FROM THE ROAD TO THE STREET: DIVERSIFIED AND INNOVATIVE CONCRETE PAVEMENT STRUCTURES FRENCH TRENDS AND GUIDELINES

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Abstract
Concrete pavements are found on rural roads as well as on urban and peri-urban roadways. In the design of these rigid structures, official engineering guidelines in France have been completely revised in the past 5 years. The urban environment has been particularly favored with the publication of manuals for standard structures and guides for the design, placement and application of concrete structures and surfacing layers taking fully into account the particular features and requirements of works in and around towns.
In addition to these generic roadway documents, particular efforts have been focused on the design of structures for specific applications. Reservoir structures and surface elements incorporated in roadways and in other urban facilities using concrete are one example, another being the pavements of traffic circles, both representing original illustrations of how the specific advantages of concrete are being put to use. These new developments call for compliance with certain rules of the art, which are reviewed in this paper, and which are also dealt with in greater detail in the documents cited in the bibliographical references.

Introduction
On approaching urban-developed zones, the user who is often a city dweller, is likely to drive over concrete pavements found on an urban expressway and major roadways of the radial or belt type, and then on streets and other roadways in town or in housing developments.
In France, existing design guides for all these types of road facilities were revised, modernized and extended in the past 5 years with general guidelines ensuring consistency and complementarity between the general documents of government agencies and specific documents of the industry. Consistency was also sought by highlighting aspects specific to each environment, whether urban roadways and streets or rural roads.

I/- BASIC DESIGN GUIDES

In application of the French pavement structural design method, new design guides covering different types of pavement structures were issued by the French highway administration in 1998 for the national highway system, mainly in rural areas, on the one hand, and in 2000 for urban roadways on the other.
These documents have the following features:

1- Catalogue (design guide) of typical pavement structures on the national highway network [1]

- Distinction between two types of roadways, those of the "backbone" network and those of the "non-backbone" network in the form of two structural data sheets describing structural design service lives of 30 and 20 years respectively, and different categories of heavy traffic loading.
- Loads are classified in seven categories based on the commercial vehicle criterion cumulated over the life of the structure. For example, the middle category, category 4, is that which will support over a service life of 30 years and a linear growth rate of 5% between 3 and 6 million trucks with a gross vehicle weight higher than 3.5 tons.
- Road bearing capacity will be increased by appropriate treatments and design. For the backbone network, the minimum modulus of elasticity is 120 MPa for heavy traffic pavements. A modulus class > 200 MPa is introduced.
- For surface layers of heavy traffic pavements an attempt is made to separate the rolling functions involving surface properties for the surfacing materials, and the other mechanical properties such as waterproofing and reflective crack control for the base course.
- Concrete pavement structures are significantly present in this guide, with six data sheets associating respectively the following combinations:
  - continuously reinforced concrete over a lean-concrete base
  - dowelled-joint concrete over a lean-concrete base
  - continuously reinforced concrete over a bituminous-concrete base
  - undowelled-joint concrete over a lean-concrete base
  - undowelled-joint concrete over a cement-treated base
  - thick-slab concrete over a porous base.

Each of these combination pairs has a privileged field of application depending on the volume and aggressivity of traffic. Figure 1 shows an example of two extreme fields of application, namely heavy traffic and moderate traffic for the backbone highway network. Note that the thicknesses mentioned are those of the right edge of the pavement, and that the cross section of the concrete pavement is characterized particularly by its trapezoidal design on one-way roadways, with a maximum thickness difference of 5 cm between the edge of the slow lane and the edge of the fast lane.

2- Urban pavement design guide [2]

- Many specific aspects of urban pavements are considered, such as the various uses of urban roadways, with less aggressive truck traffic, the residual bearing capacity of generally older pavement structures generally better than that of disturbed soils, limited thickness owing to buried utility networks, and more favorable conditions as regards drainage and frost-thaw cycles than on rural roads.
- On the other hand, urban facilities exhibit certain negative features in relation to the rural highway network. For example, projects are smaller and more complicated, involving shorter deadlines, carried out under traffic, requiring arrangements for local resident access during works, not to mention the disturbance and noise pollution generated by works, etc.

For these reasons, a certain simplification has been sought in the options offered by national rural road design guides. This is valid for traffic classes comprising a category reserved for public transportation, risk and growth rates, commercial vehicle aggressivity ratings, etc. Similarly, the limited working space on urban jobsites, as well as the rapidly changing nature of urban roadway usage, are such that trapezoidal cross sections and extra widths are generally not the rule.

- Two original guidelines have been introduced:
  . the case of partial demolition of existing pavements approaching the end of their life cycle is included
  . materials will be considered for the calculation of thickness only with the realism of can actually be done on the site (Q2 quality rating) lower than the quality required by Q1 standards in order to take into account smaller quantities, difficult compliance with thickness values, work phasing, deadlines, compacting difficulties and temperatures for the materials involved.
- Concrete pavement structures are of course present in the application of this logic. The chart in Figure 2 shows the structural designs required for different growing cumulative traffic volumes, different subgrades and with reference to the two quality ratings Q2 and Q1 mentioned above.

