methods have several advantages : they are rapid, objective and reliable; and they are not costly. But they have drawbacks : if they are to be used properly, we must be sure that the parameter analysed is closely related to the problem posed.

We have seen that in the French context, deflexion was an excellent indicator of poor condition, and that consequently it was possible to use it as such, since the problem was to catch up with maintenance work, lack of which had left the national road system in very poor condition, especially after the winter of 1962-63. On the roads which have now been overlaid, deflexion cannot play the same predominant role; in particular because on pavements whose base course has failed without exaggerated stresses at the level of the underlying soil, the deflexion remains slight, although they need to be overlaid. Similarly, the PSI obtained with the Bump Integrator in Belgium is used as an indicator of poor condition : if the PSI is below a threshold of 1.5, the pavement must be overlaid or rebuilt. This threshold probably derives from experience of a statistical relationship between low PSI and pavements needing to be overlaid. It is also very probable that in comparing the PSI maps of its road system every year, the Belgian administration can detect those sections which are declining in quality (dropping from the «very good» category to the «good» category, for example); the evolution of the riding quality parameter, even within the category in which the pavement is considered to be satisfactory, is also an indicator of condition.

Methods having recourse to a single parameter are therefore extremely worthwhile, but in order that they may be transposed to other countries, and in particular developing countries, we must first check that they indeed meet the question which arises, and that consequently an analysis has been made of the process of deterioration of the pavements of the road system in question.

(*) PSI = Present Serviceability Index.
(**) RI = Roughness Index, characterizing the riding quality, measured by means of the Bump Integrator.

I I. – METHOD USING SEVERAL INTER-RELATED PARAMETERS

The best known such method is the American PSI method (and its derivatives). The PSI of a pavement has been experimentally defined as :

$$PSI = 5{,}03 - 1{,}91 \log (1 + \overline{SV}) - 1{,}38\,\overline{RD}^2 - 0{,}01\sqrt{C + P}$$

for flexible pavements

and

$$PSI = 5{,}41 - 1{,}78 \log (1 + \overline{SV}) - 0{,}09\sqrt{C + P}$$

for cement concrete pavements.

In these formulae, the parameters are as follows :

SV = mean variance of longitudinal gradient.

RD = mean depth of rutting.

C = relative cracked surface.

P = relative patched-up surface.

Slightly different numerical coefficients may be assigned to them, depending on the instruments used to measure them.

This formula establishes a relationship between geometrical deformations, the pavement (longitudinal riding quality and depth of rutting), the percentage of deterioration, and the percentage of repairs. Its use may appear more satisfactory than the preceding method; but in actual fact this is not so, because in these formulae the riding quality parameter plays a predominant role by comparison with the others, and ultimately affects the result obtained for the PSI.

The advantage of such formulae would be obvious if they made it possible to interrelate all the characteristic parameters satisfactorily. Unfortunately, when it is a question of inter-relating several parameters, we must know what respective weights to assign to them. This question was raised by Group C_6 of the OECD (maintenance of roads in open country), which wondered, in the context of pavement maintenance, whether it would be better to apply measures first of all to a pavement with a perfect riding quality but with a poor skid resistance, or to a pavement with dependable skid resistance but defective riding quality. The group concluded, moreover, that it would prefer to take each parameter separately and consider a series of standards for each of them, rather than to take a single, overall standard.

The second objection is that these formulae are obtained experimentally, and that apart from the fact that the experiment has to be set up in order to determine the numerical coefficients, the results obtained depend on the country performing the experiment, the pavements analysed, and the values assigned to the PSR (1). For example, the TRRL (2) undertook a similar study in Kenya on test sections, in order to determine the numerical coefficients which would make it possible to utilize the MIT (3) model for calculating pavement costs; the conclusion was that «the behaviour of the test sections is totally different from that of the AASHO test sections».

III. – RECOMMENDATIONS

There are many parameters which can make it possible to perform overall non-destructive testing of a road system for the purpose of determining a financial envelope for maintenance and overlay work, and the choice of priorities. In practice, for each of these parameters there is a high-yield instrument which allows of suitable non-destructive testing within a reasonable period of time and at acceptable cost, lending itself where applicable to modern data processing techniques. But before transposing a method lock stock and barrel to another country, even if it has proved entirely successful, it is necessary first of all to state the problem which has to be solved, in order that the most suitable parameters may be chosen with discernment.

In order to define the overlay requirements of a road system, that is to say to separate those itineraries which may be included in the programme of standard maintenance from those which first have to be overlaid, establish a list of priorities, and evaluate the envelope of the work involved, we advocate evaluating the quality of the road system on the basis of three factors :

- The appearance of the surface, because the deterioration of a pavement is an indicator of its behaviour.
- Deflexion, because whatever criticism may be levelled at it from the theoretical point of view, continuously measured deflexion is an excellent indication of poor quality.
- The structure of the pavement, determined by exploratory drillings and by consulting road registers, accompanied by an investigation of the maintenance carried out.

The combination of the first two of these parameters provides an answer to the following problem :

(1) PSR = Present Serviceability Ratio.
(2) TRRL = Transport and Road Research Laboratory (UK).
(3) MIT = Massachusetts Institute of Technology.

– It may be that a surface condition is satisfactory because a very recent surface dressing masks deteriorations, or because traffic has not yet had time to damage the pavement. In this case, the deflexion must reveal structural weaknesses.

– It may be that deflexion is slight on a deteriorated pavement because the deterioration does not result from excessive pressures at the level of the underlying soil.

Taking these elements as a whole, the line of reasoning is as follows :

1/ We seek the process of pavement deterioration by examining the principal causes, and we define different conditions of the pavement.

2/ To these different conditions, we assign a standard solution, which may be maintenance, overlay of one kind or another, the relaying of one or several courses, etc.

3/ We establish a relationship between the parameters of non-destructive testing and these different pavement conditions (one parameter may be more or less predominant).

4/ On the basis of these parameters, we evaluate the quality of the road system.

In practice, as we have already said, we are obliged to proceed by statistical sampling. Experience has shown that a satisfactory solution is to make a continuous visual examination of the road system, codifying and quantifying deteriorations; and to make continuous measurements of deflexion on sections 1 to 2 km long, distributed statistically in the light of the visual examination so as to cover between 10% and 20% of the road network which has been tested (i.e. a section 1 km long every 5 to 10 km on the average). Thirdly, to make exploratory drillings every 5 to 10 km on the average, revealing the pavement and the shoulder.

This method is illustrated in two examples which will be given later.

IV. – CASE HISTORIES

1) Mali

a) Purpose of the study : Until 1975, maintenance carried out on the system of surfaced roads in Mali (about 1,600 km) was confined to standard curative maintenance consisting mainly of filling in potholes. With effect from 1975, the Public Works Department decided to adopt a policy of preventive maintenance and to set up an organization making it possible to undertake, with the help of a newly created asphalting unit, large scale surface repairs and repairs to the base courses of pavements, together with preparatory work prior to asphalting, and the renewal of surface courses.

The overall non-destructive testing of the Malian road system was integrated in the setting up of these new structures. Its purpose was to provide an envelope of overlay requirements for 1,200 km (400 km not being included in the programme, because they were in course of modernization), separating the itineraries to be overlaid from those to be included in the normal standard maintenance programme; to prepare a list of priorities, and to calculate the cost of the work involved after having determined the elementary tasks to be performed.

Intended for the highest levels of the administration, responsible for the definition and orientation of road policy, this study is consequently one of the management tools of the road system.

b) Principle of the study : The study consisted of :

– Examining, understanding and classifying the principal forms of pavement failure.

– Defining a methodology of analysis highlighting the different conditions previously defined.

– Selecting corresponding standard solutions and calculating their unit costs.

– Statistically analysing the road system.

– Proposing priorities in function of the national economic context.

– Calculating the overall budgetary envelope.

No study of traffic was made on this occasion, the principal data having been gathered by the Road Traffic Bureau (with the exception of the traffic spectrum, which is still not accurately known).

c) Content of the study : The road system was evaluated on the basis of :

– A rapid preliminary reconnaissance of the road system as a whole, so as to evaluate the scope of the problem and propose a basis for the study.

– A second preliminary rapid reconnaissance at the time when the study was initiated, so as to familiarize the three engineers carrying out the study with the problems encountered, to harmonize their notation, and to set up test sections.

– A minute visual and continuous examination of the 1,200 km, on foot and by car moving at very slow speed.

– Measurements of deflexion on sections 1 km long, on the basis of one such section for each 10 km of itinerary; the measurements were made with the Benkelman beam at points 20 m apart at the edge of the pavement and 100 m apart on the centre line.

– Exploratory drillings in the pavement, the shoulder and the underlying soil, accompanied by soil tests; one exploratory drilling was made for each 6 km of itinerary on the average.

– Interviews with territorial engineers responsible for maintenance and for consulting records.

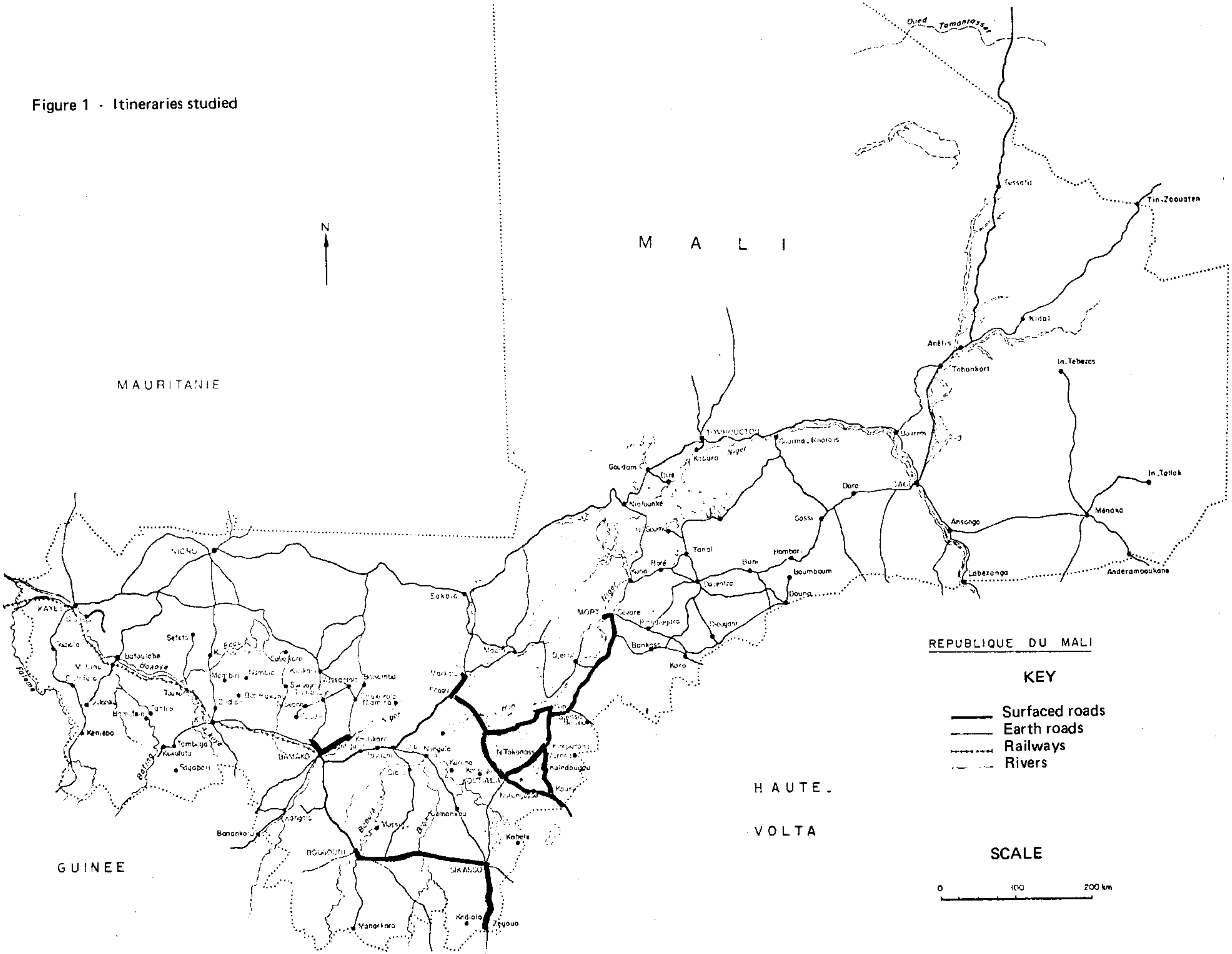
All these tasks were performed in the field by three engineers and two technicians from the French Laboratoires des Ponts et Chaussées, in conjunction with teams from the Bamako National Public Works Laboratory.

d) Results : Results were presented in two documents :

– A chart of the itineraries, on a scale of 1/50,000, presenting all the data gathered and measured on these itineraries.

– A report stating the context, traffic, climate, principal cases of failure encountered, standard solutions and their costs, an identification data-sheet per itinerary, priorities, total budgetary envelope, and the necessary lines to be followed in order to undertake pathological studies of the APS phase.

