A PERVIOUS CEMENT CONCRETE WEARING COURSE BELOW 73 DB(A)

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1- INTRODUCTION

As any modern consumer, our road user fellow citizens expect a quality of service reaching far beyond the basic road engineering utilities. One of the main expectations is traffic noise attenuation, a pollution element, which can be fought either with the reduction of the noise emission, or with the interposition of absorbent structures.
When dealing with the problem of noise at source, road engineers, besides trying to decrease the noise of the vehicles themselves, are looking two ways: micro-granular surfacing and porous surfacing, the empty spaces of which absorb part of the rolling noise. Porous surfacing particularly applies to heavily trafficked suburban areas for two reasons:

- Heavy vehicle noises are the most disturbing on such roads regarding energy (high intensity) and distance of perception (low frequencies);
- Silting up being limited (little silting material is required, the porosity is high), it guarantees the durability of the acoustic properties.

Theory shows that thick porous surfacing (laid in a single layer to avoid interface effects between layers) gives interesting results because of a first peak of absorption in the low frequencies, which is due to the large thickness implemented here, and of a second peak in the middle frequencies similar to thin pervious surfacing.
Modeling and field tests showed that a thicker porous layer reduced noise much more, particularly in the low frequencies generated by heavy vehicles. An experiment is to be organized to show the acoustic benefits gained from an approximately 15 cm-thick layer, models having shown that thicker layers did not bring any significant improvement of noise absorption. At the moment, the only road material, which can be implemented in a single wearing course that thick, is pervious cement concrete.
Pervious cement concrete, though commonly used as a foundation material, remained poorly known as regards rolling noise. Because of their sites, former experiments did not allow to measure rolling noises when a vehicle passes by.

Furthermore, pervious cement concrete possesses two relevant but still ignored characteristics:

- the possibility to implement very thick layers;
- the absence of postcompaction and possible absence of rutting.

In 1994, the potentialities of this material influenced the decision to start an experimental road work within the context of the Innovation Charter [1, 2]. The partnership research contract signed between the Road Directorate and the GTM Construction Company consists of three parts:

- the demonstration of the feasibility of a very porous pervious cement concrete wearing course;
- a technical demonstration taking place on a road available to the public;
- an economic demonstration taking place also on a road available to the public.

The purpose of the first experiment presented here, being also the first part of the draft agreement, is the optimization of the two parameters: "communicating voids in the range 25-30%" and "very good surface evenness" with pervious concrete, the mechanical strength of which can withstand a traffic of approximately 500 heavy trucks per day and per direction. Such a pavement corresponds to the Type T1 presented in the "Pavement Structure

Development and Designing" French Catalogue and Technical guidebook [3, 4] (Ti and PFi are French traffic and formation level classes, see table 3 in [5]).

The results of the mix-designing study for the finalizing of the second stage of the contract are also discussed.

2 - DEMONSTRATION OF THE FEASIBILITY

2.1- Designing

At this stage of the study of pervious concrete for wearing courses, the problem was to determine the right thickness for a type 6 concrete surfacing course [6], which, once pressed against a 16 cm-thick pervious concrete surfacing course, produces the same stress at the base of the surfacing course than with the model structure of the Catalogue.

The value of the thickness was computed by ALIZE 5 [7], with the model structure, on the one hand, and with a structure consisting of a 16 cm-thick pervious concrete structure and of a surfacing concrete course, the thickness of which ranged between 10 and 16 cm. The calculations were performed with two modulus of elasticity in the absence of a value agreed for the material studied.

The calculations show that a type 6 12 cm-thick concrete surfacing course, combined with a 16 cm-thick pervious concrete course with a modulus around 20 GPa, is equivalent to a 26 cm-thick surfacing concrete course, the thickness of which is listed in the Catalogue for traffic T1 and platform PF2 [3].

2.2- Pervious Concrete Mix-Design – Characteristics

The properties of pervious concrete used for the experimental board, which have been achieved during study and preference tests and during the building work, are given in Table 1.

Because the high porosity must be reached with ready for use constituents (gravel, sand and concrete) easily available in any concrete plant, a compromise solution between porosity and resistance proved necessary. In the absence of a clearly systematized test method for highly porous materials, a certain vagueness remains regarding the real properties of pervious cement concrete. The manufacturing mode for the samples, in particular, does not allow to assess the properties accurately after the laying, probably because the compaction energy of the samples is inadequate and varies too much.

2.3 - Spreading Reference Test

The main purpose of the spreading reference board is to test the ABG 511 spreader from the point of view of evenness, without control, the screws "being adjusted," over a base or a sub-base whose transverse and longitudinal profile is generally worse than the profile expected.