This simplified framework may of course be exceeded or completed by other arrangements. A "STRUCTUREB" software package makes it possible to simulate the different arrangements desired. Regional authorities can choose according to their specific local requirements. Figure 3 gives an example of a typical structural data sheet for what are known as "qualitative" pavements (for example deactivated concrete, with or without dowels) contained in a structural design guide of a large city near Paris.

II/- MULTIFUNCTION ROADWAYS

In addition to the conventional roadways described above, some of which may be very aesthetic in terms of surface treatment or elements, baselines have recently been published (guides, catalogues, etc.) for roadways that are more thoroughly integrated in the different functions of urban engineering. These methodological documents are based on the idea that no object of the urban infrastructure can be designed simply as a technical object because it must also fulfil usage functions involving many players in the urban environment.

Urban roadways and improvements in concrete: surfacing and reservoir structures

The originality of this document lies in how it combines concepts and techniques two by two, namely:

- qualitative (architecturally aesthetic) improvements
- reservoir structures
- poured and modular cement concrete techniques

Taken individually, these techniques are or are becoming well known, but an overall vision of the combinations and design patterns required in urban areas is taking form and will naturally find its place within the gamut of solutions for urban contexts.
The guide shows designers how the pairing of these processes and the techniques considered can meet all or part of the new requirements of municipalities for their surroundings and roadways:

- travel safety and comfort in all kinds of weather
- control of disturbances (river flooding, noise)
- pollution control and improved cleanliness (for example: pollution vehicled by rainwater)
- contribution to the principle of sustainable development by not jeopardizing choices with regard to the needs of future generations or the ability of proposed materials to be recycled at the end of their service life
- personalization of public spaces for easy perception of the function of the town and its image in terms of attractiveness and as a symbol of population well-being, safety and prosperity.

This guide reviews the principles and the advantages of reservoir pavements, the notions of water cycle, and hydraulic and mechanical structural design methods.
Structural data sheets of the type shown in Figure 4 provide examples of the structural design of reservoir pavements based on distributed inflows as well as localized inflows (Figure 5), for high and medium storage capacities. For all the data sheets concerning the following:

1. Non-traffic areas: terraces, swimming pool surroundings
2. Parking lots for light vehicles
3. Pedestrian ways, service roads, housing development roadways
4. Heavy traffic distribution roadways
5. Main distribution roadways
6. Roadways in industrial parks and public transportation corridors,

there is a great diversity of dense, porous, modular and continuous materials; Class 5 dense concrete, porous surfacing concrete; porous sublayer concrete, paving blocks including porous concrete paving stones, slabs, untreated porous base material.
The photos in Figures 6 to 10 give examples of reservoir structures with a porous surfacing, but there are of course, as we pointed out, reservoir structures with dense impervious surfacing through which local water penetrates.
Note also that the temporary storage of rainwater in the reservoir pavement does not obviate the need to provide for the flow of this water. Slopes are required in the subgrade as well as on the surface. Figure 5b gives an example of appropriate design features for both cross and longitudinal sections.

Long considered to be characterized by conflicting materials and designs, the urban roadway is enjoying a new harmony in which different elements share public spaces technically and aesthetically to yield pleasant, functional surroundings. Reservoir pavements in concrete contribute in varying degrees to this trend towards "qualitatively" and technically shared spaces, in a number of ways:

- their horizontal dimension with diversified surface motifs
- their vertical dimension with the composite character of certain structures
- their versatility enabling them to perform different functions at different times; for example, their porosity favors flood control when needed, while providing year-round rolling noise abatement
- their contribution to risk control and public safety
- pollution control.

A specific response to each project is called for, favoring the qualitative "personalization" of urban improvements where increasing efforts are made to ensure consistency with the existing built-up environment. This guide adds to the range of available solutions, allowing gainful use of conventional and new techniques and offering new possibilities for optimized designs.
This guide, focusing particularly on cement concrete construction and its different forms, joins a collection of general and special documents which reflect the growing interest of French communities in multifunction concrete pavements (Figure 11).

Another special-purpose pavement: concrete pavement structures in traffic circles

For reasons of safety and traffic engineering logic, traffic circles are being built increasingly in France, where there are about 20,000. Certain surface and structural pathologies have been observed at a significant number of sites, giving rise to proposals regarding the use of cement concrete around traffic circles and transition slip roads.
Traffic circle pavements are subjected to specific stresses owing to:

- The development of shearing stresses due to tangential forces generated by the rotational movements of single and dual axle loads, and even pivotal loads in the case of tridem axles. These surface forces are especially felt where radii are smaller. Access roads also give rise to braking and acceleration leading to shearing forces which are channeled in the surfacing
- The development of significant dynamic loads due to the existing profiles at intersections with access roads, and also centrifugal forces which disturb the distribution of loads between the wheels of a given axle or a group of axles. The characterization of these loads is poorly understood, but some studies conducted in France and elsewhere show that they may reach and even significantly exceed in some cases from 10 to 20% of the static load.
- Rather low speeds in relation to general traffic, extreme channeling of loads, special load transfers at joints, and the difficulty of finding design combinations and job phasing to deal with small-radius circles, departing from usual highway engineering with its straight lines and large radii, etc.
- Site execution constraints which are often difficult at points of traffic concentration often calling for works without interrupting traffic, multiple job phases, fast restoral of traffic, control of pavement interfaces, transitions, connections, etc.