Figure 1 - Itineraries studied



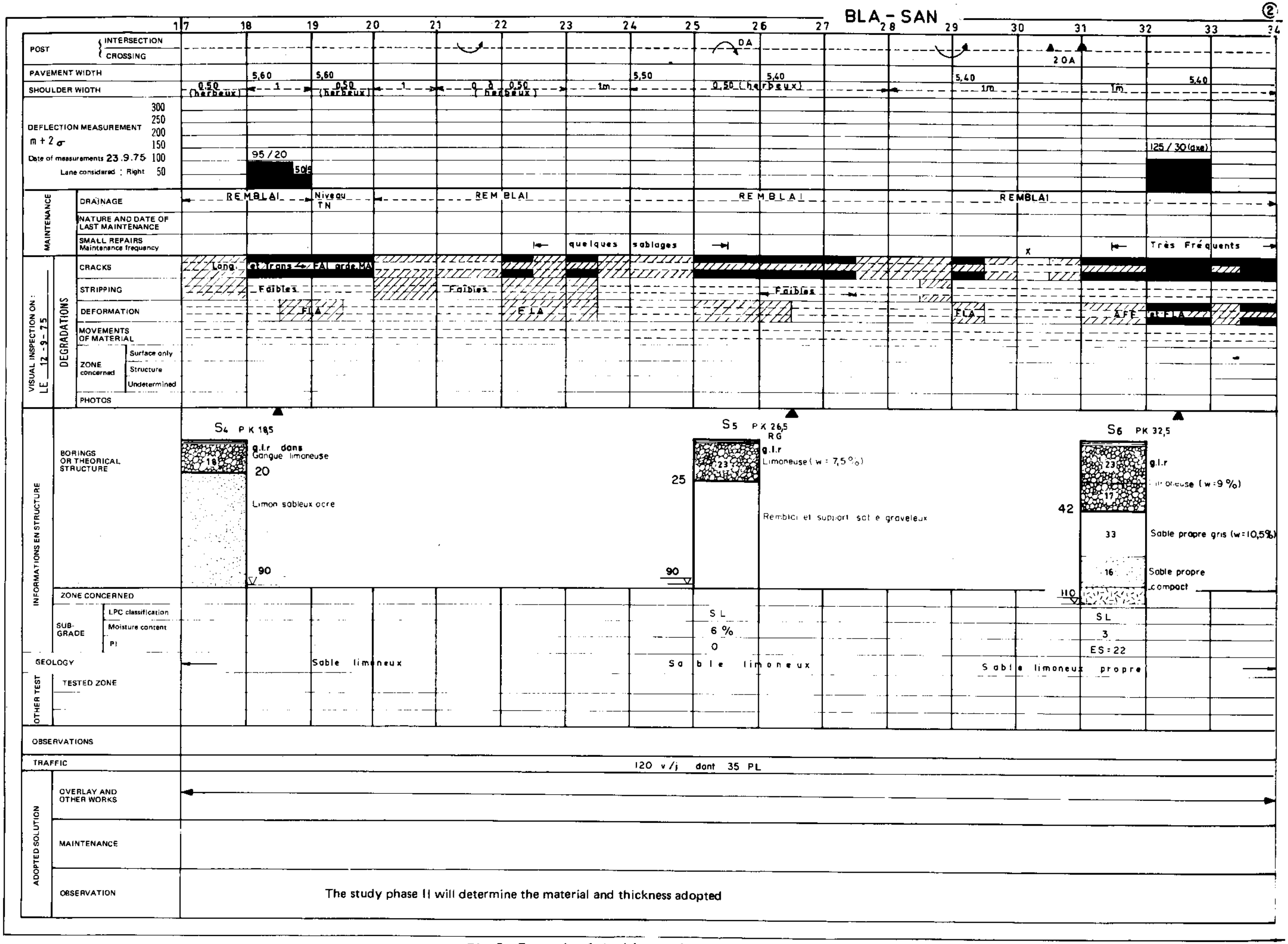


Fig. 2 - Example of the itinerary's chart used in Mali

TABLE OF SOLUTIONS

ITINERARY X . . . .

P.K. 0 to P.K. 210

Length : 210 km – Width : 5 m to 5.4 m

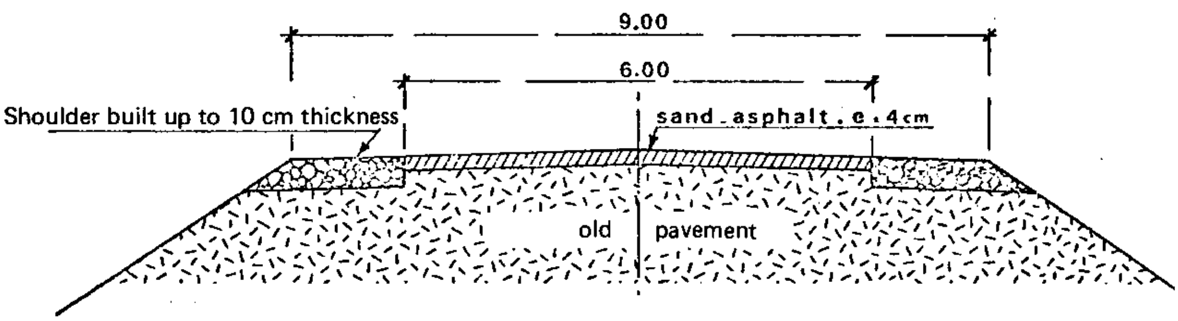
BREAKDOWN OF STANDARD SOLUTIONS		Km	%
OVERLAYING			
Addition of new courses			
– Surface dressing (urgent)		110	52
– sans-asphalt 2.5 cm			
– sand-asphalt 4.0 cm		23	11
Reconstitution of pavement			
– total (base + foundation)			
– base only		2	1
– localised rebuilding operations :	number	30 to 40	
MAINTENANCE			
– classed under routine maintenance			
– pavement requiring a thick wearing course		75	36
AUXILIARY WORK			
– widening of pavement surface from	5.2 m to 6 m	170	80
	5.5 m to 6 m	40	19
– reclamation of verges for widening			
– build-up of shoulders			
- with an overlay	5 cm	62	30
	10 cm	1	0.5
- without an overlay	5 cm	93	44
	10 cm	12	6
- with rebuilding of pavement		2	1

Figure 3 - Recapitulative table per itinerary

Cost per kilometre N° 4

Overlaying of pavement with a new sand-asphalt wearing course

Standard transverse profile applied



sand-asphalt wearing course

shoulders built-up with laterite gravel after cleaning their existing surface

Cost per kilometre in Malian francs

– Cleaning of shoulders	3000 m^2 x 100	= 300,000
– Building-up of shoulders	315 m^2 x (3500 + 530)	= 1,269,450
– Bonding	6000 m^2 x 300	= 1,800,000
– 4 cm of sand-asphalt	6000 m^2 x 3000	=18,000,000
		21,369,450

Rounded off to 21.4 million

Figure 4 - Example of the calculation of unit cost for a standard solution

RECAPITULATIVE TABLE OF COST PER KILOMETRE

TO THE CONTRACTOR

Nº	Designation	Cost in millions of Malian francs, all taxes included
1	Complete reconstitution of pavement	24.0
2	Replacement of base course	20.1
3	Addition of new base course	17.4
4	4 cm of sand-asphalt	21.4
5	2.5 cm of sand-asphalt + shoulders	13.0
5 bis	2.5 cm of sand-asphalt	12.2
6	Surface dressing + shoulders	8.8
6 bis	Surface dressing	8.0
7	Widening to 6 m	2.7
7 bis	Widening to 6 m + surface dressing	4.0
8	Building-up of shoulders (5 cm)	1.0
8 bis	Building-up of shoulders (10 cm)	1.6
9	Localised rebuilding, per operation	1.6

Figure 5 - List of unit costs of standard solutions

2) Algeria

a) *Purpose of the study :* The purpose was identical to that of the case history just described; the operation consisted of testing about 6,000 km constituting the skeleton of the principal road system, so as to establish overlay requirements and priorities.

b) *Principle of the study :* Under the responsability of the SETI* (Service d'études techniques et d'infrastructure) this study is currently in progress and has recourse to several consultancy organizations. It comprises numerous tasks ranging from the overall evaluation of the road system through an inventory of quarries, an examination of techniques which can be used (in particular the use of tuff), the preparation of a catalogue of structural design of overlays, etc.

c) *Content of the task of evaluating the road system :* The non-destructive testing of the system is based on the same parameters as those previously described :

- A record of continuous deflexions over the 6,000 km using the Lacroix deflectograph.
- Exploratory drillings, one per km on the average.
- Continuous visual examination of the pavement.

In practice, apart from the visual examination, which was purposely dealt with rather summarily, the principal technical elements necessary for the APS were gathered at the feasibility stage. This procedure has the advantage of providing very exhaustive elements at the feasibility levels, but carries the danger of rendering certain elements null and void if the second APS stage is carried out more than three or four years after the feasibility stage. It also requires a very large personnel to carry out all this work in a reasonable time.

The SETI solved this difficulty by dividing the whole work into several batches, each assigned to a different consultancy organization, and coordinating the whole itself.

With regard to the record of deflexion, the Algerian National Laboratory had a single Lacroix deflectograph and could not make all these measurements itself. The SETI therefore had recourse to the French Laboratoires des Ponts et Chaussées which, using four deflectographs, made measurements over 2,500 km between December 1975 and March 1976, at the rate of 200 km per month and per deflectograph. The results were processed by the Trappes Coordination Centre on a programme specially established for the use of the SETI, and the results were submitted one month after the measurements had been made in situ.

This example is interesting. The National Public Works Laboratory in Algiers has adequate personnel and equipment under normal circumstances (the APS stage, for example); to cope with this very large-scale feasibility study it would have has to acquire additional equipment and train additional personnel in a very short period of time. Recourse to French cooperation avoided this (the Laboratoires Français des Ponts et Chaussées was responsible for 2,500 km of deflexion measurements out of the 3,000 programmed, and about 1,000 exploratory drillings, equivalent to one-third of the programme), but this cooperation was only possible because the SETI had opted for a methodology similar to that in use in France.

* Service d'études techniques et d'infrastructure d'Algérie.

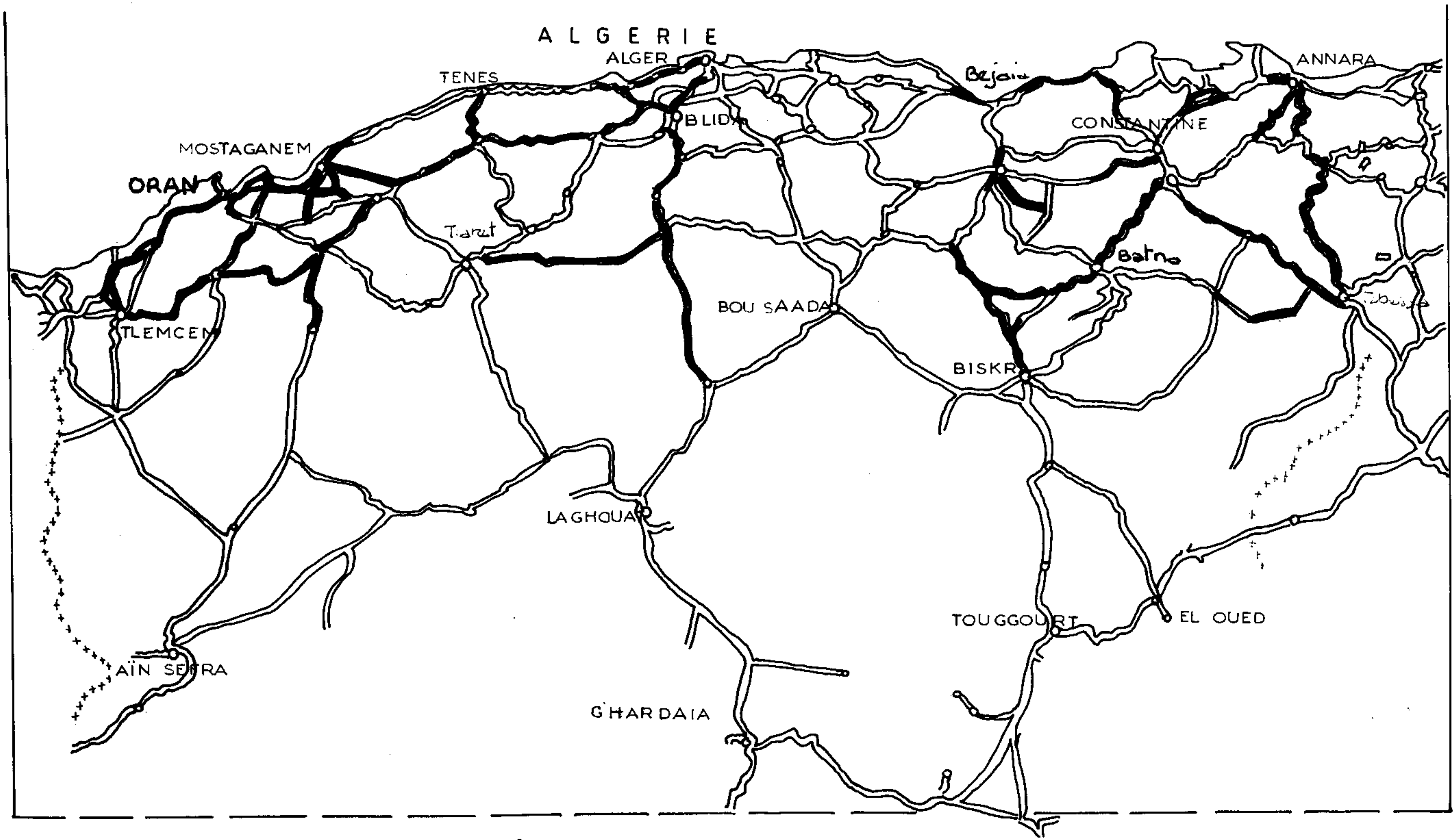


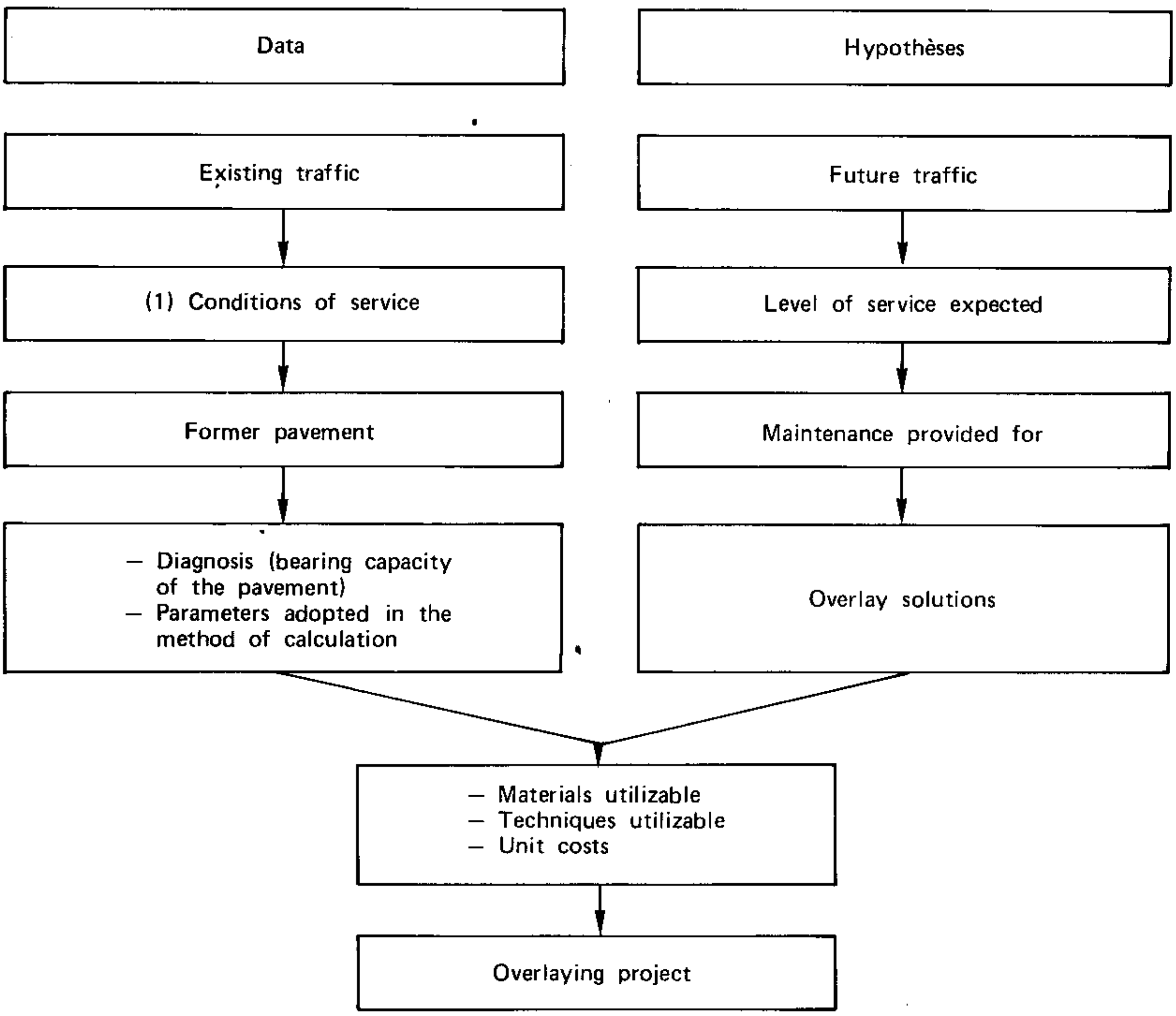
Figure 6 - Deflexion programme carried out with 4 LPC deflectographs between December 1975 and March 1976 on the basis of a minimum of 200 km of measurement per month (real rate > 10 km per working day). About 2,500 km altogether.