The results of the preference test are:

- thickness is good, the density being a little high on the left and a little low on the right;
- evenness is sharply improved between the support course and the pervious cement concrete course: in CAPL (longitudinal profilometer measured coefficient), it means the value changes from 8.8 to 3.6, namely an improvement of 59%.

Preference boards have reached their objective: the geometry and density characteristics of the course to be executed are in accordance with the expected ones and the pace of the worksite is acceptable.

2.4 - Observations During The Executing Phase

The finisher ABG 511 with a very heavy screed (HPC in French) is a standard piece of equipment (Figure 1). Longitudinal evenness is correct and proves that the objective to be reached, that is, achieving the maximum level of compaction of the material with the sole screed of the finisher, makes spreading less dependent on the stops of the spreader. The regularity and continuity of the spreading, however, remain one of the major parameters for the

satisfactory laying of wearing courses. Nevertheless, porosity and surface texture are similar with those obtained during the reference test (Figure 1) .

2.5- Surface characteristics

2.5.1- Evenness

The level of evenness of the experimental cement concrete board must be high to comply with the basic specifications for wearing courses as regards comfort, on the one hand, and to avoid generating excessive rolling noise, on the other hand.

Table 2 lists the ordinary levels required in a cumulative histogram of the values over a long section (first two rows). Because of the short length of the experimental board (200 m) and to make sure the laying method allows to respect these specifications on the national road network and, a fortiori, on motorways as well, the level of evenness, which is expressed in CAPL, should be lower than or equal to 6 at any point.

Such values are easily achieved from the moment the course, over which the finisher is running, has also a level of evenness nearly complying with the specifications (Table 2, rows 3 and 4).

2.5.2- Skid resistance

2.5.2.1- Surface texture The traditional texture depth by sand patch test (HS) cannot be performed on a highly porous pervious material such as pervious cement concrete. Measurements of the surface texture are carried out indirectly with a laser profilometer, the micro-texture meter (MTM).

The mean sensor measured texture depth (SMTD) value is 1.14 mm:

- the value is high: in comparison, on the LCPC's model track, pervious macadam is approximately 0.8 mm whereas dense macadam is 0.5 mm only;
- SMTD elementary values (one every 10 m) are very homogeneous, at least more homogeneous than what their appearance lead to expect;
- the statistical relationship HS-SMTD ranging between 1.5 and 2, the actual HS value might then stand between 1.7 and 2.3 mm.

2.5.2.2- Coefficient of longitudinal friction The three French ADHERA skidding resistance trailers have applied more than a hundred braking sequences at various speed under different wet conditions on the cement concrete board of the skid resistance test track. The braking zone is within the straight part of the test track where vehicle noise measurements are carried out.

Table 3 presents the mean results achieved, which are illustrated in Figure 2. Skid resistance results are good at high speed but average at low speed. Speed having very little influence is characteristic of any pervious mix-designing.

By comparison with pervious macadam 0/10 from the model board of 1986, one could have expected better results at low speed with the cement binder than with the bituminous binder. The addition, though in very small quantity, of rounded sand and cement with colloidal silica, and therefore very fine, might account for these performances. At the time of the next mix-designing study, the effect of the fines used here on the micro-texture of the new surfacing should be considered.

Moreover, harder moistening tests up to a 3 mm-water film did not show any significant change at low speed in comparison with the standard 1 mm-moistening.

Above results have been obtained on a new, not circulated surface built in October 1994. Under traffic, this surface would probably perform similarly to the pervious macadam structure, which means the fair wear of the surface fine mortar and the progressive emergence of aggregate features (roughness, mild polishing). However, since the LCPC's test board cannot be tested under traffic, this evolution is not observed here.

2.5.3- Surface strength

During both finishing off and measurement stages, light vehicles went by approximately 200 times and heavy vehicles (deflectograph) used it a few times. However, except for a little loose gravel, no obvious sign of this traffic appears on the board.

2.6- Acoustic Performance

In order to qualify the performance of the 16 cm-thick pervious hydraulic concrete structure built on the model track of the Nantes center, several tests have been carried out:

- laboratory measurements of the coefficient of acoustic absorption in a standing wave tube (Kundt tube) carried out on many samples taken in several places of the track [8] ;
- In-situ measurement sof the coefficient of acoustic absorption through the method by pulses in several places of the track [9] ;
- measurements of the tyre-road noise according to the controlled pass by method explained in the standard S 31119 [10].

2.6.1- Coefficient of acoustic absorption

Whatever the method used (Kundt tube or method by pulses), the results of the measurements of the coefficient of acoustic absorption show that, within the "acoustic" measurement zone, the structure remains relatively homogeneous. Both ends, on the other hand, are not homogeneous. This observation is confirmed by porosity and permeability measurements.