The general and structural designs proposed take into account:

In urban areas, town roadways including service and distribution roads, main city thoroughfares, roads in industrial parks and public transportation corridors. Pavement service lives of about 20 years will correspond to a good trade-off between construction-generated disturbance, urban dynamics and the need to amortize infrastructures.
In urban areas there are also "strategic" roadways handling heavy traffic and expected to provide long years of service. Such is the case of main thoroughfares, heavy traffic routes and service roads, radial roads, belt roads and urban expressways. In this case, road structures must be designed for the longer term, e.g. 30 to 50 years, to allow for operational considerations, which will thus govern to a certain extent the engineering of facilities.
In rural areas, roads are also hierarchized. The different roads are classified according to cumulated commercial vehicle traffic over the theoretical life of the facility, of the order of 35 years for the backbone highway network, and 20 years for the non-backbone highway system (case of national roads in France).

Finally, between town and country, there is the ***peri-urban*** area with its sometimes mixed composition of transit, exchange and local service facilities. Traffic circles are used to a great extent at town entrances to highlight the difference between the two worlds and influence the behavior of motorists. In this case, what is recommended in France is the transition slip road, considered to be the least penalizing in terms of general and structural design.
The table in Figure 1 gives the contexts and load classes considered in the structural design of urban and inter-urban traffic circle pavements.
Figure 12 indicates, for a road with a bearing capacity rating of PF3 (> 120 MPa) and for different "urban" and "rural" loading patterns, the standard concrete pavements recommended, with reference to the design rules specified by French highway authorities for rural roads, and the practices and baselines used for urban roads. This figure shows the estimated correspondence between traffic on rural pavements evaluated in number of cumulative truck axles over the life of the pavement (Example: T C 5 $_{20}$ = Cumulative Truck Traffic of between 2.5 and 6.5 million vehicles in 20 years), and the more literal designations of urban pavement classifications (e.g. industrial park road; heavy transport route, etc).

The choice of structural architectures is based on the following considerations:
- in town, as more and more traffic circles are being used to connect light or medium traffic roads, single-layer cement concrete structures with conventional joints may be used. For heavier loads, bituminous material bases are proposed in preference to lean concrete for reasons of compatibility with the phasing of construction work under traffic, always a more acute problem in urban areas because towns continue to function while works are being carried out. For even heavier loading situations on strategic routes, the use of doweled cement concrete over a bituminous base is recommended because it is necessary to mediate between particularly difficult execution conditions, deadlines, phasing, lack of space and operational considerations while ensuring lasting mechanical performance. This of course is only one example the many potentials of concrete.
- for rural roads, it is often but not always easier to plan construction work under traffic with more reasonable completion deadlines. In this case it is possible to use the conventional range of concrete pavements for heavy and very heavy traffic, such as continuously reinforced concrete over a bituminous material and doweled cement concrete over lean concrete.

Note that continuously reinforced concrete will often be preferred because it involves fewer maintenance constraints, especially as concerns joints, a particularly delicate problem on these heavily trafficked facilities. Also, CRC bonded on to an asphalt base, or CRC with an asphalt overlay are solutions offering inter-layer phases allowing periodic restoral of traffic during works where necessary. Finally, the thick slab over an untreated porous base can be of value for medium traffic pavements outside of the backbone highway system.
Let us also point out that the setup of traffic circles involves the application of certain design rules specific to structures of this type, such as:
- Joints and their layout. A procedure for defining the joint layout plan is described, such that the critical areas of slabs are not exceeded and acute angles smaller than 80 or 85°, depending on traffic, are obtained.
- Treatment of ring delimitations: curb, extra width, and drainage. The advantages of cast-in-place extruded concrete curbs on an extra concrete ring thickness are highlighted for heavy-traffic circles, preferably with precast curbs, or natural stone curbs when the context allows.
- Treatment of slip-road lead-ins. An attempt is made to obtain a monolithic concrete lead-in between the approach zone, the transition zone and the middle of the traffic circle. The concrete approach zone must be at least 20 meters long. Joints between the approach zone and the transition zone must be doweled.