APS FOR A GIVEN ITINERARY

The task here is to study a given itinerary which it has been decided to overlay. The hypotheses which have led to this decision are therefore known. The pathological analysis should provide and localise the solutions to be applied to this itinerary; such solutions may very from one section to another and it is quite possible that some of them will involve simply routine maintenance.

I. – PARAMETERS INVOLVED

The different parameters determining the overlaying solutions adopted may be broken down as follows :



(1) By conditions of service are meant all those conditions which may account for the condition of the former pavement : for example, whether or not a maximum axle load is set, whether or not there are rain barriers. These conditions can be incorporated in the hypotheses, under the heading «Level of service expected».

We shall consider that the study is confined to determining the residual bearing capacity of the pavement, and to measuring the parameters taken into account in the method of calculation (which does not mean that the part relating to utilizable techniques and materials is negligible; quite the contrary, but it can be dealt with either separately, or in the APS, or in the APD).

II.– QUALITIES REQUIRED OF A STUDY

We may make a distinction between several methods :

– Those having recourse to non-destructive testing in order to measure certain parameters characterizing the mechanical behaviour of the pavement (deflexion, radius of curvature of deflexion, assessment of the quality of the materials by vibration methods, etc.).
– Those based on the external surface condition of the pavement (assessment of the surface quality by reference to a catalogue of deteriorations or standards of deterioration; measurements of geometrical deformation, etc.).
– Those based on internal observations (exploratory drillings and core sampling, assessment of the underlying soil, etc.).
– Those combining the above.

Each of these methods probably has its advantages and drawbacks, but all of them must meet the following conditions :

1) Correct analysis of the problem :

When the decision to carry out a study has been made by the department responsible for road management, the first task of the person in charge of the study is to find out why overlaying is envisaged, and what is the objective aimed at. Is the pavement at the end of its service life (hence requiring a curative overlay); is it still in good condition, but likely to have to bear a very substantial increase in traffic which it cannot withstand (preventive overlaying); must the itinerary in question be free of service constraints which have become inadmissible ? etc.

It is of capital importance to state the problem clearly before rushing into solutions having recourse to sophisticated calculations which, quite often, serve only to mask the inconsistency of the study. We therefore consider that priority must be given to the analysis, which should proceed as follows :

1/ State the problem.
2/ Establish the experimental programme in the light of the problem to be solved.
3/ Make observations and intepret them.
4/ Where applicable, perform calculations which can help in the choice of a solution.
5/ Choose the solution or solutions from among the range generally available in the light of experience acquired (if necessary, invent new solutions).

This means that we must not tackle the calculation stage until we are certain that we have properly understood the problem, and until we have gathered the correct parameters which can be introduced into the method of calculation.

2) A correct picture of the pavement :

Not only must the right parameters be adopted, but there must be a sufficient number of them to characterize the pavement. For example, is it reasonable to calculate a pavement overlay on the basis of a single CBR test per kilometre ?

Thus a distinction emerges between two types of tests :

– Those which make it possible to judge the homogeneity of an itinerary; they provide a quantitative and qualitative element (measurement of deflexion using the Lacroix deflectograph, measurement of riding quality using the Bump Integrator).
– Those which allow of only a quantitative judgement at specific points, on the basis of which it is not possible to divide the itinerary into homogeneous sections.

To illustrate this, we have taken an example of deflexion measurement. Each vertical line on the graph is a deflexion measurement, and the points of measurement are about 4 m apart. This is a deflectogram obtained by a deflectograph (figure 7). But deflexion can also be measured with a Benkelman beam, and the intervals of measurement can be freely chosen by the operator. If the interval is 100 m, as is commonly the case, we can obtain a picture of the pavement totally different to that provided by the deflectogram (whose interval is 4 m); a picture which may no longer represent its real condition, and a picture which can itself vary enormously, though the interval is identical (100 m), depending on where the measurements start from.

A statistical calculation of the population as a whole, obtained with the deflectograph, produces the following values :

– average m	140/100 mm
– Standard deviation σ	60/100 mm
– $m + 2\sigma$	260/100 mm

The continuous-line curve obtained by making the measurements every 100 m, starting at point 19,000, reveals only one value greater than 140/100 (i.e. the population average), which is only 250/100, whereas there are deflexions close to and greater than 300/100.

All the values on the dotted line curve are less than 140/100, that is to say this curve is constantly below the population average; furthermore, it does not show the deflexion peak of the point 19,200 zone; that is to say it gives a false impression of homogeneity.

It is therefore preferable to have available a large mass of data which can faithfully represent the pavement and show its homogeneity, even if this information has to be less accurate, rather than measurements which are extremely fine and accurate but which are so small in number that it is risky to extend them to the pavement as a whole.

Several methods can be found of characterizing the former pavement and calculating the overlay :

a) We use a parameter which makes it possible to judge homogeneity, the same parameter used in the method of overlaying. For example, the deflexion is measured with the Lacroix deflectograph and on the basis of the deflectogram the itinerary is divided into homogeneous zones to which we assign a deflexion value; the thickness of the overlay is deduced from a formula or a chart which sets the deflexion of the former pavement against the deflexion which it is required to obtain after overlaying.

b) We use a parameter to judge the homogeneity of the pavement, but a different parameter is introduced into the method of calculation. For example, as in the previous case, we determine the homogenous sections by means of deflectograph, but the thickness of the overlay is deduced from the method of calculation of the new pavement, on the basis of a CBR test and coefficients of equivalents of the existing courses.

c) By making spot tests here and there, we determine the overlay thickness and we choose a smoothed thickness, in the light of the values calculated, for the itinerary or a portion of it.

Unlike the forts two methods, which give a correct picture of the pavement, even though they differ in the method of calculation adopted, the third method can be very dangerous if the points of measurement are widely spaced, and we risk having very accurate calculations bearing no relation to the real value of the pavement at points other than those where measurements are made.

3) Provision of the necessary elements for the choice of a solution :

This seems obvious. In addition to the diagnosis which tells us where overlaying must be performed and explains why the pavement is in the condition observed, we must have the elements necessary for the choice of a solution. Furthermore, these elements are not necessarily measurements (e.g. localised repair of drainage defects). This condition required of the study is not so obvious as all that; a method of calculation which univocally gives an overlay thickness in function of the deflexion can sometimes lead to setbacks when the transverse profile of the pavement is very rutted and the thickness indicated by the deflexion is insufficient to correct the rutting which the study omitted to reveal.

III. — FRENCH STUDIES

This type of study has been employed in France since 1969. It was developed for coordinated overlaying, and has already been applied to the non-destructive testing of 12,000 km of itineraries, and still is applied every year by the engineers responsible for overlaying, to the extend of 2,000 to 3,000 km annually. In this connection, three documents have been produced.

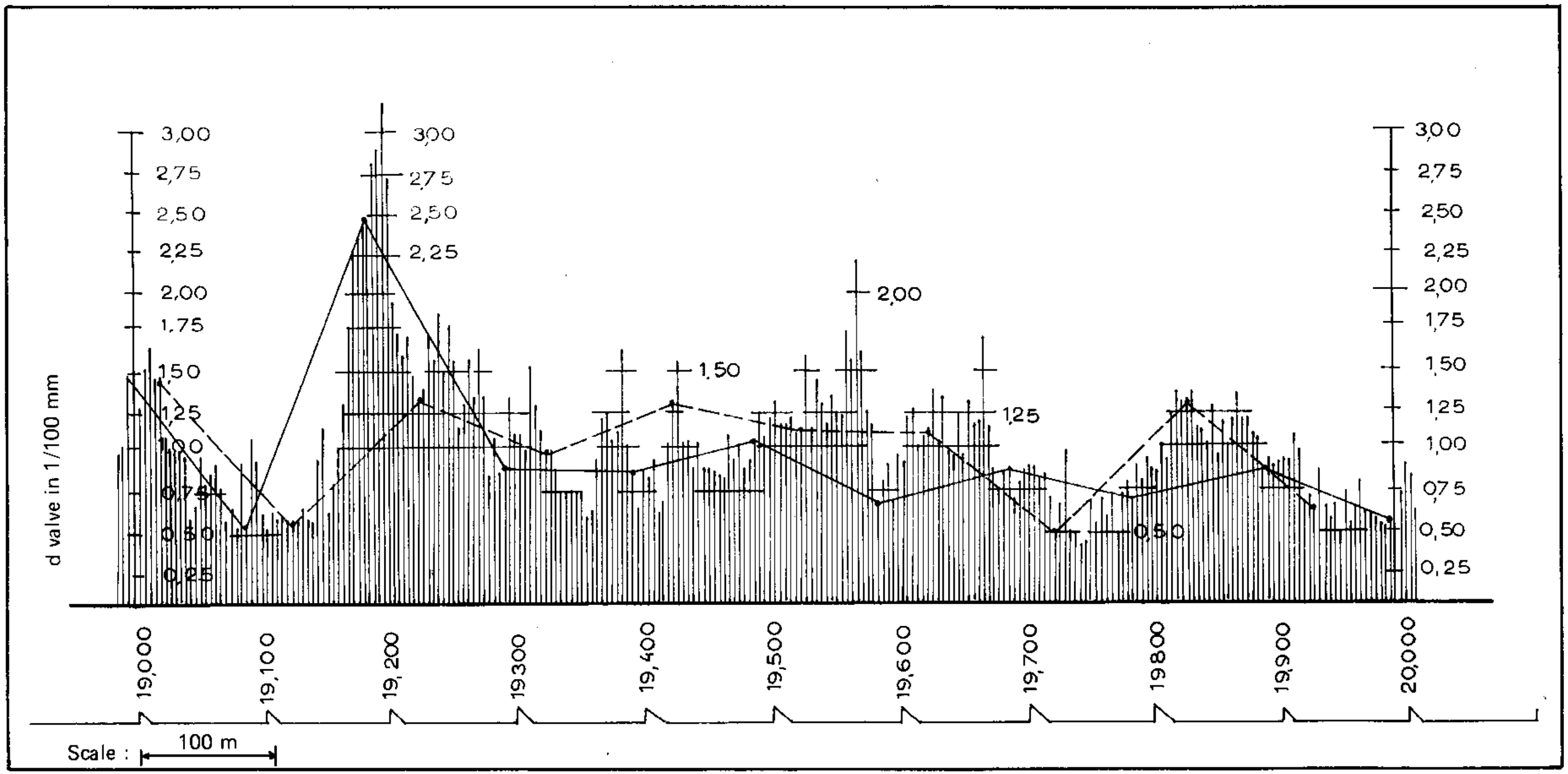
- The pilot overlay study.
- The guide to the non-destructive testing of flexible pavements.
- The method of structural design of overlays.

Priority is given to the analysis, and the general principle is as follows :

- Statement of the problem.
- Establishment of the experimental programme, and gathering of data.
- Interpretation of data.
- Choice of a solution.

Figure 7 - Influence of measurement intervals and the origin of the first point of measurement.

1. Deflectogram : 1 point of measurement every 4 m.
2. ———————— : 1 point of measurement every 100 m, starting at PK 19,000.
3. _ _ _ _ : 1 point of measurement every 100 m, starting at PK 19,025.



1) Pathological non-destructive testing : the itinerary plan

The general plan is as follows :

Firstly, the deflectograph must be passed over both lanes of the pavement, or at least over the lane carrying the heaviest traffic, during the most unfavourable period of the year (to be defined in the light of experience).

When the deflexions have been recorded, use is made of them in several stages, taking account of the deflexion average and the dispersion of deflexions at all times and for each section.

In an initial stage, statistical processing makes it possible to highlight the homogeneous zones (those on which deflexions seem to belong to a given statistical population). Processing may be either automatic or manual, giving the mean and the standard deviation over sections 200 m long in steps of 20 m.

When this initial processing is completed, the singularities of the deflectogram should be noted (in particular, localised deflexion peaks), and these initial results are compared with the visual aspects of the pavement and its surroundings. In the course of this inspection, special attention is paid to the singularities of the pavement which may explain particular points on the deflectogram (anomalies of drainage, notably improperly cleaned ditches, low points where run-off water accumulates, high points forming saddles where the water table comes close to the surface, etc.). The distribution of these various defects may require localised treatment. Deteriorations are noted with particular care, and the extent of the deteriorated zones and the seriousness of their deterioration are recorded. Reference is made to a «catalogue of deterioration» which makes it possible for everyone to use a common terminology. The deteriorations are recorded either by an observer on foot, covering 10 km per day, or by the Gerpho, covering 150 km per night. In the latter case, the itinerary deterioration chart is produced directly by the computer.

We use a graphic code to represent the degree of deterioration, which is variable from one type of pavement to another and depending on the deterioration encountered.

For flexible pavements :

- *In white :* very localised deteriorations covering less than 10% of the strip.
- *In grey :* localised deteriorations covering between 10% and 50% of the strip.
- *In black :* generalized deteriorations covering more than 50% of the strip.

We then set up a number of additional tests. These tests are performed in each homogeneous zone defined by the deflectogram.