Within the homogeneous zone, the mean values of the physical parameters of the structure are:

$$Rs = 5 \text{ rayls/cm} \; ; \quad \Omega = 25 \% \; ; \quad 2.5 < K < 3$$

Rs represents the airflow resistivity of the porous structure, Ω the connected porosity and K a structure factor also called in other publications the tortuosity of the structure.

With such values, the absorption, obtained in the low frequency domain within the range 300 - 400 Hz and within the range 800 - 1000 Hz (Figure 3), is quite interesting. One of the objectives has then been reached.
Save from a few problems regarding the accuracy of the in-situ method in the frequencies below 200 Hz (the limits of the method), the correlation between field measurements and laboratory measurements on samples is quite satisfactorily, a result, which is confirmed by the theoretical values of absorption achieved with the phenomenological calculation model INRETS/LCPC [11].

2.6.2- Tyre-road noise

Regarding rolling noise and despite the quality of the absorption affords by this pavement, it cannot be taken as certain that it is not noisy. The major criterion, indeed, on which to make sure the acoustical quality of a wearing course is good, is connected to the physical event of noise generation in the tires on pavement contact area depending on the surface texture. This event, which combines with the absorption event, can be assessed by measuring the noise of the vehicle running past a microphone place 7.5 m away and hanging 1.20 m high according to the recommendations of the standard S 31 119 [10].

Four distinct vehicle-pneumatics combinations have been considered:

- Renault Laguna + Michelin MXL tires
- Renault Laguna + Continental tires
- Renault Clio + Michelin MXL tires
- Peugeot 205 + Uni Royal tires

In order to position the results achieved on the pervious cement concrete track, similar measurements have been carried out on the 0/10 semi-granular asphalt board.

All vehicle-pneumatics combinations ran eight times on the board at a speed in the range 70 - 110 km, the LAmax values being recorded as the vehicles go past the microphone. The straight regression line corresponding to all these combinations is expressed as:

$$LAmax(V) = LAmax(90 \text{ km/h}) + a \lg_{10}(V/90) \quad (V = \text{speed in km/h})$$

The maximum value at the reference speed of 90 km/h is then extracted from the straight line.
The results are:

- pervious cement concrete LAmax (90 km/h) = 72.9 dBA
- semi-granular concrete asphalt 0/10 LAmax (90 km/h) = 77.3 dBA

When comparing these results with the "Controlled pass by" data bank of the Laboratoire Régional of Strasbourg (France), we find that:

- the pervious pavement studied here stands in the average of traditional 4 cm-thick pervious bituminous pavements (void between 15% and 20%) and a little higher than the average as regards very thick, highly porous pervious concrete asphalt, which stand around 71 dBA.
- on the other hand, it is less noisy than a traditional 0/10 semi-granular concrete asphalt, the mean value of which agrees within 2 dB around 76 dBA, a result confirmed by the measurements carried out on the LCPC's model track.

Regarding noise reduction, which remains the main objective of the experiment, we can therefore conclude that heavy vehicle rolling noise, which stands essentially in the low frequencies, is very well absorbed by a thick pervious cement concrete course, on the one hand, and that the acoustic properties of this wearing course vis-à-vis light vehicles are similar to traditional pervious asphalt (Figure 4), on the other hand. Because of the high porosity of cement concrete, it should be advisable to start the study of the megatexture of this wearing course to be able to deal with the contradiction existing between the rolling noise measured and the porosity of the material.

2.7- Hydraulic Performances

The systematic survey of the worksite with an automatic constant load permeameter is performed to assess the regularity of the apparent porosity of pervious concrete. Permeability is very high: 36.4 ± 5 l/s/m^2 .
Save from a few points at 35 l/s/m^2, this value places pervious concrete on the same level as the best pervious asphalt currently laid on French motorways (36.2 l/s/m^2). Right in the rolling noise measurement zone, the mean value is 37.2 l/s/m^2 (35.6 to 38.1 l/s/m^2).

2.8 - Intermediate Conclusion

Table 6 makes a comparison between the results achieved in the rolling noise measurement zone; the objectives; the levels defined; and the usage properties of the pervious cement concrete wearing course.
Apart from the mechanical strength (compression lower by 0.5%), the draft agreement specifications have been reached.

In view of the current knowledge of dense concrete performances under traffic with mechanical strength comparable with that of pervious concrete, fast traffic wear and stripping are highly likely to happen, should the mix-design experimented here for wearing courses be implemented under real traffic.

Nevertheless, the surface condition survey of, sometimes, more than thirty year old cement concrete pavements reveal that concrete itself does not show any deterioration, nor any extensive traffic wear. We can assume that pervious concrete mechanical strength should be in the range between the concrete mechanical strength values required to withstand the repeated stresses of the traffic and the mechanical strength achieved here. Before conducting an experiment on a pavement available to the public, an experimental pervious concrete board will be subjected to dense, heavy truck traffic so as to determine the level of specification to set.