CONCLUSIONS

The range of tools available in France for the general and structural design of highway pavements and urban roadways has been considerably revised in recent years. This has been made possible by the often concerted efforts of government agencies and private highway engineering firms working as partners. These aids provide a framework for design and construction requirements, enabling designers, builders and public agencies to fill in the gaps specific to their particular applications, whether they involve conventional roadways or special facilities, urban or rural roads, or flexible or rigid materials. The aim is not to impose standard solutions for all the roads and streets in France, but rather to offer users a background against which they can compare their specific context and find responses to their particular needs. Thus, while ensuring a measure of overall consistency, these guides allow for the expression of individual needs in specific situations.
Along with tools of this kind, which are instructive and user-friendly in the treatment of very technical subjects, training programs and exchanges of experiences are readily available to engineers and public authorities throughout France. An area in which design "catalogues" have been made available and in which these efforts have borne particular fruit is that of "shared structures," a term used in France to describe innovative combinations of rigid and flexible structures, a subject also developed upon by another article proposed for the Orlando conference.

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(RGRA (engineering magazine) – Practical guide for urban roadways - 25 parts, 2000-2001)

[6] Ministère de l'Equipement, des Transports et du Logement - CERTU - Giratoires en ville - Mode d'emploi – 2000
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FIGURE 1 - NATIONAL HIGHWAY NETWORK - CATALOG OF TYPICAL NEW PAVEMENT STRUCTURES - EXAMPLES OF TYPICAL STRUCTURES IN CONCRETE FOR THE BACKBONE NETWORK.