We perform exploratory drillings — 2 per km on average — (but it must not be forgotten that the itinerary under study is often more than 100 km long) to obtain the thickness of the pavement, and the nature and quality of the courses encountered. Sometimes the programme is complemented in certain zones by vibrator measurements and measurements of the radius of curvature (mainly in the case of sections incorporating a substantial layer of bituminous mix, or hydraulic binders). A few records of transverse profiles give an estimate of the quantity of materials necessary for the profile. Their location is always carefully chosen, and concentrated on sections selected to represent a homogeneous zone.

When all this has been done, we have fairly complete information on the pavement, and we now have to bring this information together in one synthetic document called the itinerary chart.

This document shows :

- A reproduction of the deflectogram.
- Localities, intersections and traffic.
- The visual condition of the pavement (overall condition = good, average, poor) and its detailed condition = position of lingitudinal and transverse cracks, crackling, zones of partial use, zones of bleeding, nature of the surfaces, settlements, etc. with an indication of the origin of the deteriorations.

The document also carries indications concerning the level of the section in relation to the neighbouring ground (embankments or cuttings), the environment (forests, lakes, waterways) and the drainage.

Naturally, when the structure of the old pavement has been determined, it figures on the itinerary chart. In other cases, cross-sections of exploratory drillings are given, accompanied by qualitative tests carried out on the materials of the pavement and on the underlying soil (particle size distribution, water content, etc.).

Figure 8 is an example of an itinerary chart. The normal scale is 1/20,000, but it may of course be adapted to certain singularities such as sections which pass through towns for example (scale 1/10,000). We may also have recourse to data processing to prepare this chart; an automatic programme (TASIEF) produces the itinerary chart from information gathered on the pavement and noted in such a way as to be fed into a computer (figure 9).

2) Interprétation of results

a) Principle

The principle consists of using the data gathered and entered on the itinerary chart in order to divide the itinerary under study into homogeneous sections each corresponding to a given overlay.

When the itinerary chart has been prepared, it contains a number of parameters which can be used to cut the itinerary into homogeneous sections, and for the structural design of the overlay; for example, the characteristics of pavement width essential to establish the new transverse profile, or again traffic metering. In this example, we shall study principally four of them relating to the pavement, on which the diagnosis is based :

- Past history, and in particular maintenance carried out.
- The apparent condition as revealed by visual examination.
- The structure, i.e. the constitution of the pavement proper in its geological, geotechnical (underlying soil) and hydrogeological (drainage) environment.
- A parameter of mechanical behaviour represented by deflexion.

Deflexion naturally plays an important role in dividing the itinerary up into homogeneous sections; on the one hand because in most cases it correctly reflects the behaviour of a flexible pavement – about 80% of cases encountered in France – and on the other hand because the measurements involved are continuous and they make it possible to test the criterion of homogeneity of a pavement.

But it would be a mistake to adopt deflexion as the only criterion of decision and choice in the overlaying project; partly because its measurement is an observation of a condition which it does not explain, and partly because, in 20% of cases encountered in France, it is not linked with the behaviour of the pavement. Used on its own, this parameter can be dangerous, and it is for this reason that the method of analysis described in the guide to the non-destructive testing of flexible pavements (1) combines it on the itinerary chart with three other factors : maintenance, surface condition and structure.

b) Combined utilization of these parameters

It is not easy to combine these parameters, because some of them are derived from continuous quantitative measurements and others are qualitative assessments at specific points. While bearing in mind the reservations made with regard to deflexion, the procedure consists of setting this latter parameter against the three others in order to check whether or not we may use it for dividing the itinerary into homogeneous sections and to decide on the choice of solution. Two cases may occur :

- Either all the indications deduced from the examination of each parameter concur, and make it possible to establish an easy diagnosis, in which case we use deflexion for dividing the itinerary into sections and for choosing the solution.
- Or the indications are discordant, in which case the solution can only come to light when this divergence has been explained.

To illustrate the combined utilization of these four parameters, we assign each of them only two modes :

- The deflexion will be either slight or marked, that is to say that in the light of experience acquired in the region or country where the method is applied, a low value corresponds to a pavement in good condition, whereas a high value corresponds to a pavement which usually needs overlaying (these two modes embrace other notions, such as traffic for example).
- The surface condition is either deteriorated or not deteriorated, in the light of percentages of deterioration given in the guide, and excluding certain deteriorations which are independent of the structure, such as bleeding or plucking for example (2).
- The structure, a complex notion embracing the thickness and the quality of the body of the pavement, the underlying soil, drainage, etc., corresponds (also allowing for traffic) to a correct structural design or to an inadequate structural design.
- Maintenance comes into the picture in the light of the date of the latest work performed, in order to check the validity of the visual examination leading to a rating of the surface condition; and in the light of the periodicity of minor repairs, which may be either too frequent or normal.

c) Principal combinations encointered

In practice, we do not end up with the sixteen combinations resulting from the association of four parameters each of which has two modes; we encounter six principal combinations, which are shown in the table (figure 10).

3) Choice of solutions

Two cases occur : either the deflexion is correlated with the behaviour of the pavement or it is not.

(1) Guide to the non-destructive testing of flexible pavements. Editions Eyrolles, 1977.

(2) See «Catalogue of pavement deteriorations» (SETRA-LCPC).

Fig. 8 - Example of an itinerary chart (hand drawn)

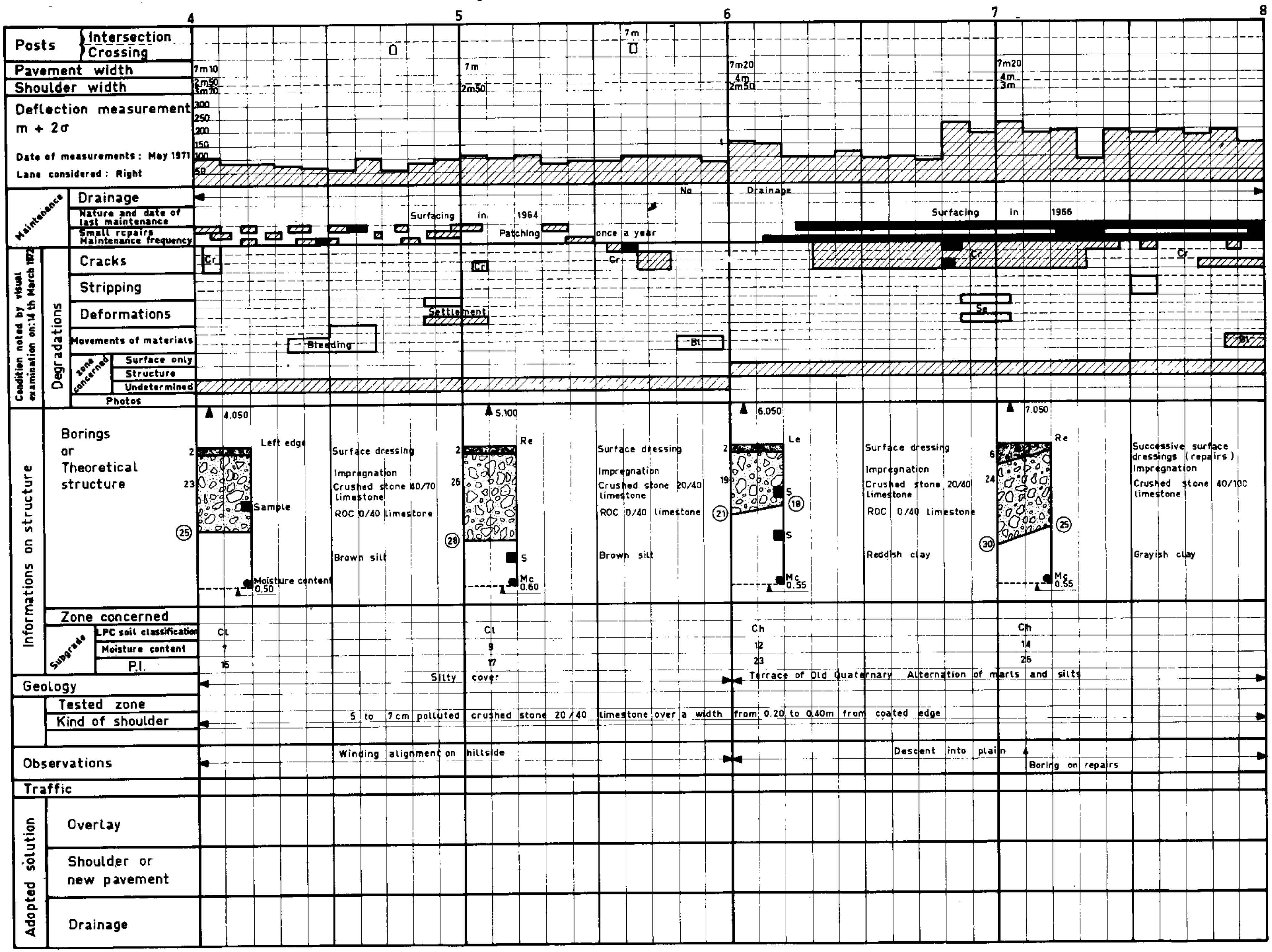


Fig. 9 - Example of an itinerary chart (computer drawn - TASIEF)

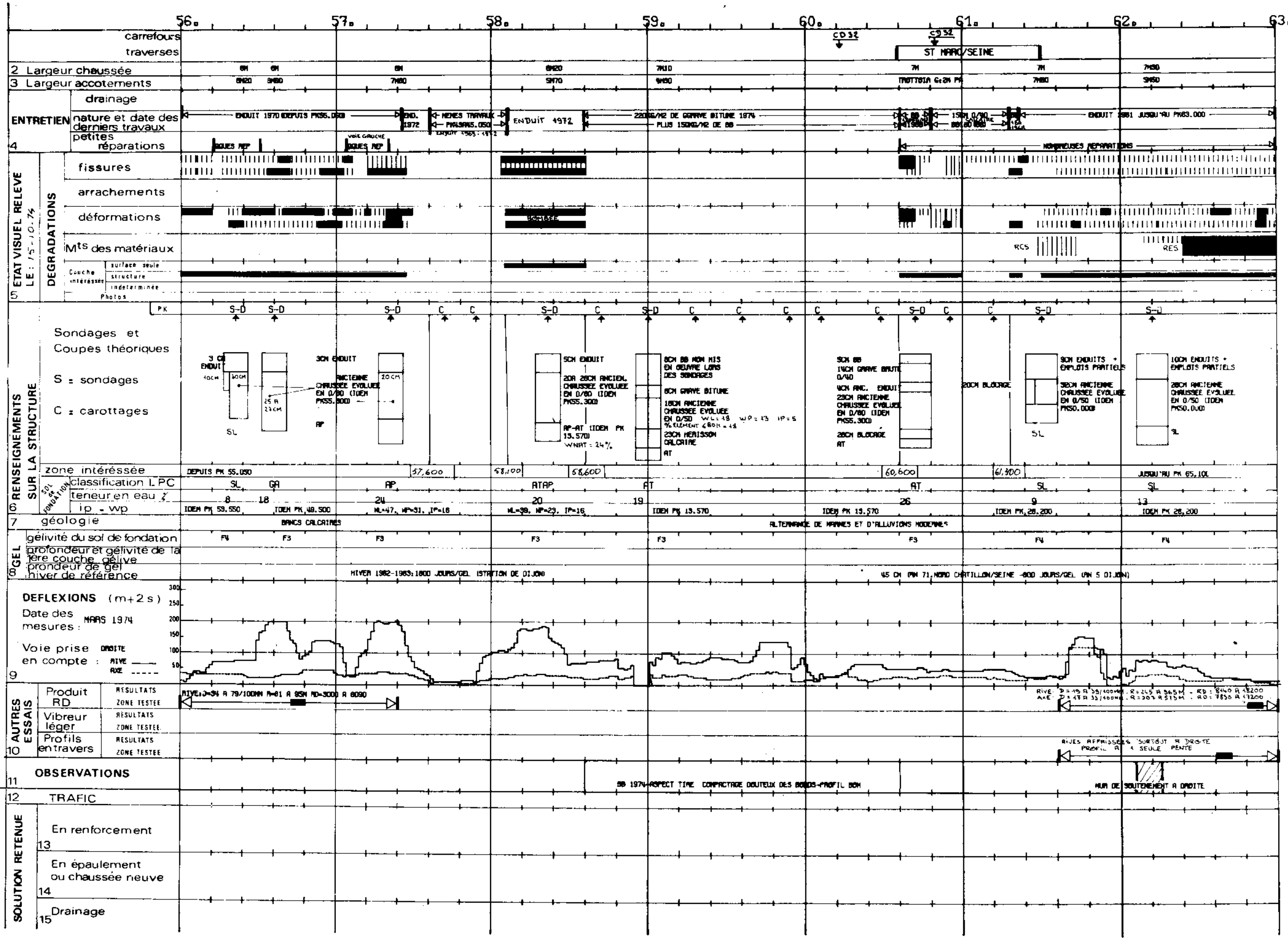


Table 10

<table>
<tr><th>GROUP I</th><th colspan="7">GROUP II</th><th rowspan="3">Diagnosis : guideline for dividing into homogeneous sections, and choice of solutions.</th><th rowspan="3">Utilization of deflexion for dividing the itinerary into homogeneous zones, and for the choice of solution.</th></tr>
<tr><th rowspan="2">Deflexion</th><th colspan="2">Structure</th><th colspan="2">Visual condition</th><th colspan="3">Maintenance</th></tr>
<tr><th>BD</th><th>MD</th><th>D</th><th>BE</th><th>DT</th><th>F</th><th>N</th></tr>
<tr><td>1) Marked</td><td></td><td>X</td><td>X</td><td></td><td></td><td>X</td><td></td><td rowspan="2">The deflexion and the other parameters are in accordance for the establishment of the diagnosis. We use deflexion for dividing the itinerary into homogeneous sections and for the choice of solution.</td><td rowspan="2">yes — The itinerary is divided into homogeneous sections from the value (m+ 26) of deflexion. To each section we assign a category Cj, in accordance with the following table :
<table><tr><td>d</td><td>0 à 50</td><td>50 -75</td><td>75-100</td><td>100-150</td><td>150-200</td><td>200-300</td></tr><tr><td>Cj</td><td>Cj</td><td>C2</td><td>C3</td><td>C4</td><td>C5</td><td>C6</td></tr></table>
yes — Cj in conjunction with the traffic gives the solution sought, for each technique, in a table of solutions.</td></tr>
<tr><td>2) Slight</td><td>X</td><td></td><td></td><td>X</td><td></td><td></td><td></td></tr>
<tr><td>3) Marked</td><td></td><td>X</td><td></td><td>X</td><td>↓</td><td></td><td></td><td>Check the nature and date of latest work. We may have a very recent surface which masks the seriously deteriorated condition before the work, or we may have a new pavement of poor structural design which is only slightly deteriorated so far by traffic because of its newness.</td><td>pershaps — After examination of the nature and date of latest work, if it is confirmed that visual examination is not significant, we adopt the preceding table and follow the same procedure for the choice of solutions.</td></tr>
<tr><td>4) Marked</td><td>X↓</td><td></td><td>X</td><td></td><td></td><td>X</td><td></td><td>There is probably a defect related to a given course and not to the structure as a whole. The problem is not necessarily to overlay by adding new courses but to neutralize this particular defect, revealed by a high deflexion, of which the solution may be independent.</td><td>pershaps — Deflexion may be used to localise the zones possessing the particular defects which have been noted. The solution may be to rectify this defect by doing away with the cause, in which case it is independent of the value of deflexion. It may sometimes consist of over-laying, by adding a fresh course, in which case we use the table above.</td></tr>
<tr><td>5) Slight ↑</td><td></td><td>X</td><td>X</td><td></td><td></td><td>X</td><td></td><td>Check the date of measurements : doubtless the deflexion is not representative. Furthermore, check whether the pavement is in fact a flexible one and in particular, if there has been widening, whether the widened parts have not been treated with cement, for example.</td><td>no — Failing any other means, deflexion may possibly serve for dividing the itinerary into zones. But it cannot be used to determine solutions ; the above table may not be used, even with the application of a seasonal coefficient to increase the deflexion parameter ; this is dangerous because it is not constant.</td></tr>
<tr><td>6) Slight</td><td>X
↓</td><td></td><td>X</td><td></td><td></td><td>X</td><td></td><td>Similar case to number 3. It is probably a question of a defect in the wearing course leading to a deterioration, without involving the structure (poor workmanship in the surface dressing or in the bituminous mix of the wearing course).</td><td>no — Deflexion is not related to the defect revealed by visual examination.</td></tr>
</table>

