« MULTIFUNCTION » CONCRETE ROADWAYS POTENTIALS IN URBAN AREAS

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I. INTRODUCTION

Noise and pollution control, improved safety, a higher quality of life with the best quality/cost ratio are among the major demands of the many populations living around large conurbation's in industrialized countries. To be able to meet such demands more effectively, highway engineers have had to broaden their capabilities and modify their working methods in recent years. The professional body of engineers, researchers, designers, application firms and infrastructure managers in France has adopted a new approach, becoming increasingly and jointly involved in studies, trials and in the monitoring of innovative prototype projects based on the new requirements of contracting authorities, with significant progress being achieved in meeting these requirements.

An example of such a unified approach was described in a paper entitled «Roads and Environment: a Marriage of Convenience» [1] presented at the 5th International Conference in Purdue in 1993 and reporting on the importance attached to environmental problems in France. Among other things, the paper described France's multidisciplinary national research projects characterized by coordinated involvement of relevant government agencies, regions, towns and various regional community groups, with the significant participation of trade associations as well as public and private highway operation and maintenance networks [2]. Initial progress was fast and encouraging, with good feedback and impressive achievements in certain areas. In other, more difficult areas, representing equally important issues and potentials, progress took place more gradually and resulted in innovative techniques that are still being used and monitored jointly by government agencies and private contractors. The French Highway Innovation Charter, for example, instituted to offer incentives and to channel efforts in this area, is an outgrowth of this new philosophy, as is the multifunction pavement that will be dealt with more particularly in this paper.

The present paper describes the extension given in the past four years to such initiatives in France, some of which departed significantly from customary highway engineering concepts. This overview, without claiming to be exhaustive, seeks to provide a broad enough view of what is taking place in France against the current background of changing requirements, new ideas and new technological responses within that country's context.

II. RELEVANCE, REFINEMENT AND EXTENSION OF THE « MULTIFUNCTION » PAVEMENT CONCEPT

The initial idea behind the concept of a multifunction pavement is that the objectives assigned to so special an civil engineering structure as a road pavement can no longer be confined strictly to such conventional basic characteristics as durability, safety, comfort, availability and economy. To meet the needs and desires of today's road users in urban areas, pavements are expected to offer such additional services as:

- improved aesthetics, with clearly perceived comfort, cleanliness, matching surroundings, and safety
- less noise, pollution, congestion, and other disturbances.

Porous urban pavements (PUPs) constitute one response to these developments. Their three principal functions, namely reservoir function, noise attenuation function and anti-hydroplaning function implemented according to the

respective nature and thickness of surface and base materials used, contribute effectively under certain conditions to the fulfillment of these new needs.

A classification of such multifunction road structures has been established (Figures 1-2 and Table 1), and the privileged fields of application of each show that, although not a cure-all, it is possible to handle a large number of functions and that, in any case, expertise is being acquired in the abatement of disturbances such as noise and those due to precipitation water (flooding, skidding, splashing, glare, pollution transmission, soiling, etc.) which correspond precisely to the disturbances most often cited by road users and local residents.

The relevance of this multifunctionality consisting in requiring roads to play an active role with regard to noise, water cycles and driving safety, in addition to the basic functions of any pavement, has been confirmed by a number of very important regulatory decisions that have marked French procedures and rules of the art in connection with the design of residential projects and public spaces, as well as the transportation infrastructures serving them.

As concerns noise:

The French «Noise Law» No. 92.1444 of 31 December 1992 relative to the control of noise, including that generated by land transportation infrastructures, was accompanied by a number of decrees, application orders and circulars allowing the effective implementation of the principles set forth. Accordingly, since 1995 the following developments may be noted:

1. The obligation to inventory and classify land transportation infrastructures in which the existing or expected annual average daily traffic is higher than or equal to 5,000 vehicles per day, or 100 buses per day for right-of-way public transportation lines (decree No. 95.21 of 9 January 1995).
2. The definition of sectors affected by noise, located in the vicinity of the inventoried infrastructures within a strip having a maximum width of 300 meters on each side, and the noise levels that building and road contractors are required to take into account (order of 30 May 1996).
3. Calculation methods to be used for the noise classification of land transportation infrastructures (road facilities, railways, streetcar lines and right-of-way bus lines) (circular letter of 25 July 1996).
4. Rules to be applied in respect of noise limitation in land transportation schemes and infrastructures (decree No. 95.22 of 9 January 1995).

Tables 2 -3 and figure 3 cover some aspects of these technical and regulatory provisions, the effects of which are particularly important for highway builders and managers as well as for building promoters.

Just a few years ago, official procedures governing the evaluation and reduction of disturbances due to noise from road infrastructures did not take into consideration the nature and quality of surfacing materials. Today, however, it is possible to design, build, maintain and characterize « less noisy » surfacing and even « low-noise » surfacing, some of which can represent noise levels from 7 à 8 dB (A) lower than materials used not too long ago when there was less concern for vehicle-generated rolling noise (bituminous concrete, surface dressings and coarse-graded cement concrete) (Figure 4).

The text of the French circular letter of 25 July 1996 stipulates

> « *There are more or less noisy pavement surfacings, the influence of which may be taken into account for the evaluation of noise emission. The noisiest surfacings can thus be penalized: in the very special case of cobblestone pavements, a correction of + 5 dB (A) will be applied, and in the case of surface dressings with a high macrotexture or grooved surfacing, the correction will be + 2 to + 3 dB (A). On the other hand, pavements designed particularly to minimize emission noise may, as soon as reliable results are available, be considered if the declared performance is durable and observed by measurements representative of the long-term service conditions, and if the maintenance techniques also allow the performance to be maintained. Additional information on the possibility of allowing for the influence of the properties of these surfacings can be made available later* ».

Having thus considered how pavements of various noise levels can be taken into account, the conditions for accomplishing this on dependable scientific and technical bases must be clarified, and this is what is made possible by the studies and trials on multifunction pavements. Let us state again that legitimate preoccupations with regard to performance durability, explicitly dealt with in this text, should not due a disservice to low-noise concrete pavements, owing to the structural strength of the mixes and their non-rheological deformation by post-compacting under heavy traffic and high temperature.

As concerns water:

Reference will be made to French law No. 92.3 of 3 January 1992 on water, and to the application decrees 93.742 and 93.743 of 29 March 1993 relative to the procedures and to the nomenclature of authorizations and declarations provided for by the law. The law is based on the principle of the need for balanced management of water in all its aspects and its entire cycle, in order to better satisfy and reconcile its different uses: flood protection, drinking water, agriculture, industry, transportation, tourism, etc. The application of the mandatory provisions calls for the production of certain planning tools which will be available towards 1997.

Concretely, it is now mandatory in any project of significant size, including roads, to deal initially with the question of repercussions on rainwater, quantitatively for hydraulic systems and qualitatively for conveyed pollution. Procedures for obtaining authorizations and for prior declarations have been instituted, involving the preparation of documents on environmental impacts in respect of water disposal and the technical provisions adopted to make them technically and economically acceptable with time.

Tables 4 to 6 cover some examples of new legislation applicable to all projects, except for very small ones, as well as the issues in terms of conveyed pollution.

As in the case of noise and the design of low-noise pavements, the law and its decrees set a framework, officialize the obligation to consider all aspects and to use the know-how of professionals to find appropriate technological solutions, and this includes structures of quite modest size, as is clearly shown in the list of Table 4. Reservoir pavements form part of this chain of possible solutions, just like the more conventional solutions of retaining basins, prefabricated treatment systems or treatment stations, or more innovative solutions such as lamellar settlement tanks accelerated when rainwater from the road pours into a unit network.

As concerns road safety:

Legislative and regulatory means have been used widely in the past to ensure very significant progress in this area, and it would appear that in order to progress further today, other approaches are called for, such as the design scheme [3]. The principle is to spontaneously elicit, in the motorist, a behavior, and even driving reflexes calmed by the perception of the spaces around the vehicle. Roads not devoted exclusively to traffic should not resemble motorways or heavy-traffic roads. The choice of surfacing different from conventional road pavements, the introduction of masonry bonding patterns in the different areas encountered and their harmonious combination with buildings, plantings and urban furniture, are some of the methods, among other design techniques, for achieving better cohabitation between passenger cars, trucks, public transportation, cycles, pedestrians, local residents, each with their great diversity of situations and expectations with regard to the road.