In order to reduce the risks, the strength must be increased significantly before carrying on with the experiment on a real road. A tensile strength by splitting higher than 2.5 MPa is the limit set for the additional mix-designing study described below. To hope to achieve such a high strength, the gravel-fines optimum study has been conducted, at first, without considering the problem of the manufacturing of the constituents.

3 - TECHNICAL DEMONSTRATION: SECOND PART

3.1 - Objective of the preliminary mix-designing study

The above mix-designing was studied until the tensile strength by splitting was more than or equal to 2.5 MPa, a value providing sufficient quality to resist heavy truck traffic and to continue the development process, that is the construction in 1997 of an experimental section on a road available to the public.

3.2 - Pervious concrete new mix-designing

Pervious concrete for wearing courses must meet all requirements characteristic of roads (bearing capacity, durability and security) and attenuate road noise. In terms of specifications, these functions are just three nouns long: texture, porosity and mechanical strength.

The difficulty of the mix-designing lies in the achievement of a large quantity of communicating voids (25%) to absorb noise and of a tensile strength high enough to avoid stripping of aggregates under dense traffic.

3.2.1 - Selection of the aggregates

Aggregate size range is 6 - 10 mm. This choice is imposed by the balance, which has to be kept between the two following features: The maximum size is limited by tire-road noise emission, on the one hand, and, as the pores have to be large enough to prevent clogging and make cleaning easier, the aggregates must combine a fair size with a granular range as small as possible, on the other hand.

3.2.2 - Pervious concrete mix-designing

Mix-designing results depend on the compromise porosity/resistance. To compare the performances of many mix-designs, laboratory tests must be carried out. The preliminary stage consisting in the development of a method to prepare samples, has proved successful regarding reproducibility and achievement of a densification close to what is obtained with a finisher. A controlled parameter vibrocompression unit has been selected (Figure 5). The vibration rate is set to control the flow of the binder while keeping compaction effective. The sample is progressively put under pressure according to the curve recommended in the method to determine compaction performances of foundation materials, which are not hydrocarbon binder graded materials [11].

3.2.3 - Concrete porosity

Porous concrete is classed as cement asphalt consisting of two phases: binder and aggregates. The binder coats the aggregates, which are pressed against one another during the compaction phase, thus evacuating some of the binder into the porosity of their arrangement.

For given aggregates (particle shape and size distribution), the main parameter for porosity is the green binder/aggregates voluminal ratio (Figure 6).

The second parameter is compaction. Laboratory tests carried out on an identical mix-design show that, when compaction is light, the densification of the mixture is very quick, the global porosity then decreasing progressively (Figure 7). This parameter is linked to the adjustment of the compression unit and to the performance of the material according to the type of compaction.

The characteristic we were aiming at, was not global porosity but communicating voids. These voids, of course, are lower than the global porosity, the difference measured depending on the level of the porosity. As we studied the mix-designing containing aggregates within the range 6 -10 mm, we underscore that this difference can be assumed nil beyond a global porosity of 27%.

3.2.4 - Material strength

The global porosity of green cement and the material resistance are two conflicting characteristics. For given aggregates and a given quality of binder, the resistance varies with porosity according to a linear scale (Figure 8). The second major parameter is the quality of the binder. Quality and quantity of cement, with the quantity of water inside the binder, affect the resistance of the material. The improvement of the quality of the binder moves the straight line of the curve, resistance vs. porosity, toward the top.

The achievement of a high level of communicating voids demands a low quantity of binder. The addition of sand decreases the voluminal quantity of the binder, communicating voids remaining constant, and, thus, is used to reduce the resistance.

High resistance Portland cement and powerful superplastizers are used to obtain a splitting resistance of 2.5 MPa for a material with 25% of communicating voids.

4- CONCLUSION

The results of the demonstration of feasibility for a highly porous pervious cement concrete wearing course proved satisfactory as regards acoustic absorption capacity, particularly in the low frequencies, hydraulic properties and user comfort. The second part of the experiment, as defined in the draft agreement, should take place in 1997 since:

- to guarantee the level of the performances and a reasonable durability under real traffic, the tensile strength by splitting was brought up to 2.5 MPa and the additional mix-designing study shows that such resistance value could be achieved while still complying with the other specifications such as communicating voids among others;
- the good noise absorption results achieved in the low frequencies (standing wave tube measurements) still need to be confirmed by rolling noise measurements when heavy trucks are passing by, which cannot be carried out on the present board, the construction of the new board being planned during the second phase;
- the pavement designing suggested here requires to be sure of the adherence of both layers, an adherence that should be formally checked;
- Finally, though it appears possible to contemplate giving up the use of the compactors behind the screed finisher, manufacturing still needs to be optimized to improve the homogeneity of the material, particularly regarding porosity.