Structure BD : Good structural design
MD : Poor structural design

Visual condition D : Deteriorated
BE : Good condition

Maintenance DT : Nature and date of latest work
F : Frequent (more than normal)
N : Normal

a) Solution not related to deflexion : In table 10, we see that when the solution cannot be linked with the deflexion, it results directly from the analysis and depends only on the defect observed — it is not necessary to calculate the thickness because the overlaying does not involve a structural additive.

b) Solution related to deflexion : In this case, a structural additive is necessary. For each technique (bituminous mixes, gravel-bitumen, gravel-slag, etc.) we have a table which gives the solutions sought for category Cj deduced from table 10 and for the traffic Ti in question. We shall see later how these tables were established.

4) Example

The following example relates to figure 8; the itinerary chart has been prepared, and it remains to determine the sections which will receive an overlay of uniform thickness.

a) The width of the pavement is greater than or equal to 7 m at all points. So there will be no problem of adjustment of the width. But we shall have to decide whether or not to back the overlay course if need be.

b) The traffic, not mentioned in this example, is light and constant over the 4 km in question.

c) There are two populations of deflexion : the first from PK 4,000 to PK 6,800, and the second from PK 6,800 to PK 8,000. Can PK 6,800 be considered a valid kilometric point ? To answer this question, we must look at the other parameters.

d) Maintenance : the latest wearing courses were laid some time ago and consequently visual examination is worthwhile. There is curative maintenance every year, in the form of localised repairs between PK 4,000 and PK 6,000, and a general adjustment of the verges between PK 6,000 and PK 8,000.

e) Surface aspect : visual examination shows two zones whose dividing line is PK 6,300. The first zone shows little cracking, while in the second zone between 10% and 50% of the surface is cracked over a length of more than 1 km. On the whole, there are few geometric deformations — a few localised settlements — and no rutting (so there will be no need to allow for an additional reprofiling thickness).

f) Structure : this is a traditional flexible pavement composed of dressings of semi-penetration macadam and run-of-crusher limestone. The thickness of 25 to 30 cm is probably sufficient between PK 4 and PK 6, where the underlying soil is a fairly dry silt, but insufficient in PK 6 and PK 8, where the underlying soil is a more plastic and damp clay. Exploratory drilling at PK 6,050 shows inadequate structural design. PK 6 is a geological and topographical boundary; a winding course on a hillside, on a naturally drained silty underlying soil gives way to a straight course through a plain where wheat is cultivated and where the pavement rests on a damp and plastic marly substratum where drainage is non-existent.

This leads us to adopt the following division into sections :

PK	Déflexion	Structure		Visual condition		Maintenance			Comparison of the 4 parameters	Adopted cutting	Class
		BD	MD	D	BE	DT	F	N			
4.000 – 6.000	Slight								Agree	section I	C3
6.000 – 6.800	Slight								Disagree See*	section II	C5
6.800 – 8.000	Marked								Agree	section II	C5

* Between PK 6,000 and PK 6,800, the body of the pavement is not sufficiently thick in the light of the value obtained at PK 6,050 and in the light of the nature of the underlying soil and the drainage. This zone is cracked, and has already necessitated numerous repairs to the verges. It is therefore not normal to have a deflexion half that of the following zone. This corresponds to case number 5 in the preceding table. The period at which the measurements were made (May 1971) is probably one of the causes, in view of the rainfall in this region at that time. In any event, account has to be taken of the elements derived from the three other parameters (structure, visual condition, maintenance), and the section boundary should be fixed at PK 6,000.

IV. – APPLICATION : TRANSPOSITION OF STUDIES

1) Transposition of studies

The question asked by those responsible for the Public Works Administration of a country faced with this problem for the first time is always the same : what method should be adopted, and can methods applied in other countries be easily transposed ? When the methodology of the study rests on the utilization of a single parameter which is very well known experimentally in a given country, it is always tricky to transpose it to another country unless *all* the conditions on which the experiment was based are identical. Let us take the example of a method consisting of measuring deflexion only, and associating it – in function of traffic – with an overlaid thickness deduced from full scale experiments conducted over many years on the road system of a given country. There is no doubt that this method may be valid in the country where it has been developed. But would it not be dangerous to transpose to humid tropical Africa, for laterite gravel pavements carrying slight traffic but with a high percentage of heavy vehicles, a method resting on the absolute value of deflexion measured in a temperate climate on pavements incorporating thick bituminous layers and carrying heavy traffic with a very broad spectrum ? The method described in the previous paragraph is, in our view, transposable; for it is not based on exclusive use of a single parameter, and it gives no a priori value to any of the points analysed.

The diagnosis is established on the basis of four parameters : past history and maintenance of the pavement, in situ structure, visual condition, and bearing capacity as expressed by deflexion. The first three are directly useable, because they are purely local; the fourth must be transposed, because its significance depends on local circumstances, but is should be noted that it is used more as a relative value than as an absolute value; that is to say, more for expressing the homogeneity of the pavement. It must however be calibrated in the country where the study is carried out, and this is generally fairly easy, the more so if a phase one study of the type advocated in the first section of this communication has already been carried out.

2) Tunisian example

This study covered about 200 km of itinerary in the context of the modernization of the Tunisian road network. It comprised a study of catching up on maintenance over the five itineraries in question, and modifications or modernization including rectification of the plane alignment and the longitudinal profile, widening and width adjustment, drainage work, pavement overlaying, and progressive modifications in the light of traffic growth. This was accompanied by an investigation of suitable materials for carrying out the work.

a) The APS phase

This comprised :

The fine pathological non-destructive testing of the itineraries of the model previously described, including the continuous measurement of deflexion by the National Public Works Laboratory in Tunis, which possesses a Lacroix deflectograph; visual examination on foot, exploratory drillings (one per km on the average) and analysis of past history and maintenance on the basis of information provided by the department responsible, and consultation of graphic records (figure 11).

A study of traffic through surveys of origin and destination, analysis of the existing number of vehicles, and existing data.

Topographic record of the plane alignment and longitudinal profile in order to establish proposals for modifications (figure 12).

Reconnaissance of quarries along the itineraries, complemented by a study of the techniques useable in Tunisia (in function of materials and binders).

An economic study of costs and profitability.

Several variants of modifications to the itinerary and of progressive overlaying were proposed to the Administration, which made a choice.

b) The APD phase

The technical part of the APD phase was very short; it consisted of adapting the APS in the light of the solution adopted, together with a comprehensive study of the few quarries selected. The APD was mainly the preparation of invitations for tenders, and proceeded exactly in accordance with the principle described in the introduction to this communication.

c) Solutions

The solutions covered a very wide range, because some of the itineraries were similar to major French highways (motorway, entrance to Tunis) while others carried very little traffic. Consequently, though the diagnosis was performed in the same way, the conclusions differed according to circumstances : a chip surface, a limestone-gravel 0/20 overlay topped with a surface dressing, or a gravel-slag overlay of considerable thickness, covered with surface dressing.

Furthermore, the use of the deflexion parameter for structural design caused no difficulty, since Tunisia has been measuring and using deflexions for many years, and moreover an overlay catalogue using the same parameter had been prepared in the course of the phase 1 study.

d) Duration of the study

The fine diagnosis, comprising the record of the visual examination, the exploratory drillings, the establishment of the programme of laboratory tests, and the transport of samples, the entering of data on the itinerary chart, and the study of solutions, generally involves one month of work in situ by an engineer and an assistant.

Photo 1 - Exploratory drilling in Tunisia

Depending on the size of the pavement, the exploratory drilling was either in the form of a trench astride the shoulder and the verge of the pavement (approximately 1 m on the pavement and 0.50 m on the shoulder), or a double drilling, that is to say one composed of two holes, one in the verge and the other in the centre line.

The depth of the drillings was about 0.50 m below the pavement, and the density about 1 per km, the spot being chosen on the basis of the deflectogram and visual examination.

The exploratory drilling team, headed by a member of the LPC mission, comprised 8 locally recruited workers divided up into two-man teams; the equipment (shovels, picks, tampers, road signs) was kindly lent by the subdivisions of the Public Works Department. Twelve drillings a day were made (three per team).

Nearly 200 exploratory drillings were made in this way in slightly more than three weeks.

3) Iranian example

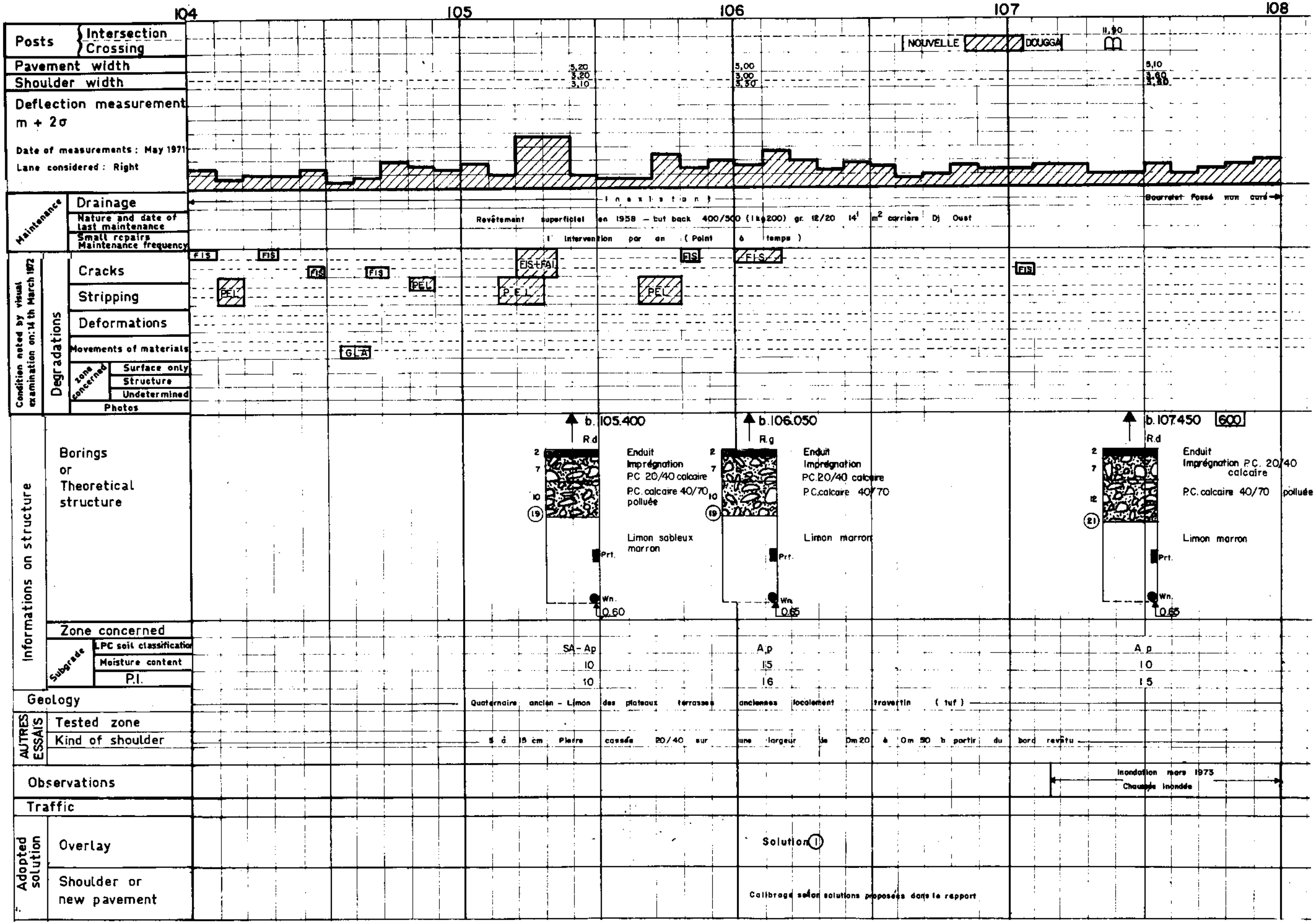
This example lies in a different context from the preceding one. The Ministry of Roads and Communications assigned the L.C.P.C. a mission comprising several objectives, including :

- The design of a cell for the non-destructive testing of pavements.
- The establishment of a plan of research concerning deflexion.
- The training of the Iranian team in charge of the deflectograph.
- The establishment of a pilot study for overlaying.