The contribution of cement concrete in this logic is increasingly important given the great diversity of products, surface conditions and colors. To mark this difference between the road and the street, use is readily made of modular elements in concrete (paving stones and tiles) in a continuous surface or a composite surface, as well as deactivated poured concrete or textured concrete allowing the enhancement of public spaces which are by their very essence of a multifunction nature, with a very good quality/cost ratio.

Quality surfacings, among the most economical, consequently resist. It is however important to ensure proper application in terms of both design (consistency with traffic level) and execution. Recently renewed technical literature, testifying to new cooperation between officials, design offices, suppliers and application firms allows appropriate use of this very rich range of solutions that also favors multifunctionality through a different hierarchy of values assigned to the features required for these surfaces (Figure 5).

Finally, in conjunction with safety operations, we can mention the very significant extension of the « roundabout » (traffic circle) of every size. The most recent assessments within our context appear to show good compatibility with the traffic and safety objectives in general. However, on the other hand, the mechanical performance of pavement structures and surfacing is far less satisfactory (Figure 6).

Construction conditions, with partial use of old structures, the phasing of worksites under traffic, horizontal stresses and shearing stresses of a very specific nature generated by heavy vehicles in rotation explain the pathologies and very short average service lives of these pavements. Prototypes in cement concrete should make it possible, while overcoming difficult execution conditions, to partially solve this delicate problem which, in addition to the structural heritage, involves the properties and conditions of the surface and hence road safety.

In addition to the regulatory aspects or the guidelines of development and rehabilitation policies, which are the most powerful stimuli for overall reflection on the design of projects, including small ones, and hence for the systematic introduction of multifunctionality, there are other conditions favorable to the development of multifunction roads within the French context, namely:

1. Emergence of new tools for determining and detecting cases favorable to the use and implementation of this extended multifunctionality principle. Functional analysis and value analysis are privileged instruments. Used up to the present time for major operations, it will be possible to have such methods applied more generally towards the larger number of medium-sized and even small project. A guide for functional analysis in the design of urban public spaces, prepared jointly by the French municipal engineers' association (IVF) and the technical network of the French Public Works Ministry, was recently published. Consistently raising the question of roads as a service to whom? Organizing the work of the designer methodically and in a structured manner in keeping with the requirements of the players of the road, utilization situations, user expectations, functions for meeting these expectations and criteria relevant to these functions, confronting these approaches with clearly defined constraints, this is also a favorable context which often leads quite naturally to multifunctionality in overall design but also to the main objectives giving cohesion and a body to the public space in the roadway with its structure and its surfacing.

   In urban and peri-urban areas, multifunctionality is the rule whenever one considers requirements and service to users taken individually and collectively. Porous urban pavements constitute a privileged range of solutions, neither unique nor exhaustive, resulting from such analyses in which one is sometimes led to upset the conventional hierarchy of the features required in pavements.

2. A field and an overall coordinated range of potential applications are gradually being built up. France's program for the study and thorough rehabilitation of urban expressways is an example. The methodology, worked out in 1995 for the 1,530 kilometers of pavements in this network (total linear distance of the two traffic directions) is based largely on the concept of « quality and environment ». It would also be possible to speak of requalification of urban expressways, in particular for half of them that work in a meshed network dependent on all the other networks of road infrastructures in the region around Paris. Under these conditions, what is involved is not only the analysis of pavements in the conventional sense of their structural and surface dependability, but also and more largely the questions of operation which govern the maintenance strategies, without forgetting the importance of lighting, drainage, geometrical design, landscape improvement, and noise control. This type of integrated, pluri-disciplinary approach, incorporated methodically from the outset in a coherent and interactive whole, emphasizes, among other solutions, composite pavements that combine the best features of concrete pavements with their durability and their low or almost nonexistent structural maintenance requirements, and asphalt pavements that offer greater comfort (Figure 7).

3. Multifunction pavements have also developed with a wider choice, and increasing technical and economic competition between types of paving materials. Today, the technical solutions available to clients are not only more diversified but also more precise in terms of their fields of application and their execution and maintenance requirements. Entirely porous surfacings and structures could appear a few years ago to be a sort of single-culture of the low-noise reservoir pavement with a high level of comfort and safety. The utilization limits of this concept are better understood today, in particular as concerns porous surfacing materials in the case of urban roads in city centers, and it is possible to build structures and surfaces generating little and sometimes even very little noise with nonporous materials, in asphalt as well as cement concrete. Provided certain rules of mix design discontinuity, and maximum grading of the order of 6 to 8 mm, are observed, very rough dense materials exhibiting good surface property stability with time can be applied [4]. These observations moreover help to call into question and even to work towards changes in technical specifications. As concerns surface textures, the tendency in France is to characterize skid-resistance requirements of pavements placed in different situations in terms of site and authorized speed applying a macroroughness/microroughness combination. The latter would be characterized simply by the true sand patch depth for macrostructure and a weighted indicator for microtexture integrating the accelerated polishing coefficient (APC) and the maximum particle size (D) passing 2 mm (significant of the importance of the sand fraction in the mortar). Along these lines, it is important to note that the best microtexture classes are obtained with high APCs (≥ 0.55), small Ds (≤ 6 mm) and a high number of elements passing 2 mm. It may moreover be added that the influence of the mortar and its hardness plays a significant part in the durability of the macrotexture/microtexture couple and that this would warrant being taken into account better than allowed by current practices.

Based on recent assessments of low-grading pavements, many possibilities are now offered for the design of comfortable, dependable and silent multifunction pavements with bases or sublayers in natural or artificial porous materials and appropriate impermeable surfacing. The porous urban pavements 10 and 11 in the general classification table of Figure 1 represents this case which will be experiencing a certain development.

III. A MORE REFINED DOCTRINE REPRESENTING EVEN BETTER THE SPECIFIC CHARACTERISTICS OF URBAN PAVEMENTS

The 1997 edition of a technical guide for Porous Urban Pavements, prepared jointly by the French association of municipal engineers (IVF) and the technical organizations of the Public Works Ministry (design center for networks, transportation, town planning and public construction, and the LCPC (transportation research laboratories)[1] reflects the experience acquired to date and provides practical design recommendations for contractors. The multifunction aspect appears clearly because, based on a classification of porous or nonporous materials and typical structural architectures presented at the start of this text, the following are dealt with successively:

- Aspects of resistance and durability with «mechanical» structural design,
- Noise aspects with «acoustic» structural design,
- Reservoir aspects for the management of rainwater flow and pollution with «hydraulic» structural design.

The optimization principles for these three simultaneous structural designs are indicated in the guide for the different objectives sought, depending on whether the project is to cater to all or just some of the functions mentioned above. The document also indicates the types of pavement structures currently operational in 1997 over the French national territory, those involving experimental operations and finally those requiring prior studies on more fundamental aspects in terms of the type of placement, in thick to very thick layers and/or materials with a very high communicating voids ratio. With its preferred range of average and especially high thicknesses, cement concrete covers all three situations but still requires extensive trials.

Finally, the important question of maintenance is dealt with, in particular concerning the essential precautions that change the habits of maintenance or sanitation departments in towns, underscoring in particular the pore flushing operations.

Some hypotheses and trends that seek to represent the allowance for urban specificities in this approach are considered below as an example, it being understood that they were incorporated to a greater or lesser extent in the final document owing to the caution called for in a widely circulated general publication.

As concerns mechanical structural design, the pavements and other areas in urban settings are characterized, among other things, by:

- Highly variable theoretical service lives of structures and surfacing, considering the changing nature of the urban environment and the types and architectures of buried networks. The average duration of a surfacing material before overlaying or «milling-overlaying» is 24 years, and a third of French towns have a renewal period longer than 30 years. Published catalogues of existing structures for large conurbations predict pavement lives within the range of 10/50 years. Based on this observation, and for easy use, the guide provides a set of sheets on comparative typical structures for periods of 20 years, and charts for performing the operation over any other lifetime. Figure 8 gives an example of typical structures proposed using several families of cement concrete.

- Pavements for which the circulatory function is predominant, and others for which it is not. In the latter case, designers often wish to mark the different functions assigned to these spaces for the use of qualitative materials possibly side by side with conventional materials. A range of structures using porous concrete paving blocks on the surface is proposed on the basis of long experience already acquired in the Bordeaux region (Figure 9).

[1] In addition to the authors of the present paper, others that also contributed to the guide included J. BALAY, J. BEAUMONT, Y. BROSSEAUD, D. SOULAGE and G. RAIMBAULT.