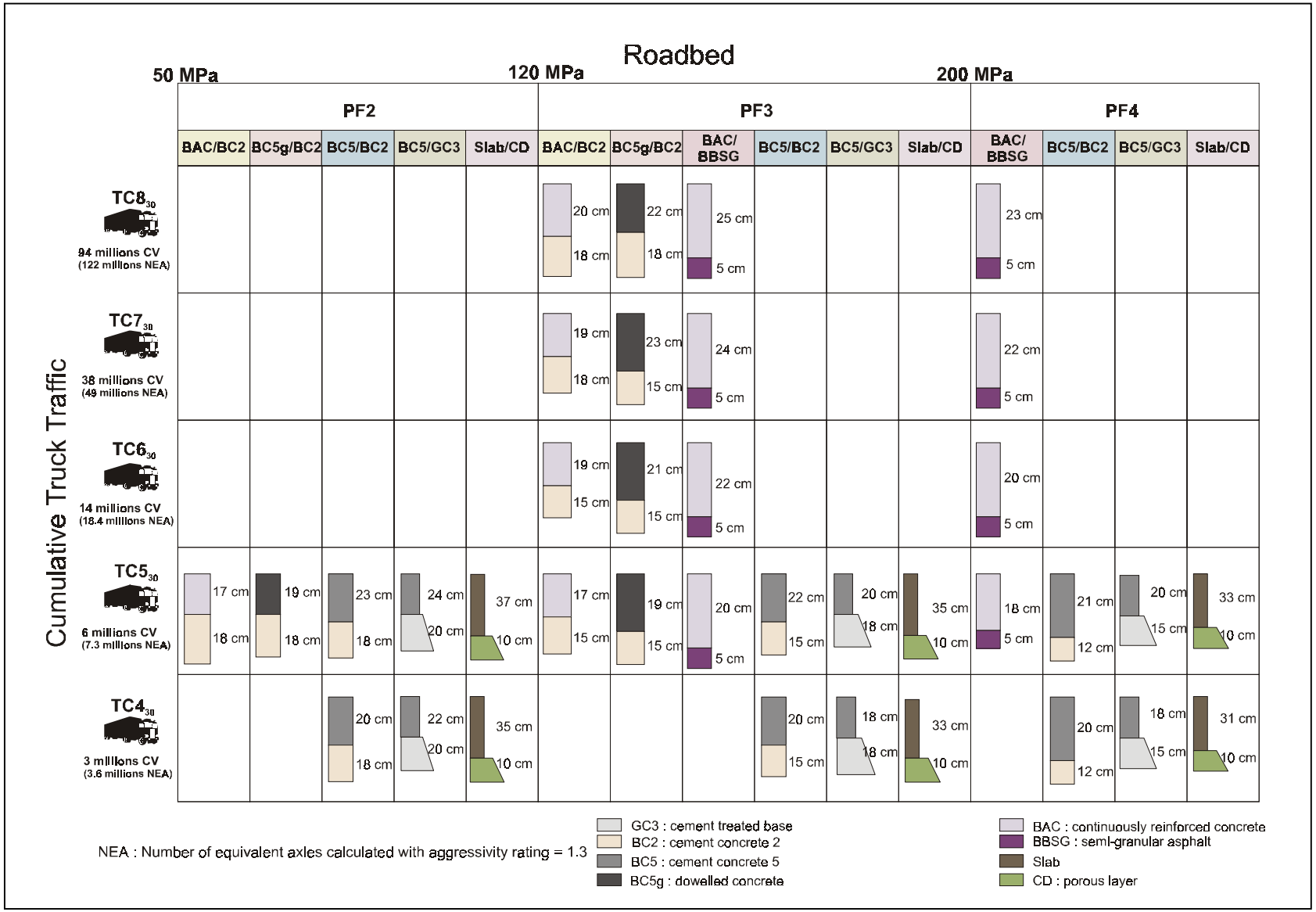
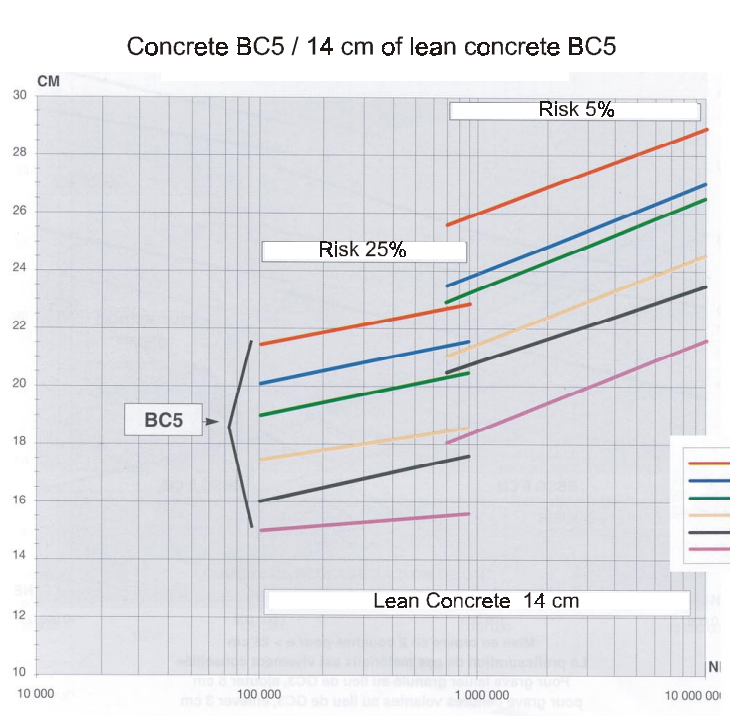
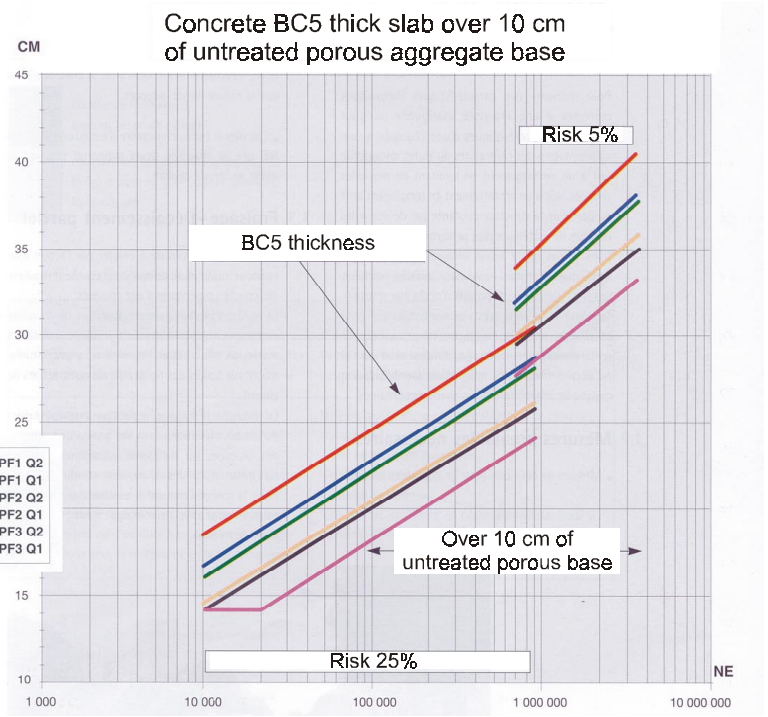


FIGURE 2 - URBAN PAVEMENTS - STRUCTURAL DESIGN CHARTS FOR DETERMINING THICKNESS OF UNDOWELLED SLABS ON LEAN CONCRETE OR UNTREATED POROUS BASE FOR DIFFERENT ROADBEDS PF1, PF2 AND PF3 AND FOR THE TWO QUALITY RATINGS Q1 AND Q2





	Quality Q1		Quality Q2	
	Modulus of elasticity	σ^6 MPa	Modulus of elasticity	σ^6 MPa
Cement concrete	35 000	2.15	31 500	1.90
Lean concrete	24 000	1.63	21 600	1.37

Note : required contract performance will be that imposed by standards, hence Quality Q1