The pilot study (figure 13) was carried out on the model previously described, using measurements made with the Lacroix deflectograph by the Iranian team. If had two main points of originality :

Examination of causes of deteriorations which were in some cases of a special type not encountered in France. On photos 2 to 4 we note cracking due to heat shrinkage on flexible pavements incorporating 8 cm of bituminous mix. In the final

Fig. 11 - Example of itinerary chart made in Tunisia



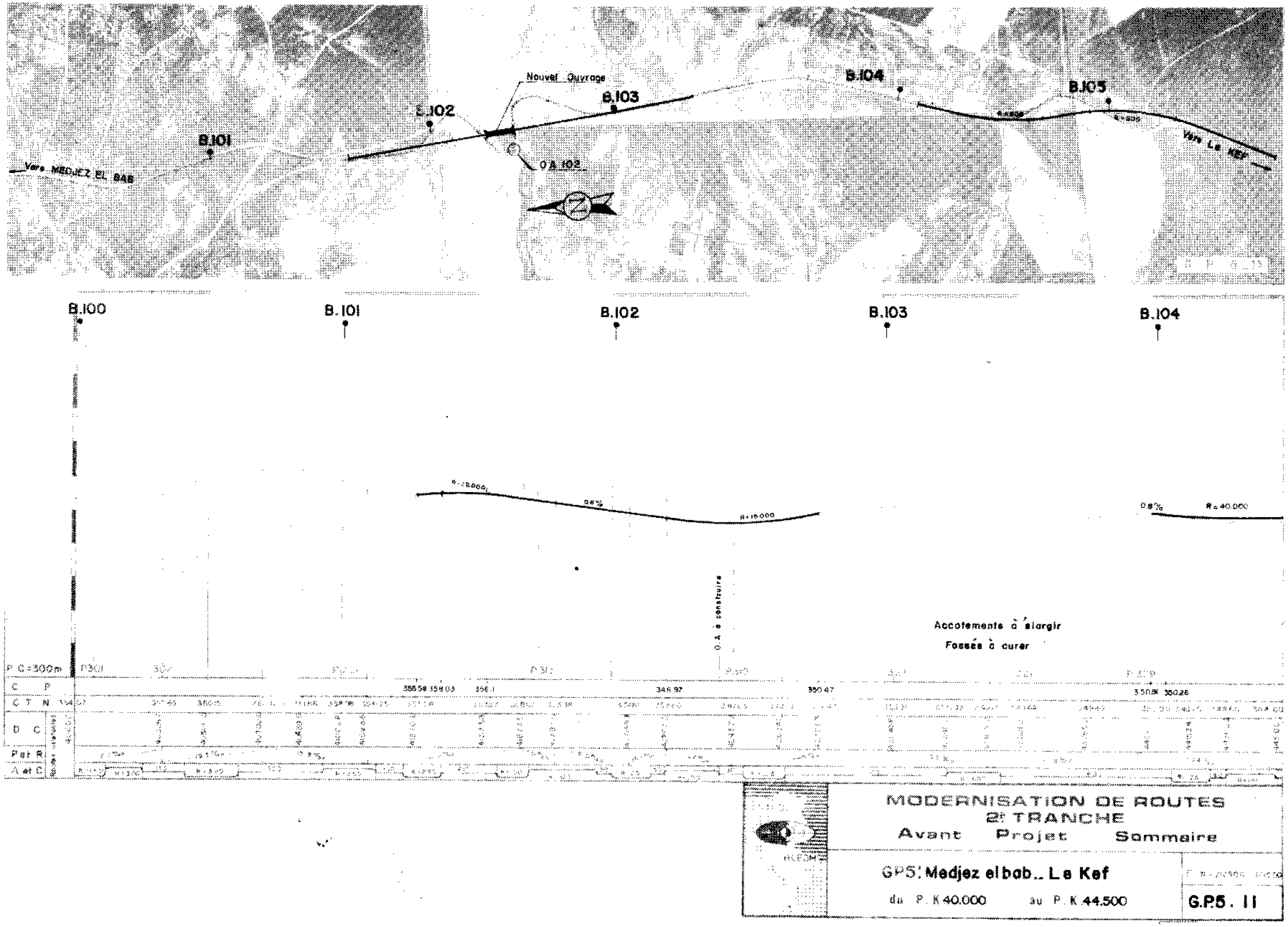
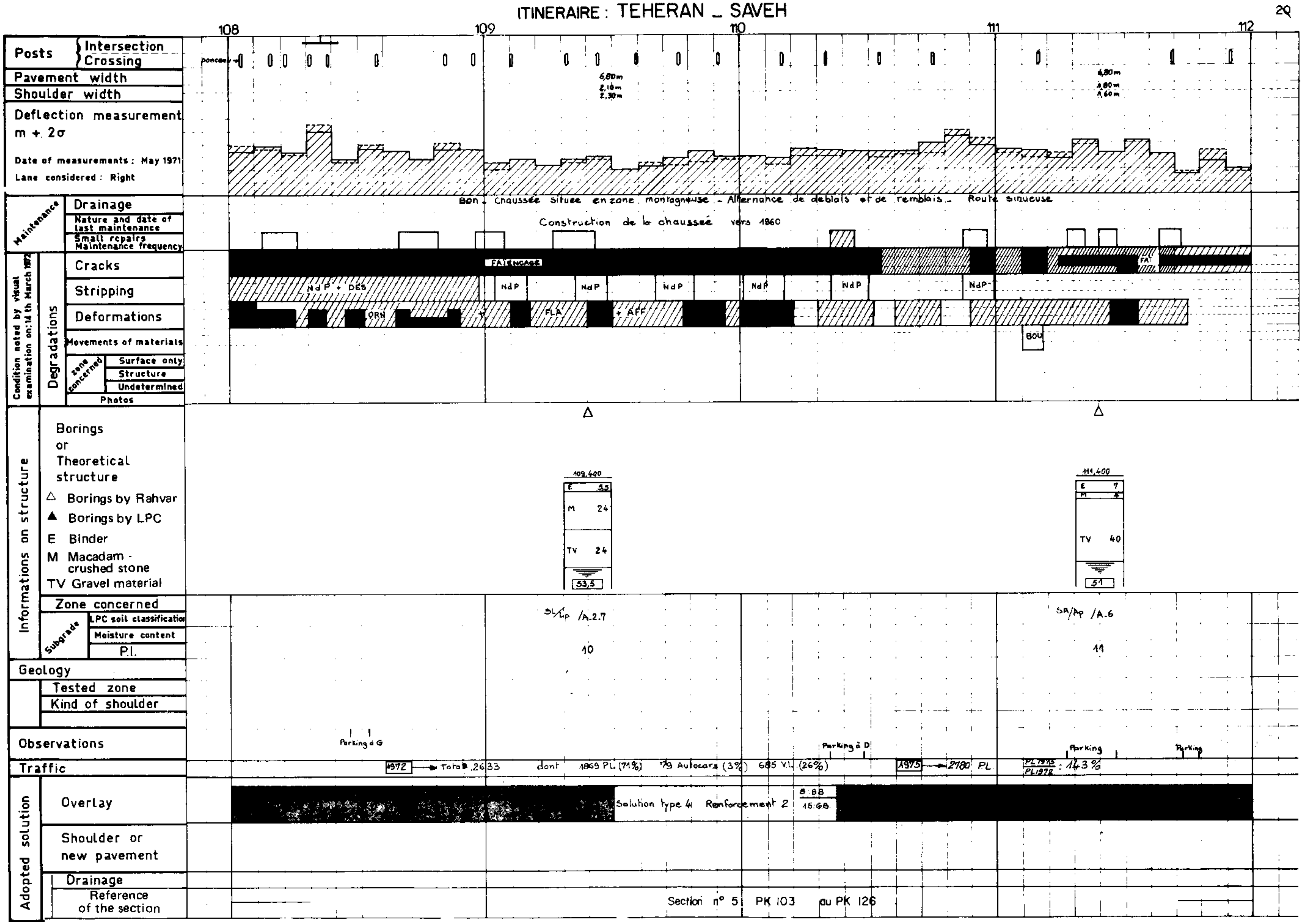


Fig. 12 - Road modernisation - 2nd Stage - Preliminary design study (APS)

Fig. 13 - Example of itinerary chart used in Iran



phase, this cracking led to a loosening of the pavement into blocks, without deformation of the transverse profile. Among the causes of these deteriorations may be cited temperature differences between summer and winter (+ 50°, – 20°), the very dry weather in the summer, snow in winter, practically no rain, the good bearing capacity of the underlying soil, which is moreover very well drained, the very heavy traffic, and the inadequate structural design of the base course.

Calibration of the deflexion parameter, which was used very little in Iran before the advent of the deflectograph in 1974. This calibration is in progress at the National Laboratory of the Highways Ministry in Tehran, but in the course of this study it was possible to arrive at a closer approach to the orders of magnitude, on the one hand by measurements on old pavements and new pavements before the latter were put into circulation, and on the other hand by measurements on an overlaying working site, on the old pavement and on each of the three layers of bituminous mix (reprofiling, base course, wearing course). On this occasion, it was possible to verify that the parameter K used in the formula for reducing the deflexion $e = K \log \frac{d_0}{d_1}$ * was of the same order of magnitude as the values obtained in France (K = 50 for thicknesses of around 8 cm and K = 30 for thicknesses of around 15 cm). The following figures were obtained on the different sections shown in figure 14 :

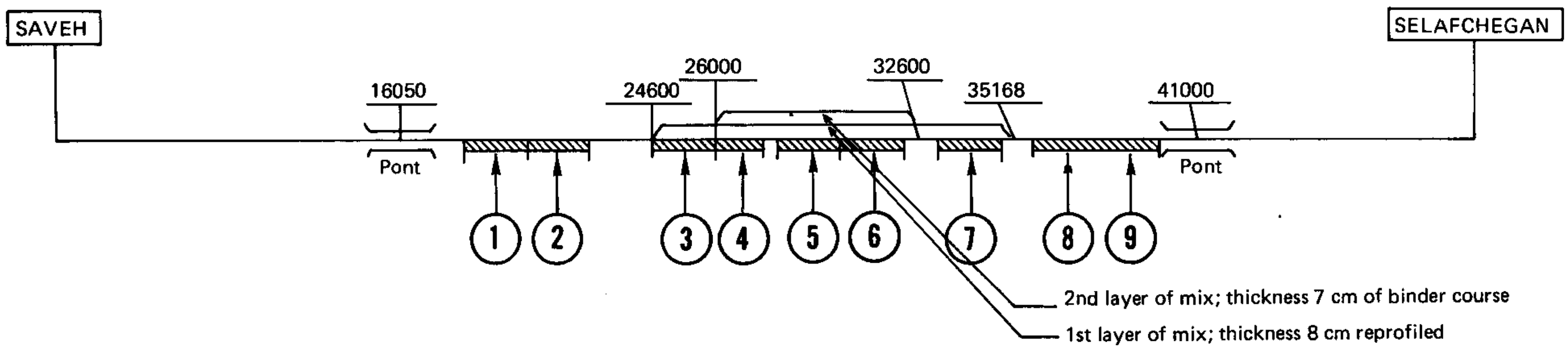
N° of section	Average deflexion m	m + 2 σ	Km	K m + 2 σ	P m	P m + 2 σ
1 2 8	152 120 114	240 170 160	– – –	– – -	– – -	– – :
3 7	84 87	110 120	52	47	6,4	7,1
4 5 6	68 40 43	94 50 67	31,3	33,1	10,6	10

(Km corresponding to the value deduced from average deflexions m, and Km + 2 σ corresponding to the value m +2 σ, $P = \frac{333}{K}$ with K in cm).

The deflexions measured on the new pavement between Rezaiyeh – Khoy – Evoghlu over a length of about 70 km before it was opened to traffic were also of the same order of magnitude as those measured in France. This pavement, incorporating 30 cm of alluvial gravel, 15 cm of 0/20 bituminous gravel, and a wearing course comprising 5 cm of 0/10 granitic mix, revealed a deflexion of between 50/100 and 75/100 mm.

* In this formula : e = thickness of overlay
d_0 = deflexion before overlaying
d_1 = deflexion after overlaying
K = a parameter which has the dimension of length and which depends on the overlaying material.

Figure 14 - SITUATION OF MEASUREMENTS



Statical calculation on sections not overlaid

- Section n° 1 : pk 18 - pk 20
- Section n° 2 : pk 20 - pk 22

Section n° 8 : pk 36 - pk 38
Section n° 9 : pk 38 - pk 40

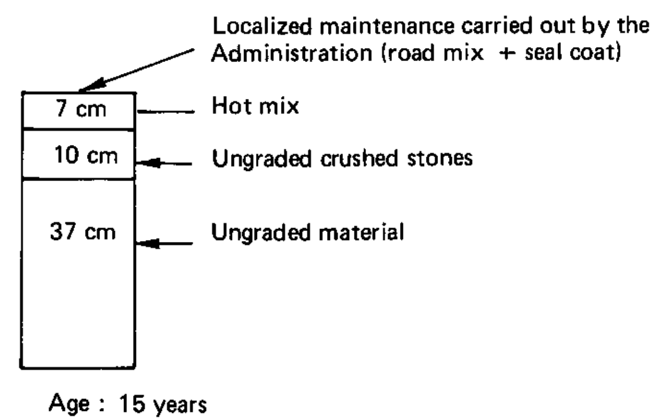
Statistical calculation on sections overlaid with a layer of mix

- Section n° 3 : pk 24,600 - pk 26,000
- Section n° 7 : pk 33 - pk 35

Statistical calculation on sections overlaid with two layers of mix

- Section n° 4 : pk 26 - pk 27,500
- Section n° 5 : pk 28 - pk 30
- Section n° 6 : pk 30 - pk 32

Section of old pavement
(between pk 0 and pk 66)



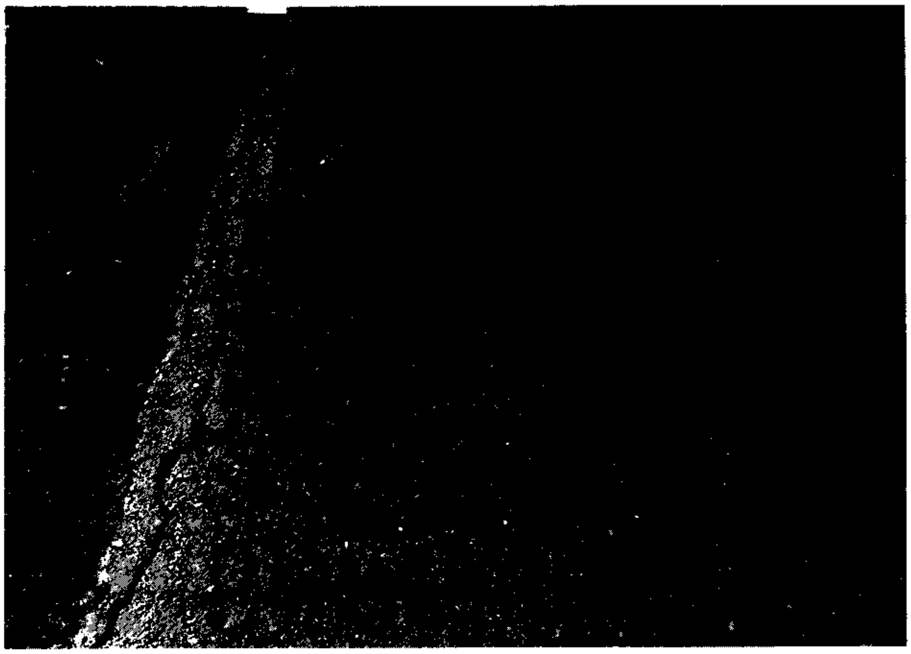


Photo n° 2 - Longitudinal and transverse cracking at the edge

Photo n° 3 - Very wide transverse crack

No course of this pavement incorporates cement.