- The aggressiveness of commercial vehicle traffic, significantly lower than what is observed on rural roads. In cities, several series of measurements carried out with piezo-electric cables and fine traffic analysis stations on roads of various typologies and functions have led to measurements of the aggressiveness coefficient on the order of 0.2 to 0.3 and even less, whereas conventionally much higher values are used in structural design. To be on the safe side, in urban roadways use is currently made today of aggressiveness coefficients of 0.5. The guide has taken this option for light-traffic pavements (T4 - T5 level), but has conserved the usual values of 0.8 to 1.3 for medium and heavy traffic pavements.

As concerns noise reduction, it is the surfacing material alone, which may be thick, which is responsible. The diversity of the functions and uses of urban roadways has made it possible to determine quite rapidly the limits and the inappropriateness of the use of porous surfacing in urban areas for service streets and the town center in particular, and in the present state of maintenance procedures. Low-noise, compact surfacing materials have thus logically been considered, and an overall classification is presented. The trends observed, for all surfacing materials taken together, are the following:

- When the size of the aggregate is reduced, the LAmax decreases,
- The change from a compact surfacing to a porous surfacing in a thin layer for a given chip size decreases the LAmax by about 3 dBA,
- Trials on porous pavements consisting of high porosity materials (> 20%) in thick layers (10 to 15 cm) yield the best results; gain of 3 dBA on average in the best categories of compact surfacing.

As can be observed, very similar progress has been achieved today with the two technologies of porous surfacing [5] and compact surfacing. Research is being continued in order to achieve further progress in terms of decibel absorption and emission through both technologies. Research and experimentation is also being fine-tuned to meet more closely targeted objectives such as the reduction of commercial vehicle noise, which involves more the lower frequencies and for which thick porous surfacing would appear to be more appropriate (Figure 10) [6].

As concerns the reservoir function, the matter of urban rainwater pollution has already been discussed, and we shall say here only that porous pavements act as a «coarse filter» retaining a large part of the pollution on the surface or in the vicinity of water penetration and flow zones. For the main pollution criteria, the reduction in the most critical periods is often at least 50%.

As regards the water cycle after the water has gone through the porous structure, there is the question of direct infiltration into the underlying soil, and the examination of groundwater pollution risks. In this regard, several aspects must be considered:

- On old built-up sites, roadbeds offer significantly more bearing capacity than a new site because they have been consolidated by activity based on the history and development of the town. Deep networks, basements and the waterproofing of sidewalks contribute to the effective draining of pavement structures,
- The infiltration of water into the pavement subgrade is not always possible and may reduce the bearing capacity of a large number of «sensitive» soils,
- The time the water spends in the reservoir structures is short compared to that of water trapped in conventional pavements, thus reducing the damage caused by the presence of water.

The amount of traffic handled, and the permeability of the subgrade and its sensitivity to water will determine the weighting to be given to each aspect. A tentative selection chart is proposed, but it is recommended in each case that a device be used to separate the reservoir structure and the soil with a geotextile in case of infiltration.

As concerns cleaning, what is considered is basically the practices and special approaches that must be adopted with porous surfacing, as towns have very long experience with other types of surfacing. The importance of preventive maintenance is stressed, consisting here of simple suction without sweeping. The use of conventional sweepers drives the clogging elements into the voids of the porous surfacing and favors clogging in depth. After the preventive maintenance period, it is also more difficult to apply curative maintenance techniques, carried out today using specialized hydromechanical treatment machines (high-pressure spraying of water with rotary jets and very powerful suction).

Also considered are some of the basic rules important for limiting the effects of clogging, namely choosing a porous surfacing with more than 20% communicating voids, and with the largest possible voids, preventive cleaning by periodic suction, sufficiently soon after rainy periods, as well as curative treatment using specific equipment before complete clogging.

IV. TOOLS BEING DEVELOPED AS AIDS TO THE SELECTION AND EVALUATION OF MULTIFUNCTION STRUCTURES AND SURFACING IN URBAN AREAS

Developments explicitly or implicitly called for by society for better consideration of the user, the environment, safety and health, improved preservation of resources, user surveys and transparency, are such that very many actions are being undertaken to produce or requalify an urban setting for the values of the day, anticipating the expectations of tomorrow to the extent possible. The subject treated here is only a modest contribution, in which we would like to mention as an illustrative example three actions currently under way which will make it possible to meet the well-determined requirements. This will lead us to provide brief information on the evaluation of low-noise pavements in urban areas, a methodology for roadway maintenance in a large city, and finally, national, regional and local innovation programs relevant to the problems dealt with here.

① Classification and evaluation of surfacing from the viewpoint of noise in urban areas:

Acoustic characterization methods applied to wearing courses in accordance with French Standard NF S 31-119 based on two procedures, namely the controlled vehicle (measurement of noise level as a well-defined test vehicle passes in the absence of any noise source) and the isolated vehicle procedure (measurement of noise from vehicles isolated acoustically from the traffic on a busy road) are not suited to the urban environment, because of:

- correct positioning of microphones, rarely possible to achieve,
- the surroundings which disturb the transmission of noise,
- the high vehicle speeds in urban areas.

The official method based on the equivalent noise level Leq on a facade, as specified in texts associated with the Noise Law, does not allow a clear distinction as to the effective contribution of the tire/pavement contact noise to the result.

To overcome these drawbacks, liable to jeopardize the monitoring and assessment of a low-noise surfacing policy in towns, a near-field acoustic measurement system is being investigated, in particular by different players confronted with the problem in the Paris region. Figure 11 represents the schematic diagram of such measurements for which the microphone is placed 0.60 m from the wheel centerline, at a height of 15 cm from the surface.

A procedure describes very precisely the preparation, phases and analysis of the measurements. Tests on repeatability and on the incidence of the vehicle, the tire and the surroundings of the acoustic capture field demonstrate the reliability of the measurement.

This method allows *(*)*:

- the acoustic classification of pavement surfacing in urban areas,
- testing of the acoustic homogeneity of a surfacing,
- relative comparisons of tire/pavement contact noise levels before and after surface modification.

The graph in Figure 12 illustrates the acoustic gains evaluated according to this method between an old grooved concrete pavement and a new continuously reinforced concrete base, intended for the construction a composite pavement and before the laying of the porous asphalt surface. As an example, the graph also indicates the results obtained on a recent porous concrete surfacing project.

(*) This method is in good coherence with the principle of the ISO/DIS 11819.1 Standard which aim is to classify the different pavement surfacings according to their influence on road traffic generated noise. As a matter of fact, an additional procedure that completes the field of application of the SPB -Statistical Pass By-

(urban area, large scale, continuity, etc ...) is currently being examined : the so-called trailor method, with several types of tires representative of the tire population.

② **Pavement maintenance methods used in Paris**:

The city of Paris has long contributed to trials with multifunction porous pavements in cement concrete, and this was described in detail on the occasion of a previous Purdue conference. This action, as well as others of the same kind relative to overlays in porous asphalt or in porous cement concrete applied in thin layers over old concrete slabs, is aimed at finding comfortable, very silent surfacing materials where justified, along with a reservoir function useful for the long term.

While the use of porous surfacing materials on Paris streets has been put on the backburner today by the city, the principle of «rolling noise» reduction has indeed been included in maintenance planning programs [7]. The chart in Figure 13 shows that the acoustic classification of surfacing takes place very early in the selection of segments to be surveyed for maintenance.

The methodology is based on the definition of five service level indicators (age of infrastructures, rolling noise, safety, bearing capacity, pathology-deterioration), whose sufficiency, insufficiency or obsolescence is qualified on the basis of a number of thresholds (desired thresholds, required thresholds, alert thresholds, insufficiency thresholds). This architecture of indicators, criteria and thresholds can lead to conventional technical solutions for works, that are both preventive, curative and safe, particularly well-suited to the urban constraints of maximum risk and disturbance reduction. Table 7 relates to the rolling noise indicator for roadway segments of the approximately 450 km of roads making up the main network.

③ **National, regional and local innovation programs**:

Although, within the French context, the national government is the smallest contracting organization for highway infrastructures, compared with the private and parapublic sectors and especially local communities, it continues to play an active role in developing and formalizing accepted doctrine for many aspects of highway engineering. Technological forecasting and innovation form part of its constant areas of interest, and in this regard the Highway Innovation Charter mentioned earlier was designed in very close cooperation with the highway industry and has allowed the channeling of efforts towards areas that represent priorities for the national government.

Each year, topics are thus defined and made known to all the players of the highway industry and, at the request of highway contracting firms using innovative techniques, agreement protocols are signed. Such points as objectives, contributions, risk sharing, monitoring responsibility and compliance with confidentiality are very precisely described at every level of the three phases of the procedure:

- Experimental section,
- Technical demonstration site,
- Economic demonstration site.