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TABLE 1- Properties Of Pervious Cement Concrete Used On The Experimental Board On The LCPC Skidding Resistance Test Track.

Characteristics	Study test	Manufacturing preference test	Spreading preference test	Carrying out
Porosity (%)	23.7	25	25	23.3 (14 à 29)
Tensile strength by splitting (28 d - MPa)	2.6	1.6 (7 d)	0.7 (7 d)	1.5 (7 d)
			1.4	1.9
Tensile strength by bending (28 d - MPa)	4.4	-	-	-
Compressive strength on samples (28 d - MPa)	22	15	6 (7 d)	14.7 (7 d)
			12	17.9
Compressive strength on cores (MPa)	-	-	-	7.2
				(5.2 to 10.5)

- not available

TABLE 2- Surface Evenness Specifications And Result Achieved On The Experimental Board (frequency of the coefficients less than or equal to in %).

	CAPL levels					Observations
	4	6	8	13	16	
Motorway	55		90	100		Specifications for several kilometer long sections
National road		50		95	100	Specifications for several kilometer long sections
Base course	63	88	88	100	100	100 % < 6 without roadwork butts
Wearing course	63	100	100	100	100	100 % < 4 without roadwork butts

TABLE 3- Standard Measurement of the Coefficient of Longitudinal Friction (CLF x 100).

Measurement speed	CLF CCdr	CLF BCdr	National envelope	
			First decile	Last decile
40	57	55	36	70
60	52	49	24	54
80	48	45	14	41
120	46	43	10	36

The distribution ranges from normal to low. CLF BCdr = Results from the reference board in pervious asphalt (reminder). The French national envelope is reminded (first and last deciles).

TABLE 4- Results Achieved Within The Rolling Noise Measurement Zone.

Properties		Objective	Level	Results	Observations
acoustic and hydraulic	Communicating voids (%)	25	22	25.9 (21.7 to 28.8)	23.3 (14 to 28.8) over the 200 m-long section built
	LA max. (S 31119, dB A)	72	75	72.9	strict enforcement of the standard including temperature corrections
	Permeability (l/s/m)			36 l/s/m	
Wearing course	CAPL	RN specif.	100 % < 6	100 % < 4	
usage	CFL (40, 60,80,120)			57, 52, 48, 46	
	Roughness (H.S - mm)			approx. 2 mm	MTM measurements
Mechanical (durability of the	Tensile strength (splitting, 28 d)	possible max.	More than 1.8 MPA	1.9 MPa	on samples
structure)	Compressive strength (28 d)	possible max.	More than 18 MPA	17.9 MPa	on samples