FIGURE 3

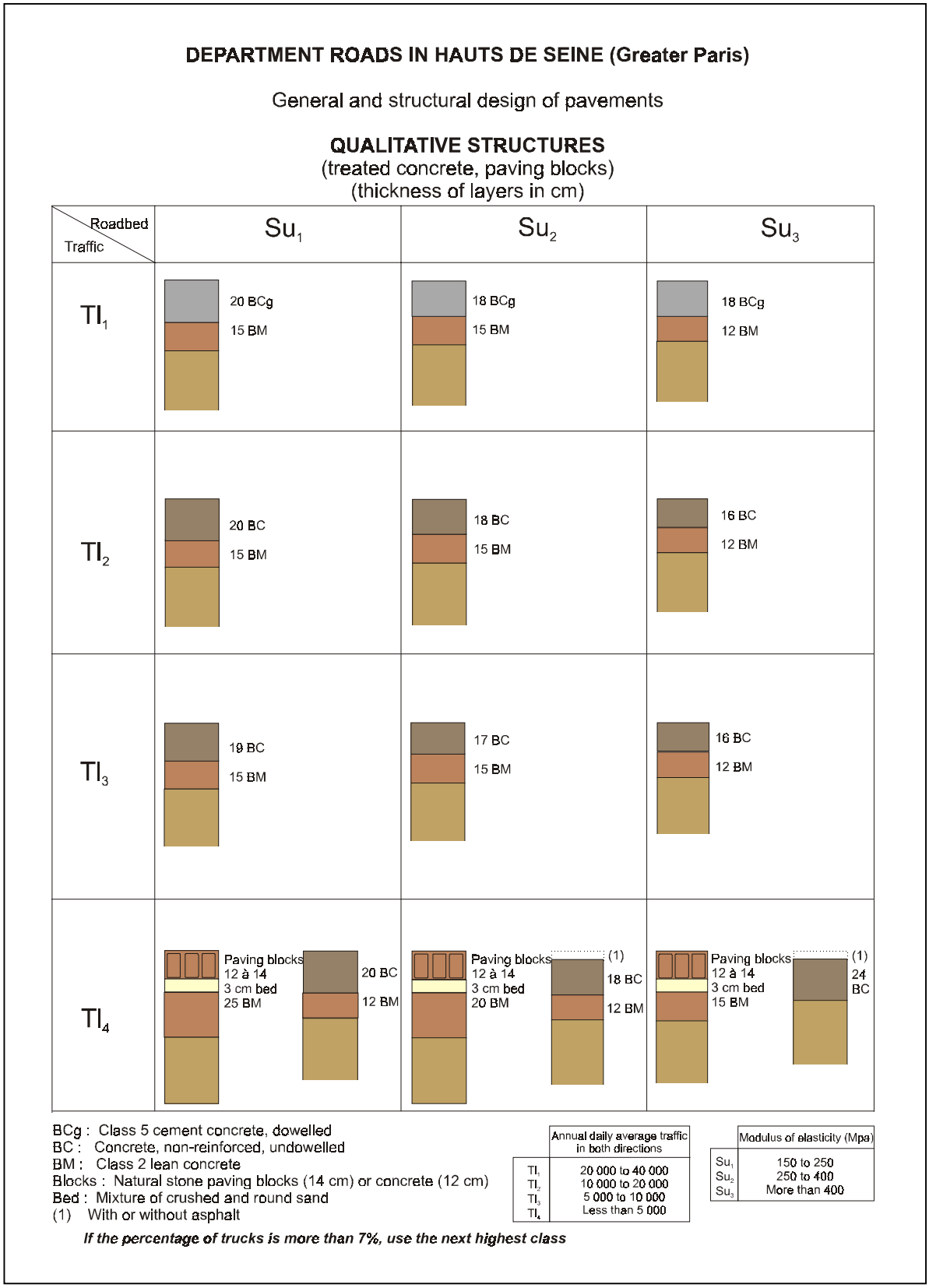

DEPARTMENT ROADS IN HAUTS DE SEINE (Greater Paris)
General and structural design of pavements
QUALITATIVE STRUCTURES
(treated concrete, paving blocks)
(thickness of layers in cm)
Roadbed
Traffic
Su1
Su2
Su3
TI1
20 BCg
15 BM
18 BCg
15 BM
18 BCg
12 BM
TI2
20 BC
15 BM
18 BC
15 BM
16 BC
12 BM
TI3
19 BC
15 BM
17 BC
15 BM
16 BC
12 BM
TI4
Paving blocks
12 à 14
3 cm bed
25 BM
20 BC
12 BM
Paving blocks
12 à 14
3 cm bed
20 BM
(1)
18 BC
12 BM
Paving blocks
12 à 14
3 cm bed
15 BM
(1)
24
BC
BCg : Class 5 cement concrete, dowelled
BC : Concrete, non-reinforced, undowelled
BM : Class 2 lean concrete
Blocks : Natural stone paving blocks (14 cm) or concrete (12 cm)
Bed : Mixture of crushed and round sand
(1) With or without asphalt
If the percentage of trucks is more than 7%, use the next highest class
Annual daily average traffic in both directions
TI1 20 000 to 40 000
TI2 10 000 to 20 000
TI3 5 000 to 10 000
TI4 Less than 5 000
Modulus of elasticity (Mpa)
Su1 150 to 250
Su2 250 to 400
Su3 More than 400