A porous concrete protocol was signed in 1994 and resulted in a certain number of mix-design studies and the setup of an experimental section in Nantes. The performance objectives for porous concrete were as follows:

- 25% communicating voids with at least 22%,
- Noise level evaluated in LP max. according to French Standard NF 31-119 (90 km/h) less than 75 dBA and tending towards 72 dBA
- 1.8 Mpa mechanical splitting-tensile strength after 28 d
- Evenness expressed as a coefficient of the longitudinal profile analyzer ≤ 6 at every point.

The surfacing was placed with a heavy finisher designed with a high compactability screed, with no compaction or touching up of any kind behind the screed. The mechanical results were not as good as the design data, but usage and acoustic properties were very satisfactory (25.9% communicating voids, 73 dBA in LA max.). After this positive result, that already followed others obtained in particular with the help of

the city of Paris in connection with an earlier national project (See Purdue 1993), the conditions to be met for the next sequence of the technical demonstration project were:

- Define a method for producing high-porosity cement concrete specimens in order to improve the predictive nature of the studies by improving the correlation between the lab specimen and field results.

- Increase the mechanical strength with more communicating voids (25%) so as to obtain sufficient stripping resistance. This objective is currently met with a splitting-bending strength ≥ 2.5 Mpa after 28 d (for 25% communicating voids).

At the end of 1996, these results were achieved in the laboratory with particular optimization of particle grading as well as with binders of the silica fume cement type and conventional additives.

The validity of such well-oriented, coordinated, innovation monitoring projects now closely followed by the national government, to the satisfaction of contractors, has drawn the interest of other agencies and in particular France's regional councils which are in charge of its "departmental" (county) roads, a very large network representing over 400,000 km of pavements. Experience-exchange clubs made up of regional road engineers regularly exchange information on innovative operations relative to specific problems. Table 8 provides one example of an arrangement proposed by the Greater Paris region and discussed with other neighboring regions in order to work out complementary arrangements depending on whether the problems are related more to urban or rural areas.

Environmental aspects appear very significantly and concrete, as well as the different cement-treatment techniques, are included in these actions.

Finally, at the very local level of French communes with their specific problems, contexts and sensitivities, innovation initiatives are possible. Let us mention, for example, an experimental porous cement concrete section using treated wood aggregate, tested for light-traffic roads and cycle paths in forests or elsewhere.

Such advances are valuable because they offer the future possibility of designing renewable pavements or light-traffic pavements based entirely on by-products from urban roads and from industrial activities.

Household waste incineration slag covered with wood cement concrete, for example, can already be perceived by certain officials as offering opportunities for the design of «sustainable development green» pavements.

This is another aspect of multifunctionality.

V. CONCLUSIONS

The range of preoccupations that must necessarily be taken into account by highway designers and managers are such that the concept of a «multifunction pavement» is increasingly becoming a basic reality and even a prerequisite in urban areas. Through the given examples of tendencies in «sensitivities» and regulatory procedures within the French context, this multifunctionality can be implemented in different ways and at different levels.

It is also seen that noise and water are two environmental factors to which the population is especially sensitive and that, along with safety, they constitute the main criteria for a new hierarchy of objectives assigned to highway structures, streets and roads.

In many areas, such as regulations, design, evaluation, maintenance and technological forecasting that characterize the French urban context, much is expected from available techniques, and concrete can play an important part in dealing with these new issues [8]. Today, the main advantages have been clearly identified, and in many cases the corresponding technical feasibility has been established, in particular for low-noise pavements. Today, efforts are being focused on the multiplication of large projects allowing the proper control of these techniques by contracting agencies, engineers, contractors and managers of the public domain.

The French context in the past five years has sufficiently strengthened the perceived relevance of this approach towards «pavements of another kind ...» so as to be ready at the right time. Investigations, demonstrations, and better individual and collective understanding of the concept of sustainable development have been progressing and for many it is now time to make the concept operational. The approaches and results described in the present paper are some of the possible gateways, provided that research and experimentation efforts are continued, because they are still important in these areas, and provided that the economic considerations that necessarily accompany any decision or any overall strategy can testify to the timeliness of this multifunctionality for a particular project (initial capital outlay and cost over the service life of the different functions).

Table 1 - Functions privileged in the different PUPs in increasing order of effectiveness

Comfortable and safe road	Low-noise road	Low-pollution reservoir (water)
PUP 1-4-7-12	PUP 8-9	PUP 3-6-9
PUP 2-5-8	PUP 5-6	PUP 10-12
PUP 3-6-9-10-11	PUP 7	PUP 2-5-8
	PUP 3	PUP 1-2-4
	PUP 4-2	PUP 11
	PUP 1	

Table 2 - Classification of land transportation infrastructures introduced in French Order of 30 May 1996

Reference noise level L_{Aeq} (6h-22h) in dB(A)	Reference noise level L_{Aeq} (22h-6h) in dB(A)	Infrastructure category	Maximum width of sectors affected by noise on each side of the infrastructure
$L > 81$	$L > 76$	1	d = 300 m
$76 < L \leq 81$	$71 < L \leq 76$	2	d = 250 m
$70 < L \leq 76$	$65 < L \leq 71$	3	d = 100 m
$65 < L \leq 70$	$60 < L \leq 65$	4	d = 30 m
$60 < L \leq 65$	$55 < L \leq 60$	5	d = 10 m

Table 3 - Permissible maximum levels for the noise contribution of a new infrastructure introduced in the French Order of 5 May 1995 relative to road infrastructure noise.

USE AND NATURE OF BUILDINGS	L Aeq (6h/22h) (1)	L Aecq (22h/6h) (1)
Health, care and social action establishments (2)	60 dB (A)	55 dB (A)
Educational establishments (except for noisy workshops and sports facilities)	60 dB (A)	
Housing in areas with a moderate pre-existing noise level	60 dB (A)	55 dB (A)
Other housing	65 dB (A)	60 dB (A)
Buildings used for offices in areas with a moderate pre-existing noise level	65 dB (A)	

(1) These values are 3 dB (A) higher than those that would be measured in a free field or on a facade, in the plane of an open window, under the same traffic conditions at a comparable location. This difference must be taken into account for any comparison with other regulations based on maximum permissible noise levels in a free field or measured in front of open windows.

(2) For care rooms and rooms reserved for the ill, this level is lowered to 57 dB (A).

Designation symbols

LAeq: Weighted continuous level of acoustic pressure A during the period indicated corresponding to the contribution of noise by the infrastructure (French standard NF S 31-110).

This level is evaluated 2 meters in front of the building facade with windows closed.

Table 4 - THE FRENCH WATER LAW - DECREE OF MARCH 1993
Nomenclature of operations subject to authorization or declaration and requiring documents covering the effects on hydraulic systems and pollution, with associated technological solutions

Project involving:

- Covering of a water body over a length greater than 10 meters
- Disposal of rainwater into surface water bodies or an infiltration basin for a scheme with a surface area larger than 1 hectare
- Creation of water bodies with a surface area larger than 2 000 sq. m
- Backfills in wet or marshy zones with a surface area larger than 2 000 sq. m
- Structures, embankments and groins in the new bed of a stream constituting an obstacle to the flow of floods
- Diversion, branching, rectification, channeling of a river bed.

Table 5 - Pavement runoff water: different forms of chronic pollution

- Macro waste (visual pollution)
- Oxidizable materials: tire wear, asphalt pavement wear, combustion residue
  Parameter evaluated globally by the COD (chemical oxygen demand) and even BOD (biochemical oxygen demand) to determine the biodegradable fraction (generally small)
- Suspended matter (SM): essentially in mineral form
- Micropollutants
  * Minerals (heavy metals)
    - Lead (gasoline additive)
    - Zinc (crash barrier corrosion, tires)
    - Cadmium, copper, etc.
  * Organic
    - Aliphatic hydrocarbons
    - Aromatic polycyclic hydrocarbons (APH)
    - Unleaded gasoline additives (MTBE)
    - Herbicides (maintenance of surroundings)

Table 6 - Examples of chronic pollution of runoff water - Data collected 1 km from street or road with 2 lanes

		Motorway handling 5000-7000 veh/day	Main urban road[1]	For information Maximum load for an event
Chemical oxygen demand	COD	310 kg		40 kg
Suspended matter	SM	300 kg	490 kg	120 kg
Lead	Pb	0.65 kg	1.05 kg	0.25 kg
Zinc	Zn	1.3 kg	1 kg	0.13 kg
Hydrocarbons	HC		5 kg	

(1) Urban and peri-urban roads generate greater fluxes than inter-city roads because of:
- Low traffic speeds: engines idling, no projections
- Soiling relative to the activity of all players of the urban public space
- Older vehicle population: more lead, less efficient engines
- but many streets are cleaned regularly by the town's sanitation department.