FIGURES

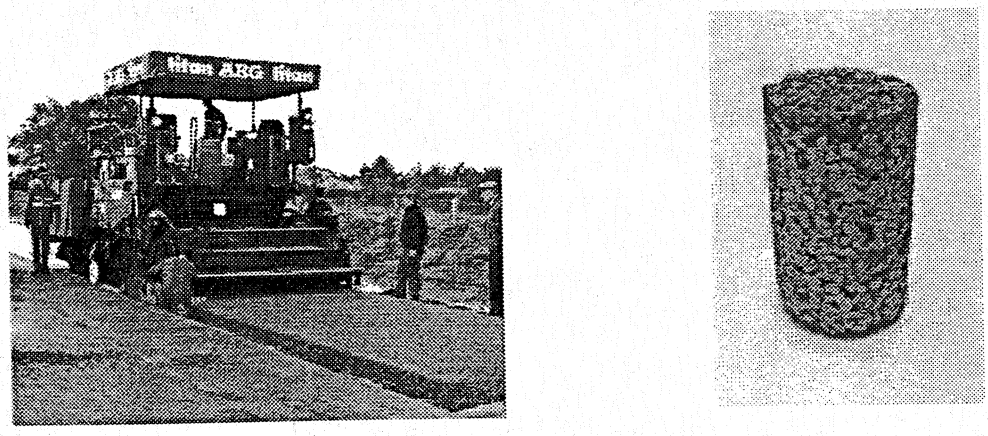


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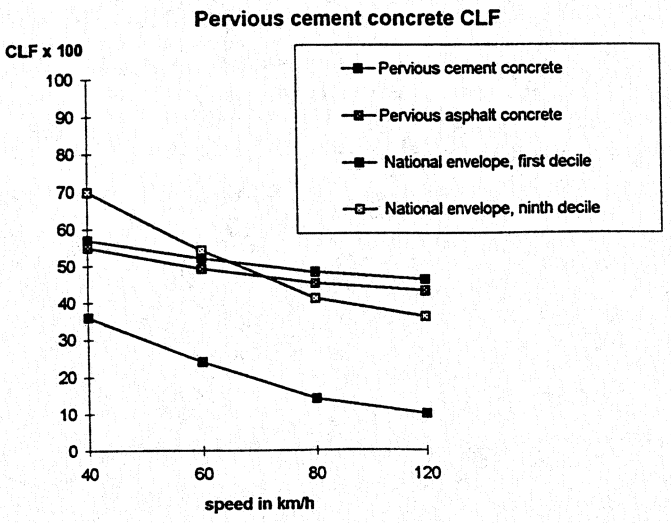


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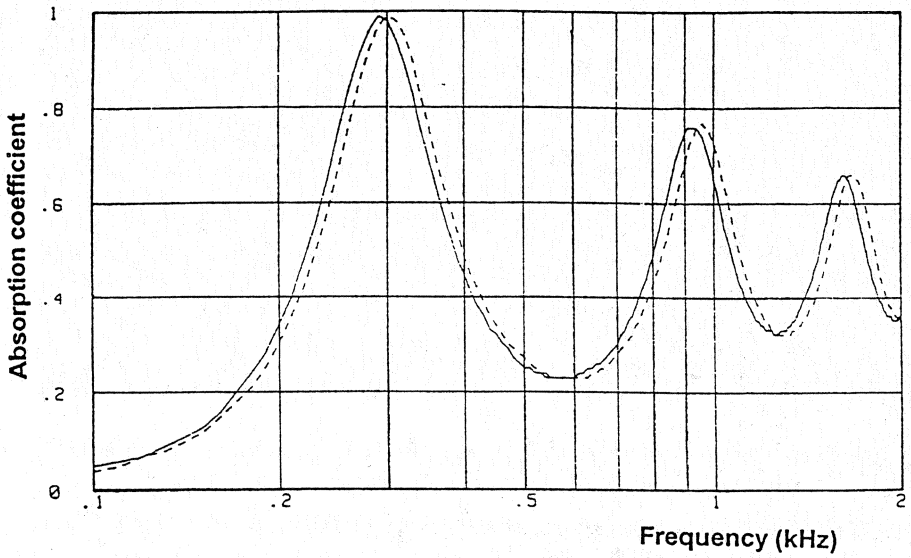


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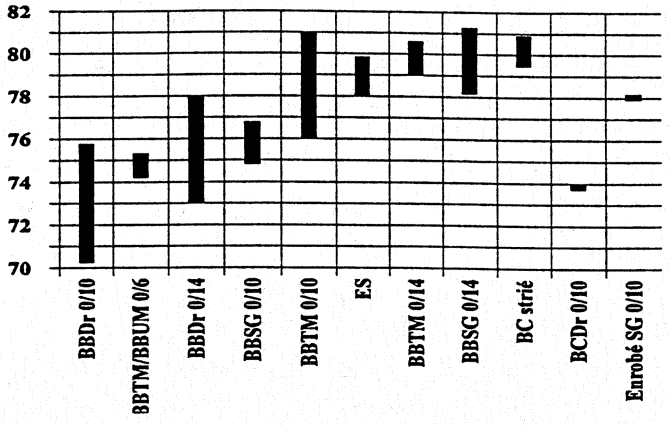


Figure 4- Distribution of rolling noise levels on 106 different pavements (LR Strasbourg - **LAmax not corrected**). BBDr 0/D: Porous Asphalt Concrete 0/D, BBTM, BBUM 0/D: Thin or very Thin Asphalt Concrete 0/D, BBSG or EnrobéSG 0/D: Thick Layer Asphalt Concrete, ES: Asphalt Surface Dressing, BC strié: Cement Concrete Pavement withTransverse Grooves, BCDr: Porous Cement Concrete