FIGURE 4 - URBAN ROADWAYS AND IMPROVEMENTS IN CONCRETE : RESERVOIR PAVEMENTS AND STRUCTURES – DESIGN EXAMPLES STRUCTURAL DESIGN OF URBAN POROUS CONCRETE PAVEMENTS

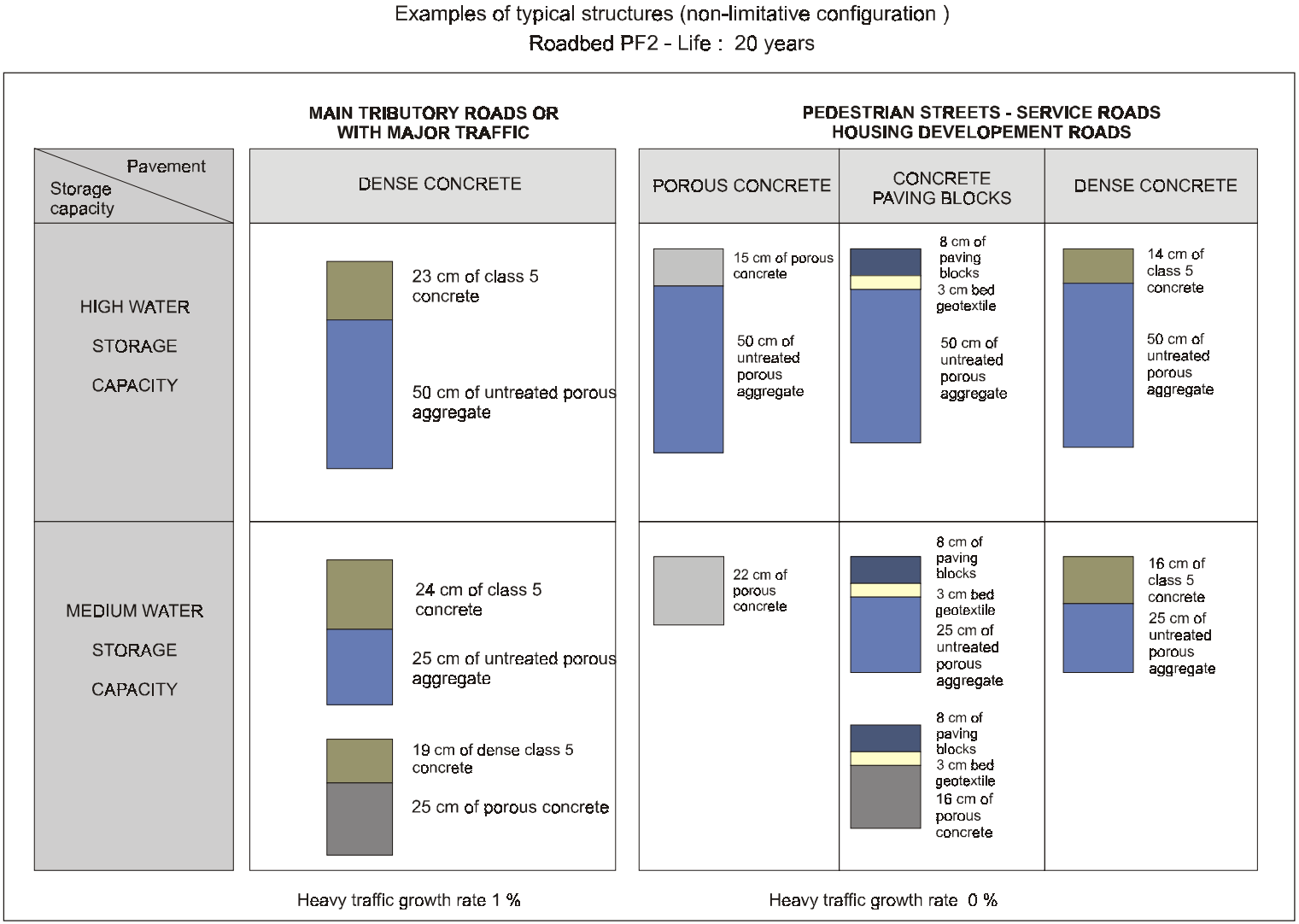
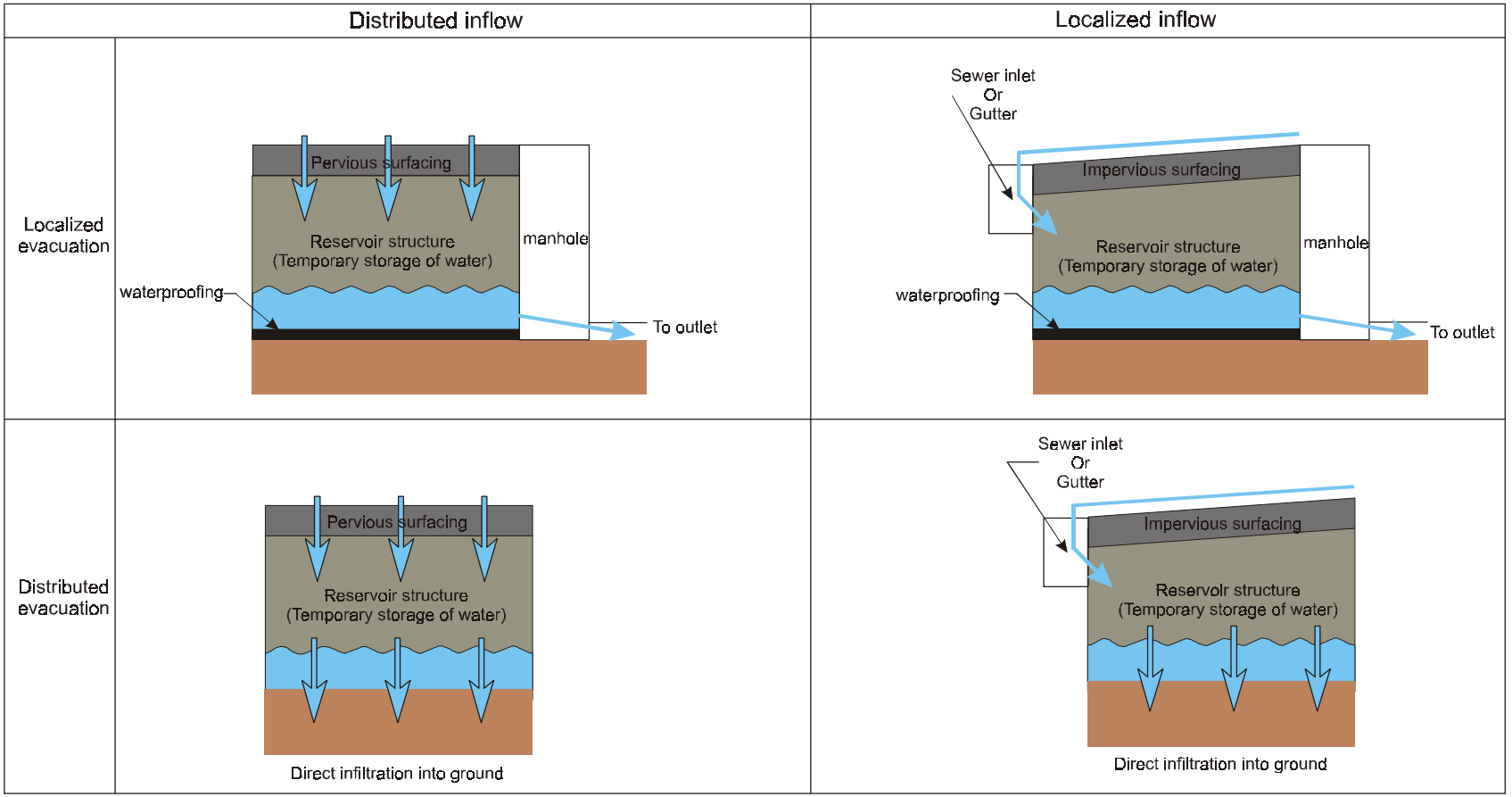