Table 7 - Management of urban pavement maintenance by service level monitoring. Example of logic applied for the vehicle rolling noise indicator

	MAIN NETWORK SEGMENTS	
	with hospitals and schools	others
Desired threshold	class 3 (1)	class 2
Alert threshold	class 1	class 0
Insufficiency threshold	class 0	

(1) minimum class of surfacing according to the following breakdown:
class 0: LAmax > 80 dBA (LA max 90 km/h
class 1: 76 dBA < LAmax > 80 dBA
class 2: 73 dBA < LAmax < 76 dBA
class 3: LAmax < 73 dBA

Table 8 - Departmental (county) road networks
Some subjects dealt with in connection with an innovation program in the highway technology area

ASPECT	PURPOSE AND TECHNOLOGY
Noise	Search for better acoustics without cost Disturbance due to background noise Technological files on porosity, microgranularity, special products
Pollution	Water pollution, application of new Water Law
Energy	Energy content of white vs black, hot vs cold materials Technological files on treated crushed concrete, in-place treatment, internally vibrated lean concrete, microsurfacing
Resources	Quarry, ballast pits, dumps, etc.
Waste	Technological files: crushed concrete, milling cuttings and demolition projects, slags in all their uses

Figure 1 : Types of porous structure

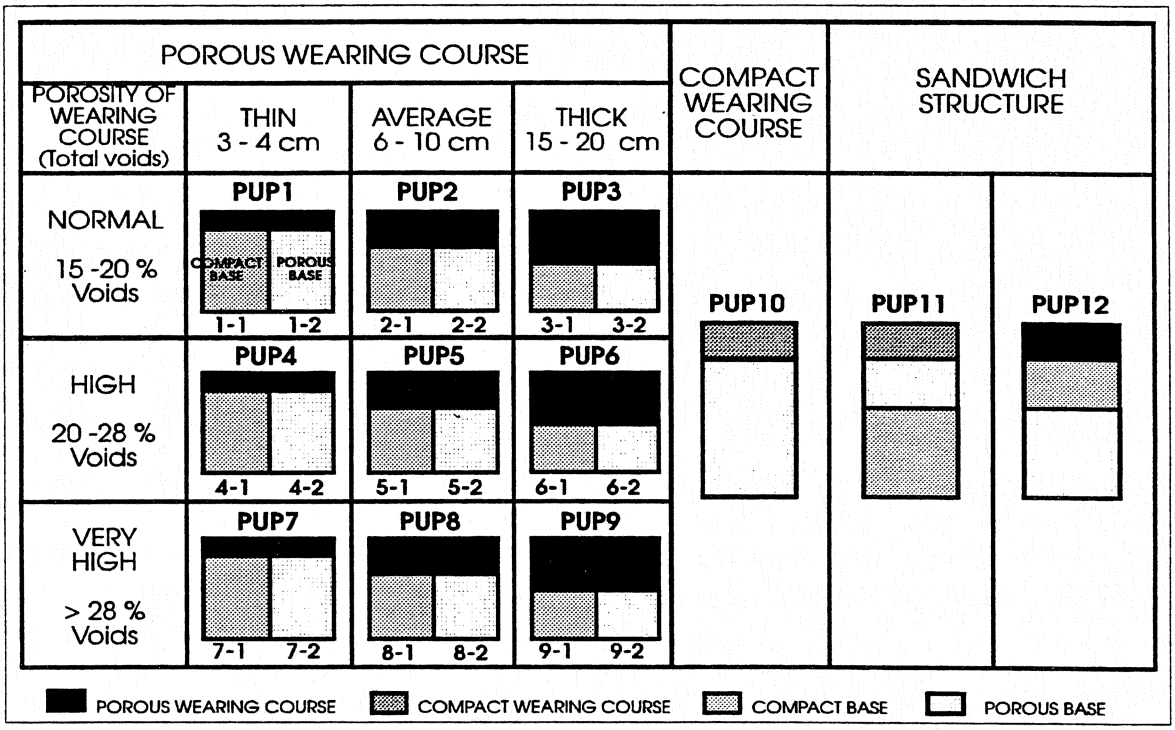


Figure 2 : Porous surfacing development level

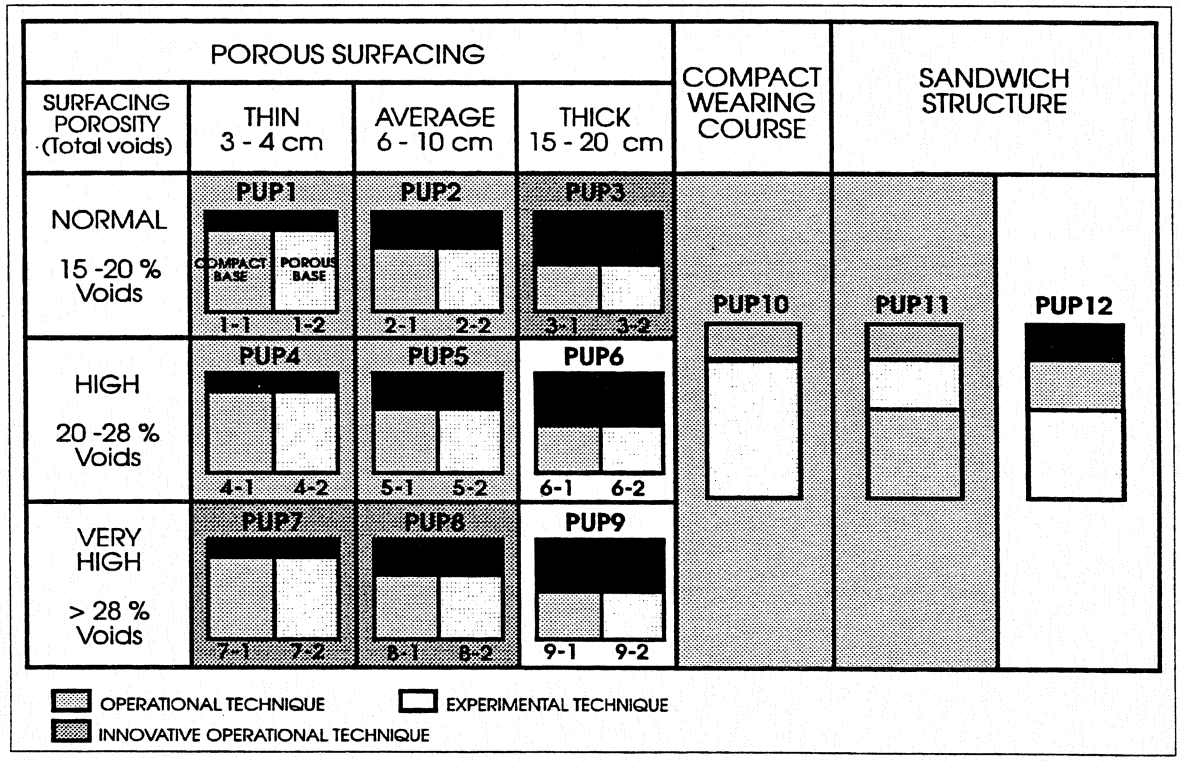
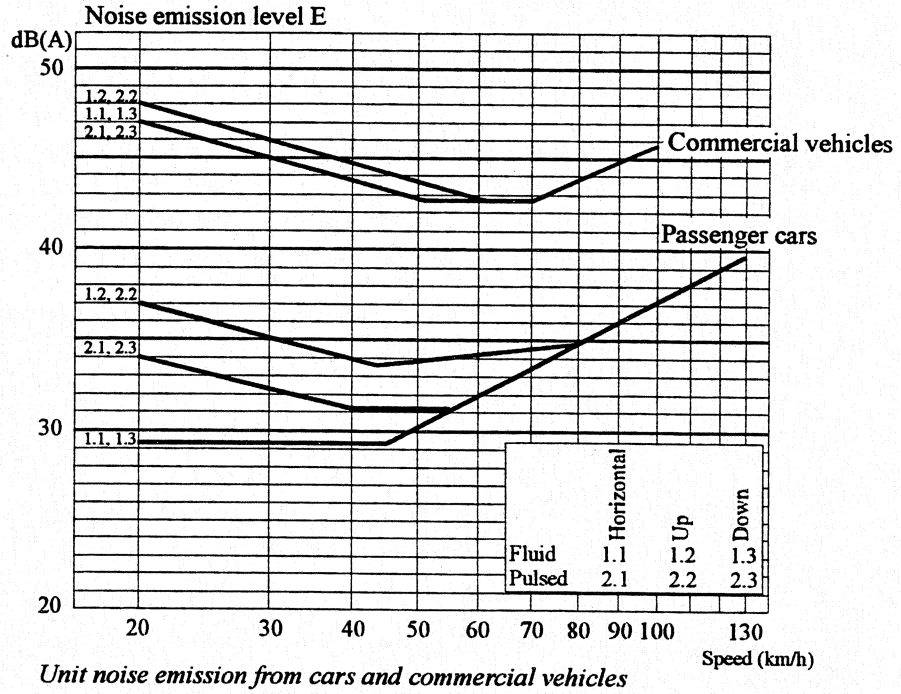