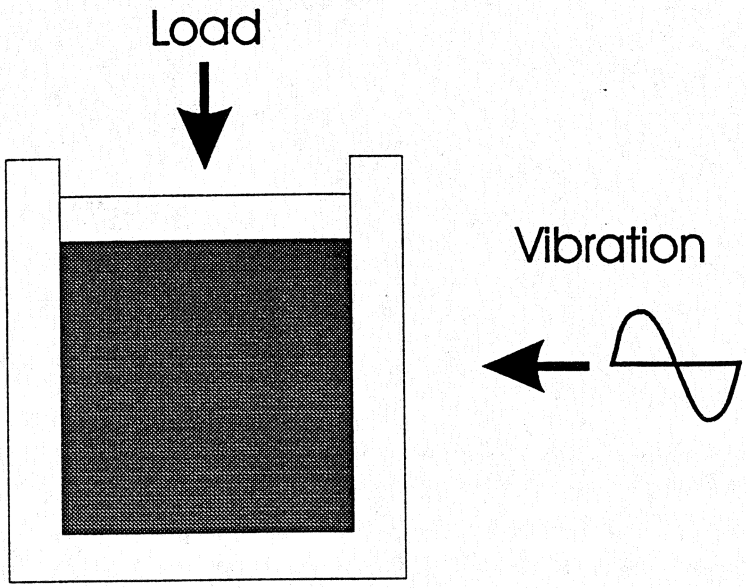


Figure 5 - Skeleton diagram of the controlled parameters vibrocompression unit (CPVC)

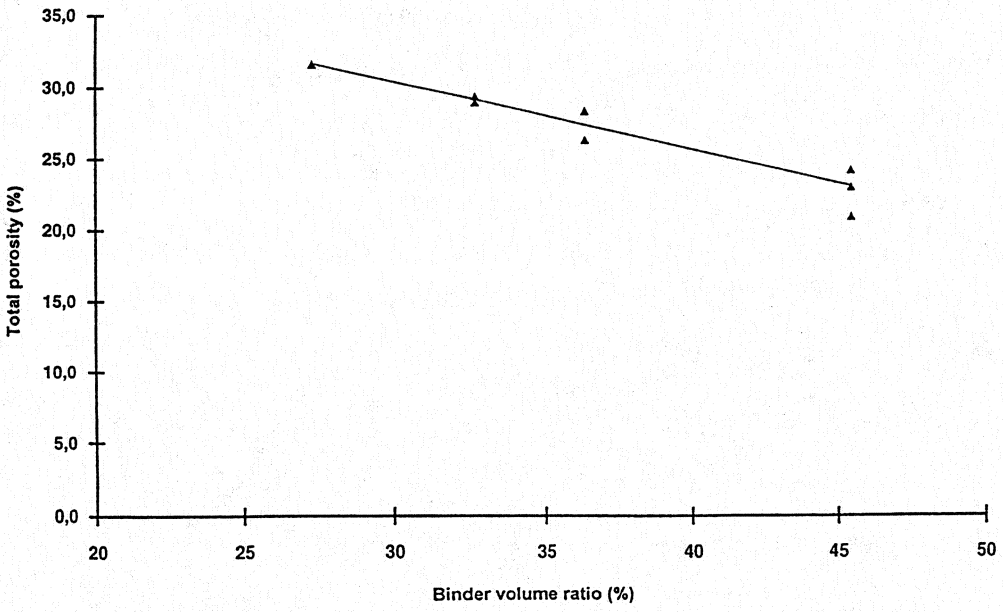


Figure 6 - Porosities achieved with various binder volumes.

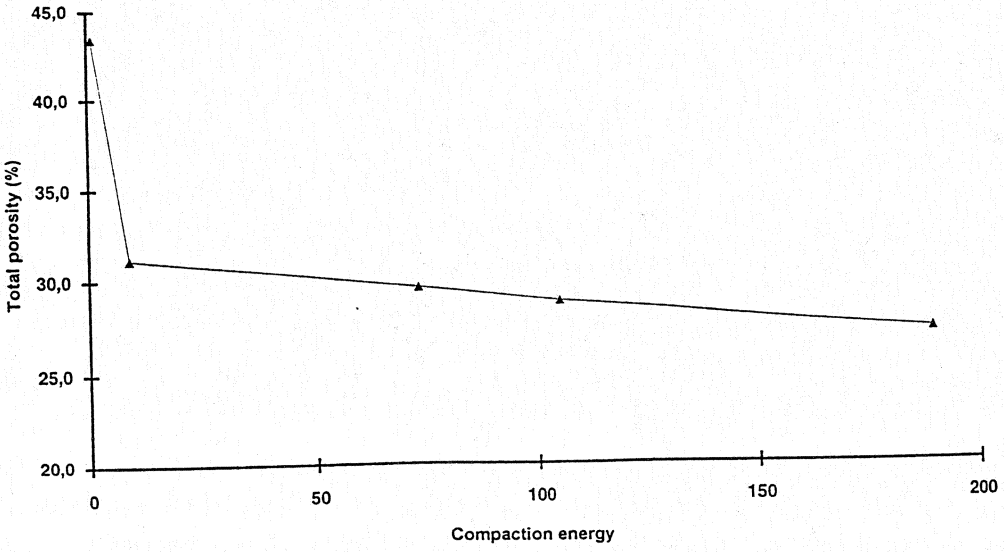


Figure 7 - Porosities achieved as compaction efficiency improves.