Photo n° 4 - Generalized fine crackling

Note that the transverse profile is not deformed.

NOTES ON METHODS OF CALCULATION

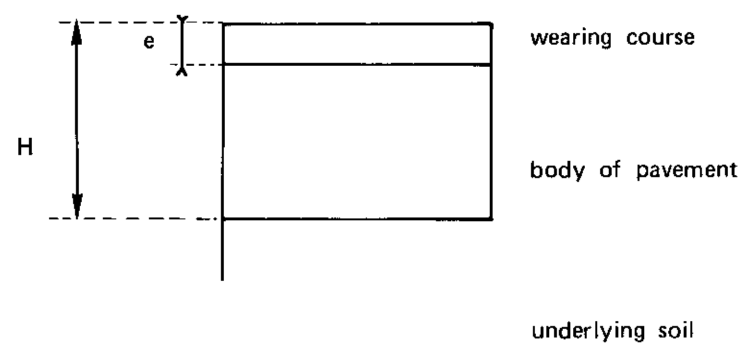
Unlike certain methods of non-destructive testing, a method for the structural design of overlays is not generally transposable from one country to another (the same applies to a catalogue of new pavements). This is so even if only because the materials, the traffic, and the objectives aimed at are different. However, all is not negative and the principle of the method can obviously be followed. To illustrate this, we shall first take a look at the principle of the LPC method, and give an example of adaptation.

I. – PRINCIPLE OF THE LPC METHOD OF CALCULATION

The principle of the calculation consists of determining a certain number of theoretical models corresponding to the circumstances encountered during the analysis of the old pavement, and then for each of these models, calculating the thickness of overlay corresponding to the technique employed and to the traffic. All these calculations are made using the ALIZE III programme of the LCPC.

1) Characterization of the old pavement

The old pavement is represented by the three-layer model composed of a single pavement body topped by a wearing course and resting on an underlying soil. e is the thickness of the wearing course, H is the total thickness of the pavement materials.



For purposes of calculation, we examine the six combinations resulting from the following cases :

e
- el – surface dressing or bituminous mix < 5 cm
- e2 – bituminous mix < 10 cm
- e3 – bituminous mix < 15 cm

H
- H1 – 30 cm
- H2 – 50 cm

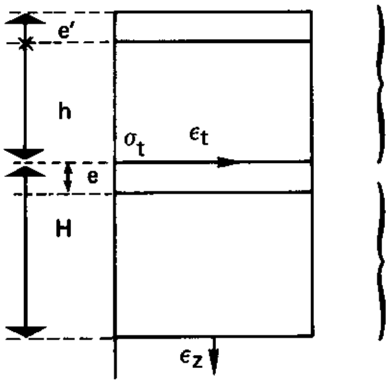
Associating with each of these combinations six values of deflexion corresponding to the six categories adopted (d = 50 – 75 – 100 – 150 – 200 and 300 hundredths of a millimetre), we reconstituted 36 theoretical models for which we calculated the moduli of each layer and of the underlying soil, adopting the following hypotheses of simplification :

– Modulus of the bituminous concrete of the wearing course : 20,000 bars at 20°.

– Ratio between modulus of old pavement and modulus of soil : 4.

2) Overlaid structures

An overlaid structure is represented by a model of the following type :



Overlay

- wearing course in bituminous concrete.
- base course in gravel-bitumen or gravel-slag

Old pavement

- wearing course in bituminous concrete
- single pavement body*
- underlying soil

* corresponding to previous models

For each case corresponding to the old pavement described in paragraph I and for ten cases of traffic, we calculated the corresponding overlay thickness, adopting the following hypotheses :

- Slipping or no slipping at the interface between the base course and the old surface.
- Modulus of gravel-slag : 150,000 bars.
- Modulus of gravel-bitumen : 80,000 bars at 20°.
- Modulus of bituminous concrete : 60,000 bars at 20°.

The thickness of the overlay must satisfy the following conditions :

- The tensile stress σ_t at the base of the gravel-slag overlay layer must be less than an admissible limit fixed on the basis of experimental observations on test sections.
- The bending stretch ϵ_t at the base of the gravel-bitumen course must remain below a limiting value fixed on the basis of the fatigue tests carried out in the laboratory.
- The vertical deformation ϵ_z of the underlying soil at the interface with the old pavement must be compatible with a limit derived from habitual deviations.

3) Traffic : number of loads

The calculation of the thickness of a layer of hydraulic gravel or hydrocarbon gravel material is based on the way the material behaves under fatigue, and takes no account of other properties, such as resistance to rutting (allowed for by the choice of formulation) or behaviour under heat, leading to shrinkage cracking. The loads borne by the overlay course are expressed in terms of the number of 13-ton axles, that is to say the traffic, whose spectrum is known as a result of weighings recorded by dynamic balances, is reduced to an equivalent traffic in terms of the number of 13-ton axles. This equivalence allows for the nature of the material, and differs according to whether it is a gravel slag or a gravel bitumen (1).

The laws of fatigue of the materials in question may be written as follows :

$$\log \frac{\epsilon}{\epsilon o} = a - b \log N \text{ for a bituminous material.}$$

$$\frac{\sigma}{\sigma_o} = a' - b' \log N \text{ for a gravel slag.}$$

This law may be written in a form close to the previous one, that is to say $\log \frac{\sigma}{\sigma_o} = a - b \log N$ in the interval considered, namely between 10^5 cycles and 10^7 cycles.

Knowing, depending on the case, the extension ϵ_o or the admissible stress σ_o and the extension ϵ or the stress σ given by the calculation model, we may deduce the number N of 13-ton axle loads for which the structure is designed.

But we must also bear the following points in mind :

- The law of fatigue of these materials is obtained experimentally for loadings of 10^6 cycles, on the basis of which we determine the corresponding extension or stress; hence there is a dispersion of results, characterized by the standard deviation of the law of fatigue.
- The thicknesses in situ themselves have a certain dispersion, characterized by the standard deviation of variation of the nominal thickness in situ.

The determination of the number N of cycles for which the structure is designed takes account ot these two standard deviations and also corresponds to a certain statistical level of risk of deteriorations, such as cracking due to fatigue, as we shall see later.

(1) For equivalence factors, see III.1.

As can be seen from the following table, which relates to French traffic categories Ti and to overlaying with bituminous materials, we may present the result in two ways. We may choose an equal period of reference P for each category of traffic and indicate the corresponding value of the risk R_1 or we may choose an equal risk R_2 and indicate the value of P_2.

T_i	Number of cycles during period of reference	P1	R1	P2	R2
T0	9.80 10^6	1	10%	1	10%
T1	3.60 10^6	1	10%	1	10%
T2	1.60 10^6	1	20%	0,8	10%
T3	0,65 10^6	1	30%	0,66	10%
T4	0,17 10^6	1	30%	0,66	10%

French traffic categories are as follows : categories T_i of traffic are determined on the basis of the average daily traffic PL on the busiest lane of the pavement during the year in which it is put into service. Heavy vehicles (PL) are defined in the catalogue as vehicles with a useful load of 5 tons or more.

T_4 ↓ T_3 ↓ T_2 ↓ T_1 ↓ T_0

50 150 300 750 .... PL traffic (daily average throughout the year) on the busiest lane.

The annual growth rate of PL traffic is 7%.

4) Presentation of results

The results are presented in tabular form. Opposite the category of pavement determined during the pathological analysis (see Table 10) and the category of traffic provided for, we find the thickness of overlay advocated. There are as many tables as there are possible techniques. Obviously, the thicknesses advocated take account of the technical possibilities of achieving them.

As an indication, figures 16 and 17 show a general table of correspondence and the table of thicknesses advocated for gravel-bitumen overlays.

II. — PARAMETERS TO BE MODIFIED

A method such as the one we have just briefly described takes into account numerical values for certain parameters which may vary notably from one country to another.

1) The old pavement — This is without doubt the easiest model to constitute. It is based on measurements made during the pathological non-destructive testing phase, and hence on local measurements. In the L.P.C. method, we have set the ratio of moduli at 4, but this value may easily be changed (In fact, it is generally between 3 and 7).

2) The overlay structure — To calculate the model of the overlay structure, we must know the materials to be used, which will be determined by their modulus, their limit of strutch, or their limit of stress at the base of the course, and by their behaviour under fatigue. In France, ϵ_0 for gravel-bitumen has been studied in the laboratory, σ_0 for gravel slag has been verified on test sections, the fatigue curves of these two materials have been plotted in the laboratory, etc.

So we must know the behaviour of materials to be used, and it is certainly not by continuing to perform CBR tests on laterite gravels treated with cement that advances will be made in rational methods of pavement calculation.

Along these lines, work done by an African engineer at the L.C.P.C. in 1975 and 1976 on laterite gravels treated with cement and lime has already given excellent indications.

Figure 15 shows the variation of the modulus and of the resistance under compression after seven days, in function of the cement content and the lime content.

In some cases, laterite gravels may have laboratory-measured compressive strengths as good as those of cement gravels.

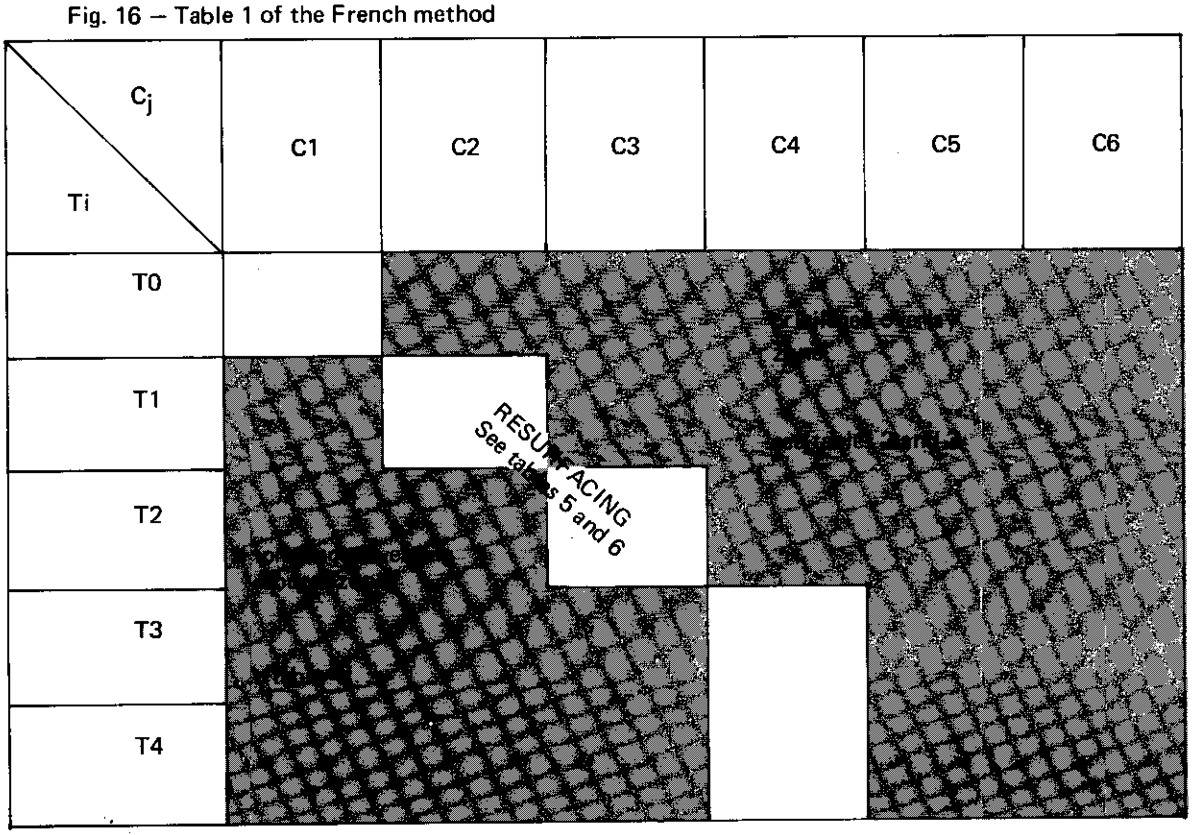
But such work is generally confined to a given type of gravel, and it seems to us essential that research should be undertaken in order to obtain a better knowledge of the principal materials, such as laterite gravels or breccia, whether treated or not, for equatorial Africa, tuffs for North Africa, etc., if we wish to make advances in methods of structural design and depart from an empiricism which, though excellent when it was a question of making tracks, may prevent the problem being seen in proper perspective when it is a question of building roads in the Africa of tomorrow.

Fig. 15 – Some values of the modulus and the resistance under compression obtained in the laboratory on samples diameter 10 H 20 after 7 days of conservation («Contribution to the study of laterite gravels in Niger» by Amadou Cissé, TFE Ecole des T.P.E., June 1976).

	Lat. G. 2% cement	Lat. G. 4% cement	Lat. G. 5% cement	Lat. G. 1% CaO 2% cement added later*	Lat. G. 2% CaO 2% cement added later*	Lat. G. 2% CaO	Lat. G. 3% CaO	Gravel cement (3.5%) **
Modulus E measured during crushing under compression (in bars)	37.000	39.000	35.000	17.000	25.000	7.800	7.700	150.000
R_c : Resistance under compression (bars)	19	41	45	22	32	10	11	43

* The cement is added 24 hours after the mixing of the laterite gravel and lime.
** This is a given 0/20 gravel treated with 3.5% of CPAL-325 cement.

Fig. 16 – Table 1 of the French method



The sole purpose of this table, which divides the space (Ti C_j) into 3 zones, is to refer to the tables of solutions (Tables 2 to 6 of the French method).

Figure 17 – Table 3 (gravel-bitumen) of the French method

Cj / Ti	C1	C2			C3			C4			C5			C6
		e1	e2	e3	e1	e2	e3	e1	e2	e3	e1	e2	e3	
T0		15 8	12 8	12 8	18 8	15 8	12 8	18 10	18 8	15 8	18 10	18 8	15 8	
T1					15 8	12 + 8 or 14(2x7) BB		18 8	15 8	12 8	18 8	15 8	12 8	18 8
T2	See table 1							15 6	12 + 6 or 14(2x7) BB		18 6	15 6	12 6	18 8
T3											15 e	12 e	12 e	12 6
T4											10 BB			12 6

– *Significance of the figures :*

15 / 8 } The first figure gives the thickness of the gravel-bitumen, and the second that of the wearing course in BB, e signifying surface dressing.