Figure 3 : Calculation of noise emission from an infrastructure section introduced in the circular letter of 25 july 1996 by the French Environment Ministry

E = (EVL+10 loq) ⊕ (EPL+10 log QPL) in dBA
E = Noise emission of infrastructure section) See graph below
EPL = Unit noise emission from commercial vehicles)
QVL = Average hourly rate of representative passenger car, depending on the period 6h/22h or 22h/6h
QPL = Average hourly rate of representative commercial vehicle, depending on the period 6h/22h or 22h/6h



Unit noise emission from cars and commercial vehicles

Figure 4 : Average noise level observed on different types of road surfacing with 0/10 and 0/14 mm grading. The range of bituminous or cement concrete products of 0/6 mm grading also easily yields low-noise surfacing.

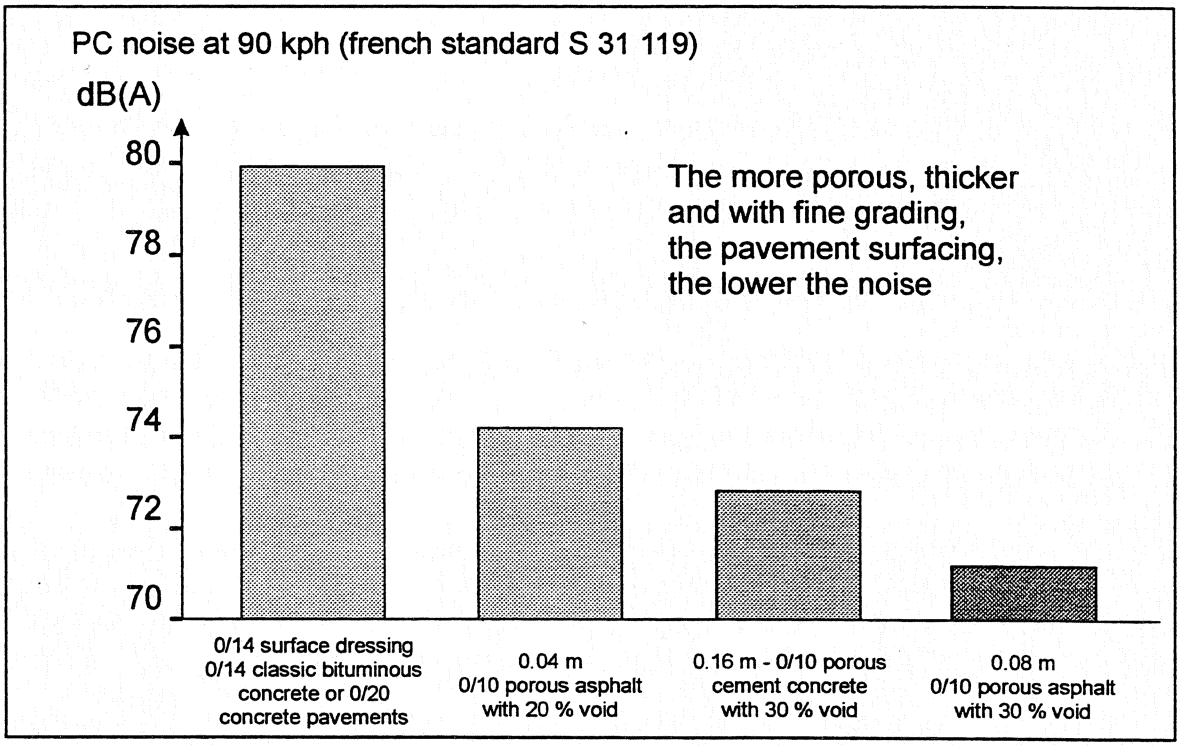
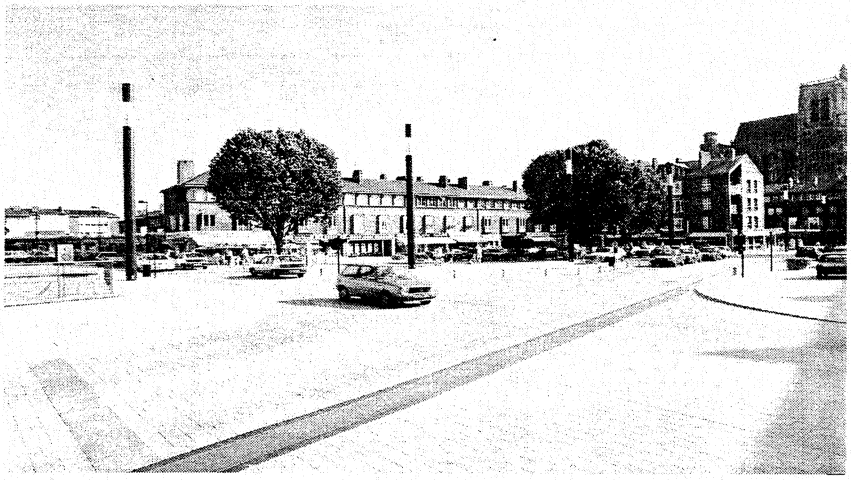


Figure 5 : Examples of the use of concrete and deactivated concrete paving blocks in urban areas, multi-purpose, multifunction



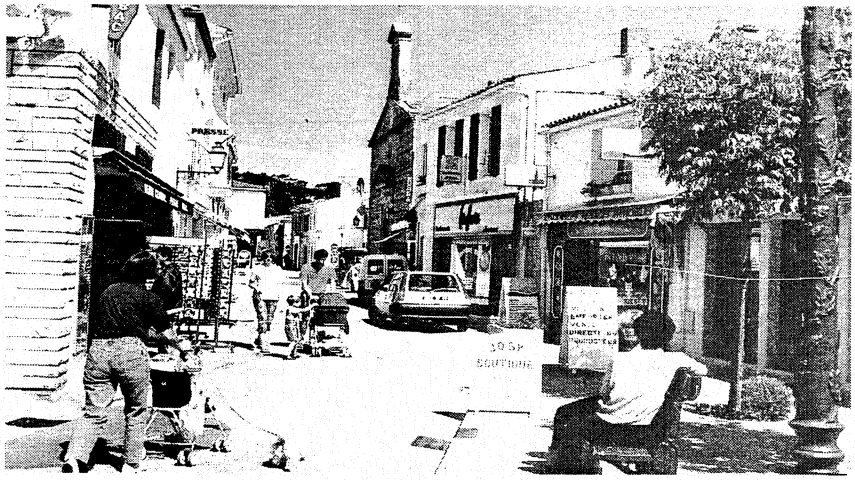




Figure 6 : In traffic circles, structures and surfacing are particularly stessed, and there are many pathologies