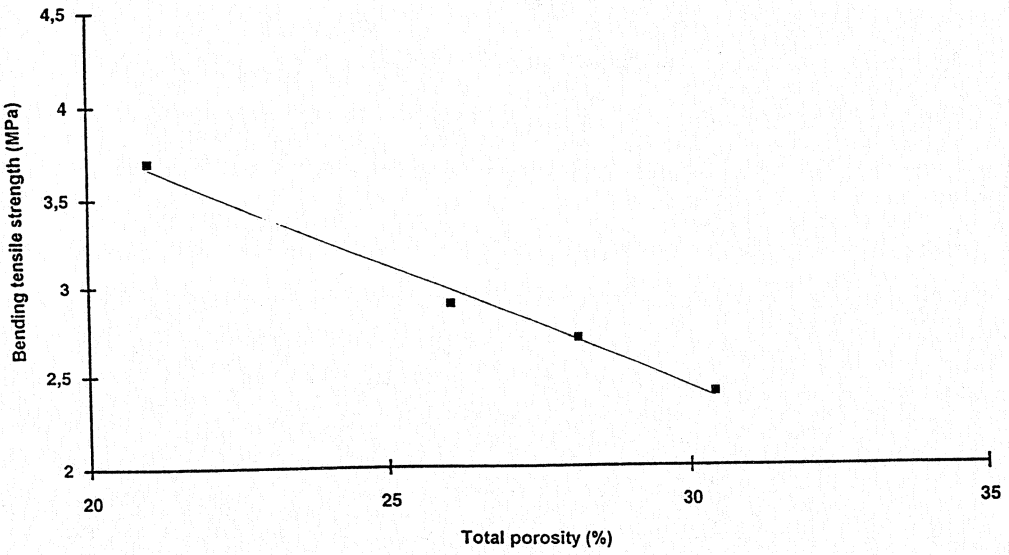


Figure 8 - Resistance according to pervious concrete porosity. Bending resistance is closely connected to global porosity.

REFERENCES

1. Dupont P. And Guidoux Y., 1995. L'innovation dans le domaine des techniques routières, RGRA n° 735.

2. Chargros Y., Guidoux Y. And Dupont P., 1996. L'innovation dans le domaine des techniques routières, l'exemple français : la charte de l'innovation routière, Routes/Roads n° 292.

3. DRCR, SETRA, LCPC, 1977. Catalogue 1977 des structures types des chaussées neuves.

4. SETRA - LCPC, 1994. Conception et dimensionnement des structures de chaussées, Guide Technique.

5. J.-L. Nissoux, J. - M.. Balay, J. - F. Corté, Et M. - T. Goux, Adjustment Of The French Concrete Pavement Design Method, Sixth International Purdue Conference on Concrete Pavement Design and Materials for High Performance, Indianapolis, Nov. 1997.

6. ALIZÉ, Logiciel de calcul des déflexions de surface, des contraintes et des déformations des structures de Chaussées, LCPC, Paris.

7. AFNOR P 98 170, 1992. Chaussées en béton de ciment - Exécution et contrôle.

8. AFNOR NFS 31065, Déteremination du facteur d'absorption acoustique et de l'impédance acoustique en incidence normale par la méthode du tube, 1980.

9. Berengier M., Delanne Y., Caractéristiques acoustiques intrinsèques d'une structure par une méthode impulsionnelle, Bull. Liaison Labo. P. et Ch., vol 139, sept-oct 1985, pp 113-118

10. AFNOR S 31 119 - Caractérisation in situ des qualités acoustiques des revêtements de chaussées.

11. Hamet J.-F., Berengier M., Acoustical characteristics of porous pavments : A new phenomenological model, Internoise'93, Leuven, Belgium, 1993

12. AFNOR NF P 98-231-3 - Détermination du comportement au compactage des matériaux d'assises, autres que traités aux liants hydrocarbonés.

ACKNOWLEDGMENTS

The experiment presented here has been carried out within the context of a partnership research contract signed between the Road Directorate and the GTM Construction Company. The authors are thanking both partners, and the following organizations or companies, which contributed with equal success to the projetct : the Direction Départementale de l'Équipement 44 (DDE 44), the Syndicat Français de l'Industrie Cimentière (SFIC) et the Syndicat Professionnel des Entrepreneurs de Chaussées en Béton et Équipements Annexes (SPECBEA), the Lafarge Ciments and Lafarge Bétons Granulats Companies, the SETRA-CSTR, the LCPC - Nantes Center - and the Laboratoires Régionaux des Ponts et Chaussées of Angers, Autun, Bordeaux, Lille and Lyon. The authors are particularly grateful to Mr. ANJOLRAS, BASNIER and BERENGIER.