– *Note :*

e1 – e2 – e3 = thickness of old wearing course with el < 5 cm, e2 < 10 cm, e3 < 15 cm.

For categories of traffic T3 and T4, we may be led to replace the gravel-bitumen and bitumous concrete by dense bituminous mixes whose formulation will be studied by the regional laboratory.

3) Traffic – Little is generally known about traffic in such projects, because it is dealt with in economic surveys for its incidence on the geometry and nature of the pavement. Rarely do we know the real distribution of axle weights (the spectrum). But this is a parameter which is very easy to measure and it can be very easily incorporated in the L.P.C. method of calculation. We have seen in a preceding paragraph that it is through that the management policy adopted is introduced into the calculation, since we determine a thickness of overlay corresponding to a given number of passages of axles (length of life) associated with a dispersion of thicknesses in situ, a dispersion of the law of fatigue of the materials selected and an admissible percentage of deteriorations for the number of axles serving as the basis of the calculation.

III.– EXAMPLE OF APPLICATION

There exist methods of calculation of traffic by totalizing the number of heavy vehicles above a given load, for example 3.5 tons useful load. This is perfectly valid if the traffic spectrum is always the same, and is well known. In the following example we shall consider two types of traffic, comparing them on the basis of this first criterion, and on the basis of a second criterion based on the real distribution of heavy vehicles.

1) Determination of a traffic index

Let

n_i = the number of vehicles of weight P_i.

P = the axle of reference of the structural design.

N = the traffic index.

α = the power of the law of fatigue $\frac{n}{n'} = \left(\frac{P'}{P}\right)^{\alpha}$

If we accept Miner's law, we obtain the relation $NP^{\alpha} = \Sigma n_i P_i^{\alpha}$ from which we can deduce N, n_i P_i and P being known. In actual fact, the stress at the base of the pavement is not proportional to the axle weight; it varies with the contact area, which itself depends on the axle weight, on the type of tyre, and on the tyre inflation pressure; it also varies with the thicknesses and moduli of the courses constituting the pavement. This leads us to correct the preceding relation and to write :

$$N = \Sigma n_i \left(\frac{P_i}{P}\right)^{\alpha'} \quad \text{or} \quad \alpha' < \alpha \qquad (1)$$

We generally accept a value of 8 for for pavements incorporating hydraulic binders, and 4 for flexible pavements. P_i is the axle weight assigned to the category of traffic fixed by the limits P_{i-1} and P_i. If the category is small enough for us to be able to assume a uniform distribution of axles within it, we obtain P_i by relation :

$$P_i = p_i \left[\frac{1 - \lambda^{\alpha'+1}}{(1+\alpha')(1-\lambda)}\right]^{\frac{1}{\alpha'}} \quad \text{in which} \quad \lambda = \frac{P_{i-1}}{p_i}$$

Figure 18 gives the values of $Z = \frac{P_i}{p_i}$ for values of λ between 0.4 and 1 and for $\alpha' = 4$, 6 and 8.

2) Application to traffic in Senegal and Madagascar

Let us take two traffic spectra (figure 19) relating to Senegal and Madagascar (These two histograms are taken from the conference by Mr. M.J. Serfass, C.E.B.T.P. : Evolution of techniques of construction of surfaced pavements in tropical and desert zones; Munich, October 1973).

These calculations were made (see Appendix) for the following values, derived from figure 19.

	Madagascar			Sénégal		
Traffic category	n_i	p_i - 1	p_i	n_i	p_i - 1	p_i
1	10 %	2 T	3,5 T	19 %	2 T	3,5 T
2	15 %	3,5 T	5 T	39 %	3,5 T	5 T
3	16 %	5 T	6,5 T	34 %	5 T	6,5 T
4	27 %	6,5 T	8,5 T	5 %	6,5 T	10 T
5	25 %	8,5 T	11,5 T	2 %	10 T	13 T
6	7 %	11,5 T	13 T	1 %	13 T	15 T

For the reference axle **P** = 10 T, which is the legal limit in Madagascar and Senegal, and in the case of $\alpha' = 8$ and $\alpha' = 4$.

– for Madagascar $N_1 = 0{,}70$ $N_2 = 0{,}53$

– for Senegal $N_1 = 0{,}24$ $N_2 = 0{,}15$

that is to say that we obtain the traffic index by multiplying the real traffic by 0.7 or 0.24 in the case of pavements incorporating cement, and by 0.53 and 0.15 in the case of other pavements.

So if we consider two pavements carrying appreciably the same number of vehicles of weight greater than 2 tons :

– if we count only vehicles greater than 3.5 tons, we consider that the traffic in Senegal is very close to that in Madagascar (80% over 3.5 tons, as compared with 90%);

– if the preceding calculation involves the fatigue of materials, the conclusion is very different, since for the same total traffic the Madagascar figure is three times as great.

We see from this example that it is not possible to adopt the conclusions of the French method ex abrupto, but that we can apply similar principles, for example to determine the number of axles of reference for which we design the pavement.

(1) $\left(\frac{P_i}{P}\right)^{\alpha'}$ is the equivalence factor of the axle of weight P_i in relation to the axle of weight P.

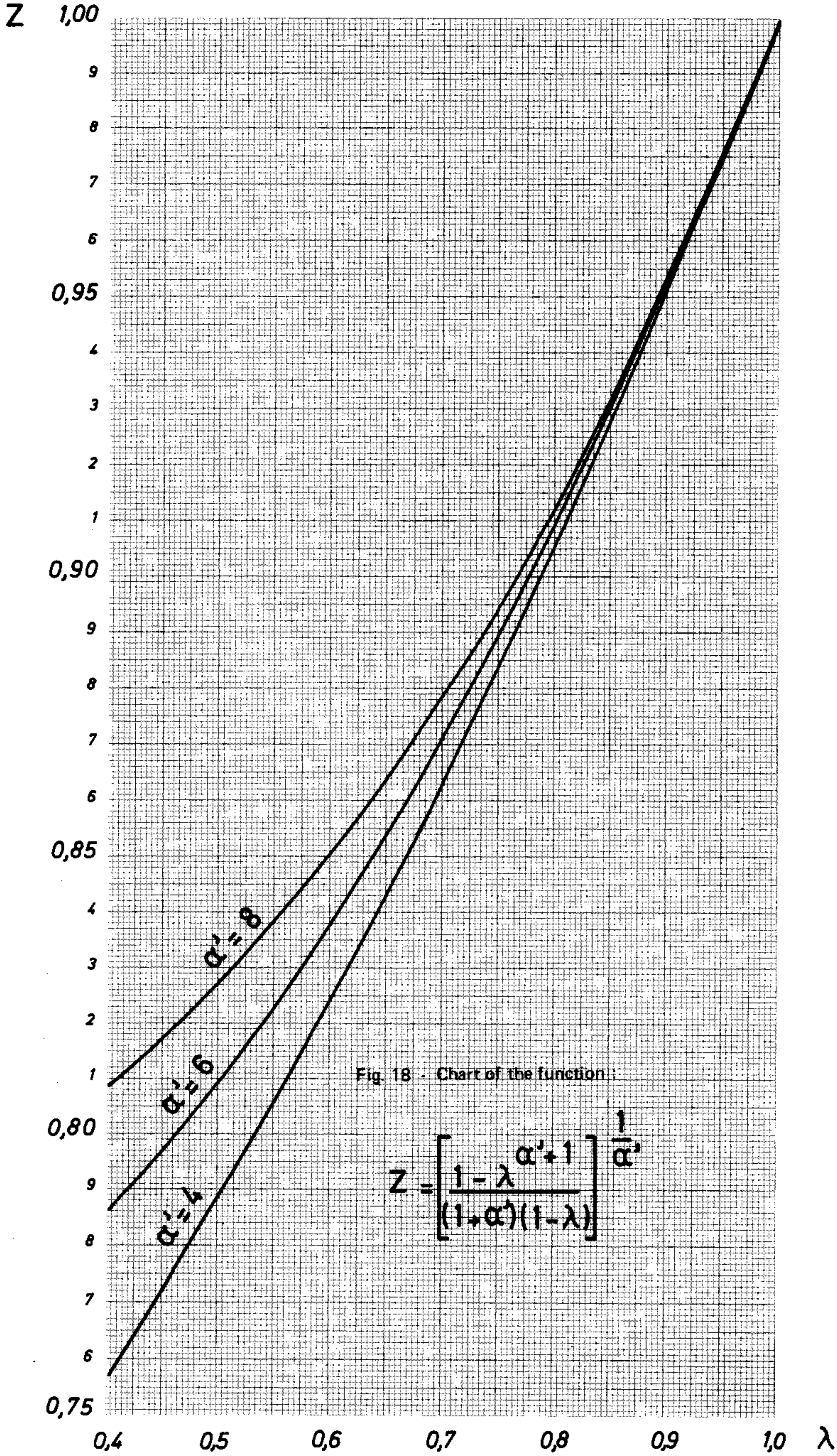
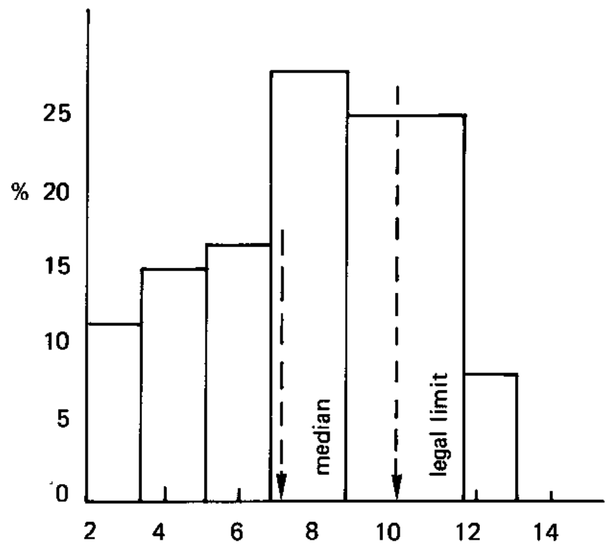


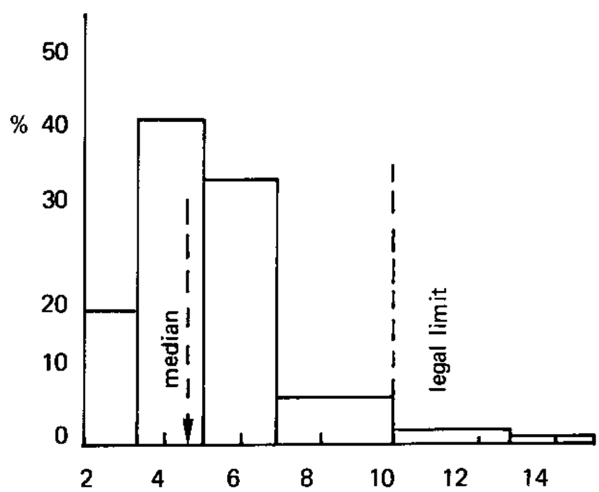
Fig. 18 - Chart of the function :

$$Z = \left[\frac{1 - \lambda^{\alpha' + 1}}{(1 + \alpha')(1 - \lambda)} \right]^{\frac{1}{\alpha'}}$$

Fig. 19 - Traffic histograms, 1970



Rear axle load (tonnes)
MADAGASCAR



Rear axle load (tonnes)
SENEGAL

CONCLUSION

It is relatively easy for a developing country to find a method of non-destructive testing for its road system, whether at the level of feasibility studies or APS or APD, which can be transposed without difficulty and which is likely to prove satisfactory. Similarly, there exist a great many instruments for non-destructive testing which have given evidence of their efficacity.

There is no doubt that it is much more difficult, if not impossible, to transpose a method of calculation, or at least of the results which it provides. In this field, it appears necessary that research should be undertaken to define the mechanical behaviour of the major formations of material encountered. Similarly, it is necessary to perform systematic weighing of axles at the same time as traffic is metered, in order to have a better knowledge of the effect of traffic on structural design. This will become all the more essential in that major highways like the Trans-Saharan and the Senegal-Kenya itinerary will soon come into being, passing through countries whose pavements are different because they have been structurally designed for different maximum legal axle weights and load distributions.

ANNEXE

Tableau de calculs correspondants à III.2

					$\alpha' = 4$				$\alpha' = 8$			
C_i	n_i	$\frac{P_{i-1}}{T}$	$\frac{P_i}{T}$	$\lambda = \frac{P_{i-1}}{p_i}$	Z	$P_i = p_i Z$	$P_i^{\alpha'}$	$n_i P_i^{\alpha'}$	Z	$P_i = p_i Z$	$\frac{P_i^{\alpha'}}{10^3}$	$\frac{n_i P_i}{10^3}$
MADAGASCAR												
1	0,10	2	3,5	0,57	0,813	2,845	65,597	6,560	0,844	2,953	5,782	0,578
2	0,15	3,5	5	0,70	0,863	4,315	346,637	51,996	0,879	4,394	138,838	20,826
3	0,16	5	6,5	0,769	0,892	5,798	1129,882	180,781	0,901	5,859	1388,541	222,167
4	0,27	6,5	8,5	0,765	0,890	7,567	3278,628	885,229	0,900	7,650	11727,62	3166,46
5	0,25	8,5	11,5	0,739	0,879	10,110	10448,397	2612,099	0,891	10,248	121666,09	30416,52
6	0,07	11,5	13	0,885	0,944	12,275	22704,970	1589,348	0,947	12,305	525665,81	36796,61
							$\Sigma n_i P_i^{\alpha'} =$	5326,013			$\Sigma n_i P_i^{\alpha'} =$	70623,161
SÉNÉGAL												
1	0,19	2	3,5	0,57	0,813	2,845	65,597	12,463	0,844	2,953	5,782	1,099
2	0,39	3,5	5	0,70	0,863	4,315	346,637	135,189	0,879	4,394	138,838	54,147
3	0,34	5	6,5	0,769	0,892	5,798	1129,882	384,160	0,901	5,859	1388,541	472,104
4	0,05	6,5	10	0,65	0,843	8,430	5051,263	252,563	0,864	8,641	31088,511	1554,426
5	0,02	10	13	0,769	0,892	11,595	18078,116	361,562	0,901	11,718	355466,614	7109,332
6	0,01	13	15	0,867	0,936	14,038	38833,827	388,338	0,939	14,084	1548431,95	15484,319
							$\Sigma n_i P_i^{\alpha'} =$	1534,275			$\Sigma n_i P_i^{\alpha'} =$	24675,427

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