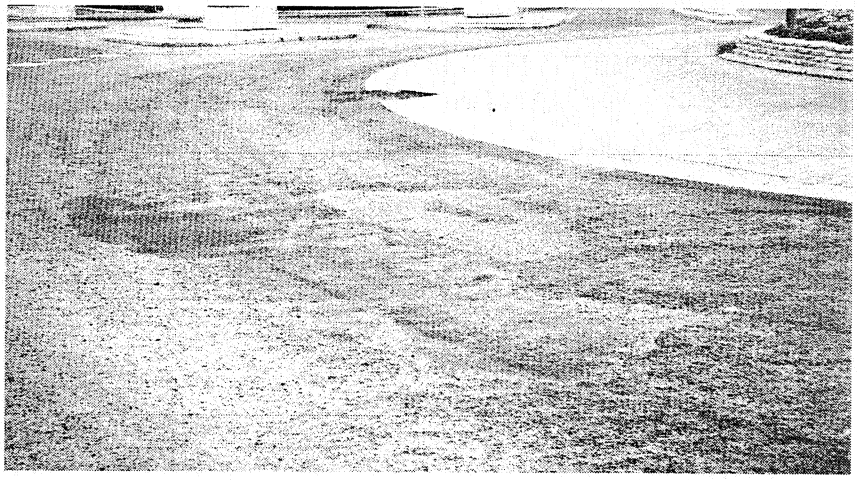




Figure 7

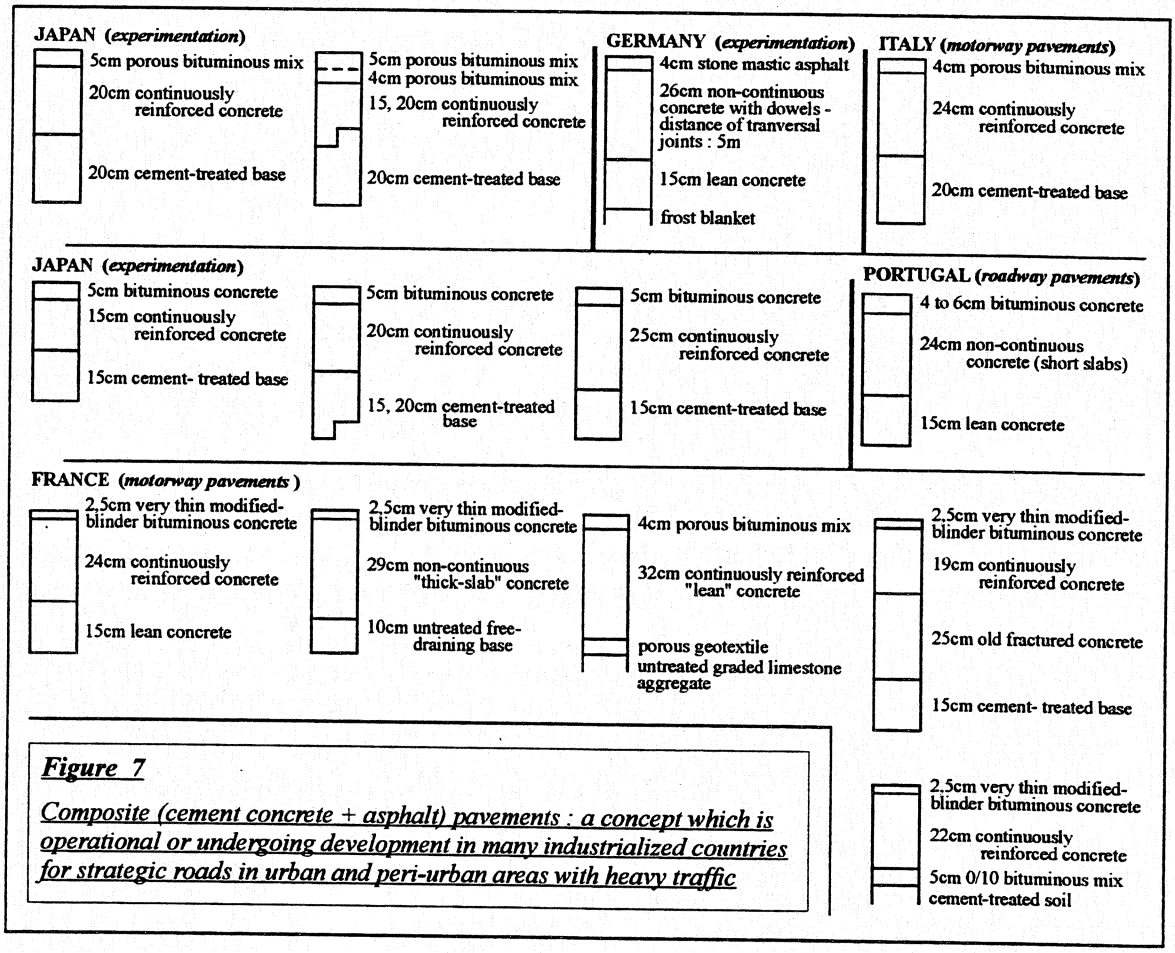


Figure 7

Composite (cement concrete + asphalt) pavements : a concept which is operational or undergoing development in many industrialized countries for strategic roads in urban and peri-urban areas with heavy traffic

Figure 8 : Example of typical structure of a porous urban pavement in cement concrete

- reference platform PF3 *- thickness in centimeters*

MAIN FUNCTION	RESERVOIR		NOISE-ABATEMENT RESERVOIR	SAFETY-COMFORT
TRAFFIC	A T5	D T3	E T2	E T2
TYPICAL STRUCTURES	BC 4 PCC2 14	BC 4 PCC1 14	PCC1 16 CC3 17	PBC 4 CC3 27 PBC 4 PCC1 27

Traffic A : Parking lots and housing development roads
Traffic D : local distribution roads
Traffic E : Main traffic roads
PCC1 : Class 1 porous cement concrete (300 to 400 kg/m3 CPA or CPJ cement, class 42.5)
PCC2 : Class 2 porous cement concrete (150 to 250 kg/m3 CPJ cement, class 42.5 or 32.5)
CC3 : Class 3 cement concrete (lean concrete)
BC : Bituminous concrete
PBC : Porous bituminous concrete

Figure 9 : Example of typical porous urban pavements with porous concrete paving blocks

- reference platform PF3 - thickness in centimeters

MAIN FUNCTION	RESERVOIR			
TRAFFIC	A T5	B T4	C T3-	D T3+
TYPICAL STRUCTURES	PC blocks 8 Sand bed UPGA 25	PC blocks 10 Sand bed UPGA 32	PC blocks 12 Sand bed UPGA 40	PC blocks 12 Sand bed PCC1 27

Traffic B : Pedestrian street
Traffic C : Service road within the town
PC blocks : Porous cement concrete blocks
UPGA : Untreated porous graded aggregate

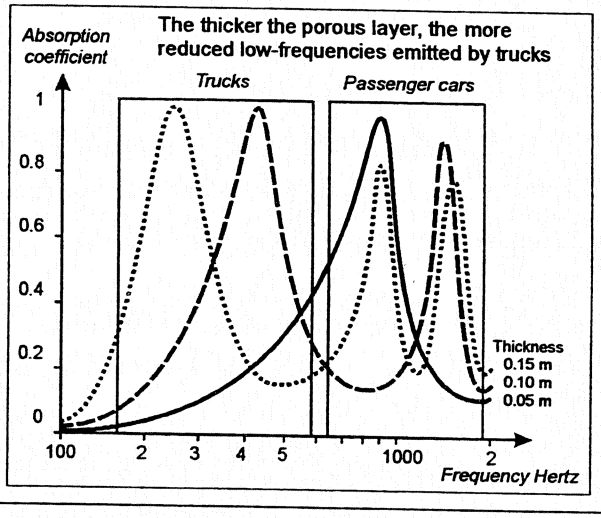
Figure 10 : Principle and results of commercial vehicle low-frequency noise reduction trials

1. DETRIMENTAL EFFECTS

Rolling and engine noises are particularly inconvenient in beltway districts where traffic density is high.
Trucks are numerous and the noise made by one of them is equivalent to seven passenger cars.

2. THEORY

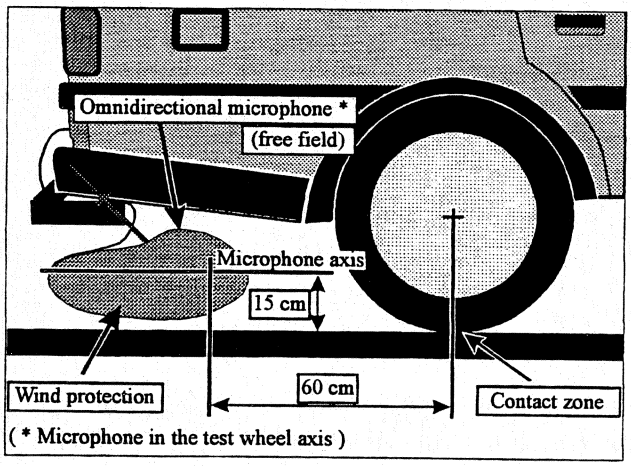
A porous surface pavement deadens noises. The more porous the surface, the more efficacious. The thicker the porous layer, the more reduced low-frequencies emitted by trucks.



3. THE EXPERIMENT

Experiments have been carried out in France, especially in Lyon, Paris and Nantes. As compared to ordinary pavement surfacings, an 0.08 meter thick 0/10 porous asphalt pavement surfacing and a 0.16 meter thick 0/10 porous cement concrete pavement surfacing with both 30 % porosity, respectively result in 9 dB(A)-units and 7dB(A)-units in noise reduction, as regards a passenger car pass-by. The 0.16 meter porous pavement surfacing asserted its efficacy in low-frequencies absorption (200/400 Hz). No significant modification of the mechanical pavement qualities results in using these porous layers.

Figure 11 : Schematic diagram and calibration of the system for measuring the acoustic characterization of wearing courses in urban areas (near-field measurements)



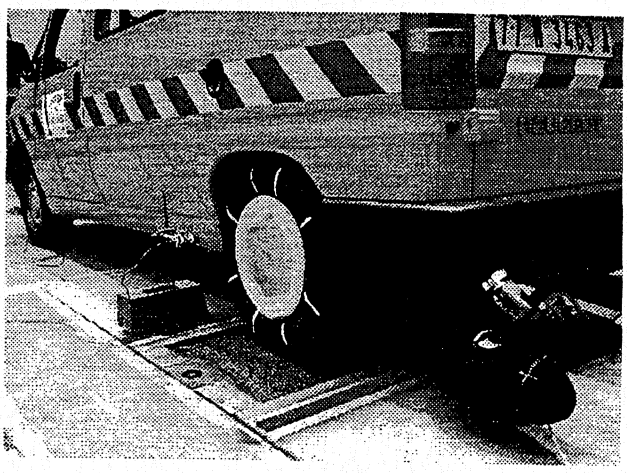


Figure 12 : Rolling noise spectra observed on old and new concrete pavements in the Paris region

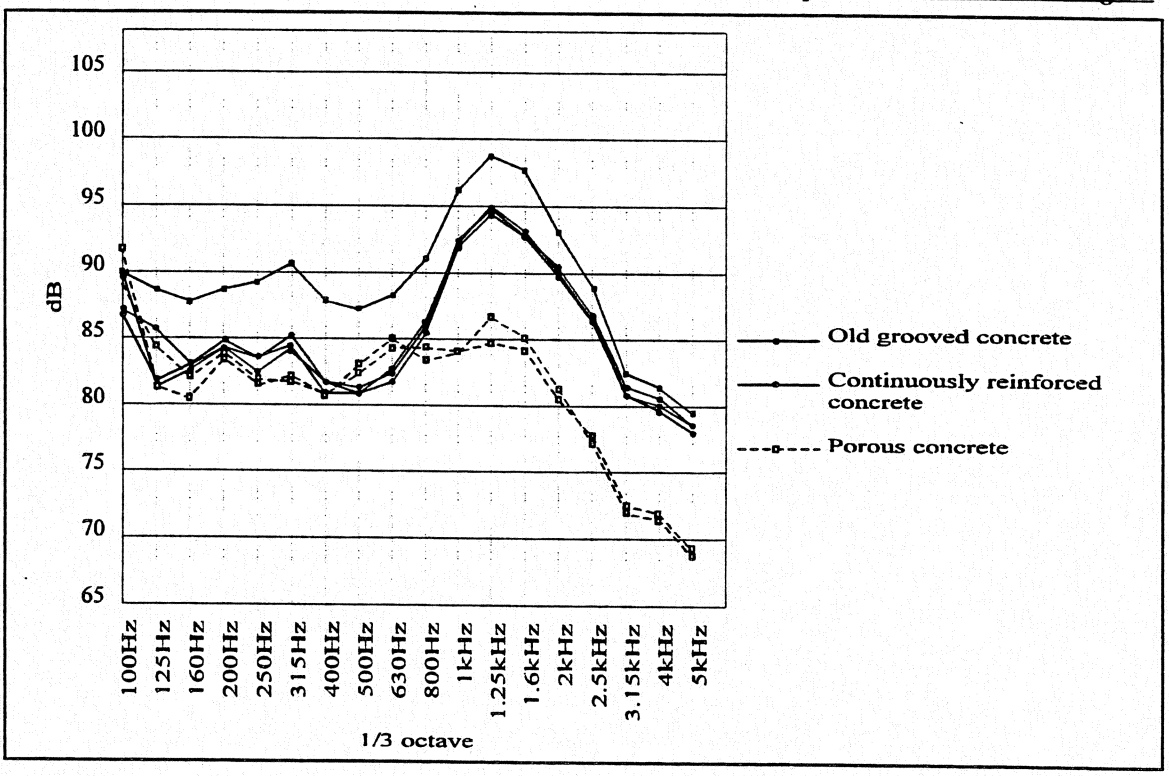
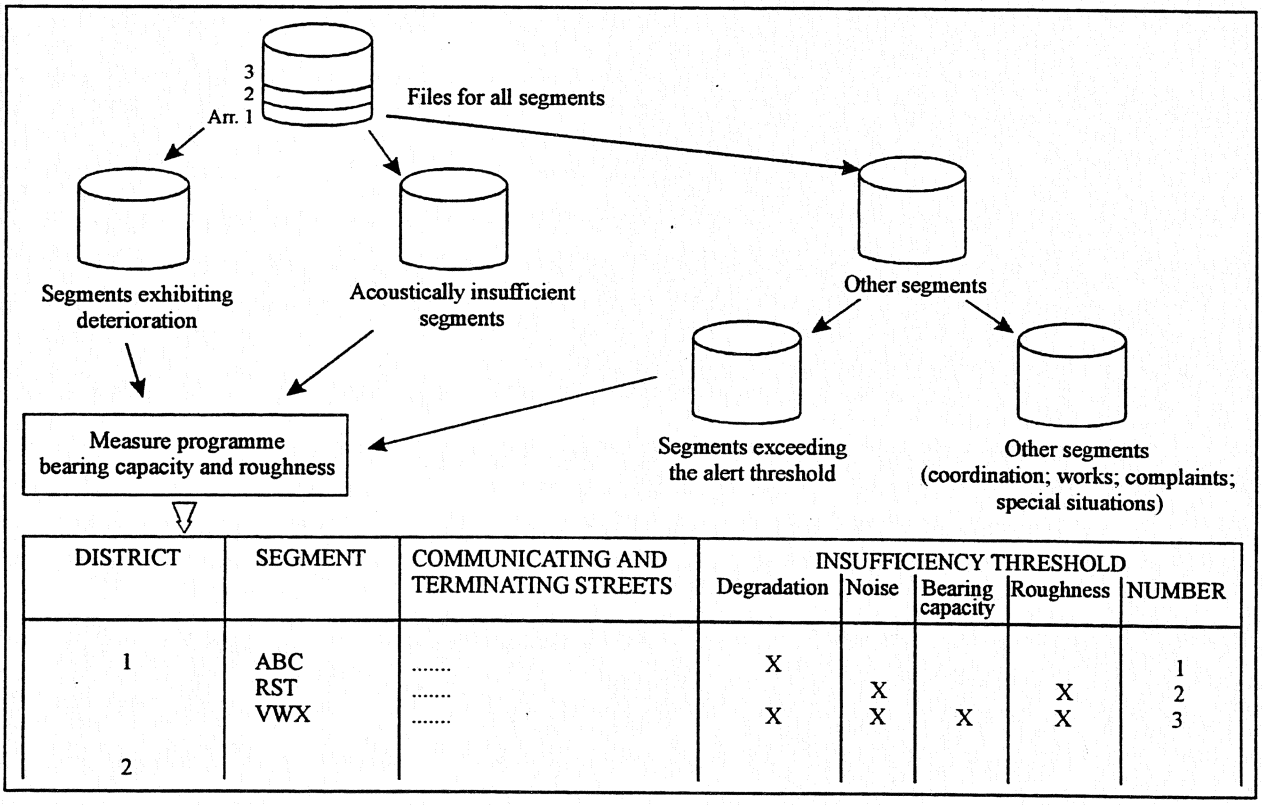


Figure 13 : Schematic diagram of urban pavement maintenance methods examined by the city of Paris



DISTRICT	SEGMENT	COMMUNICATING AND TERMINATING STREETS	INSUFFICIENCY THRESHOLD				
			Degradation	Noise	Bearing capacity	Roughness	NUMBER
1	ABC	.....	X				1
	RST	.....		X		X	2
	VWX	.....	X	X	X	X	3
2							

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