FIGURE 5 : SCHEMATIC DIAGRAM OF URBAN POROUS PAVEMENTS WITH RESERVOIR AND FILTER - POSSIBLE OPTIONS : DISTRIBUTED WATER INFLOW OR LOCALIZED INFLOW (SPILLWAYS AND DRAINS) AND DISTRIBUTED (INFILTRATED) OR LOCALIZED EVACUATION (DRAINS CONNECTED TO OUTLET).



FIGURES 6 to 10



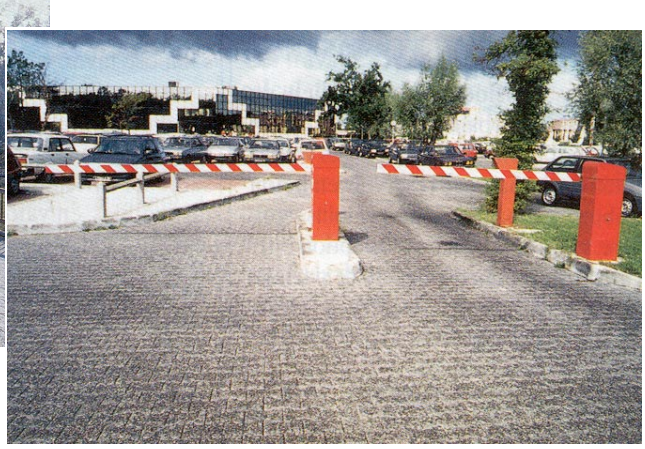








FIGURE 11 : EXAMPLES OF DESIGN GUIDES FOR MULTIFUNCTION URBAN PAVEMENTS.

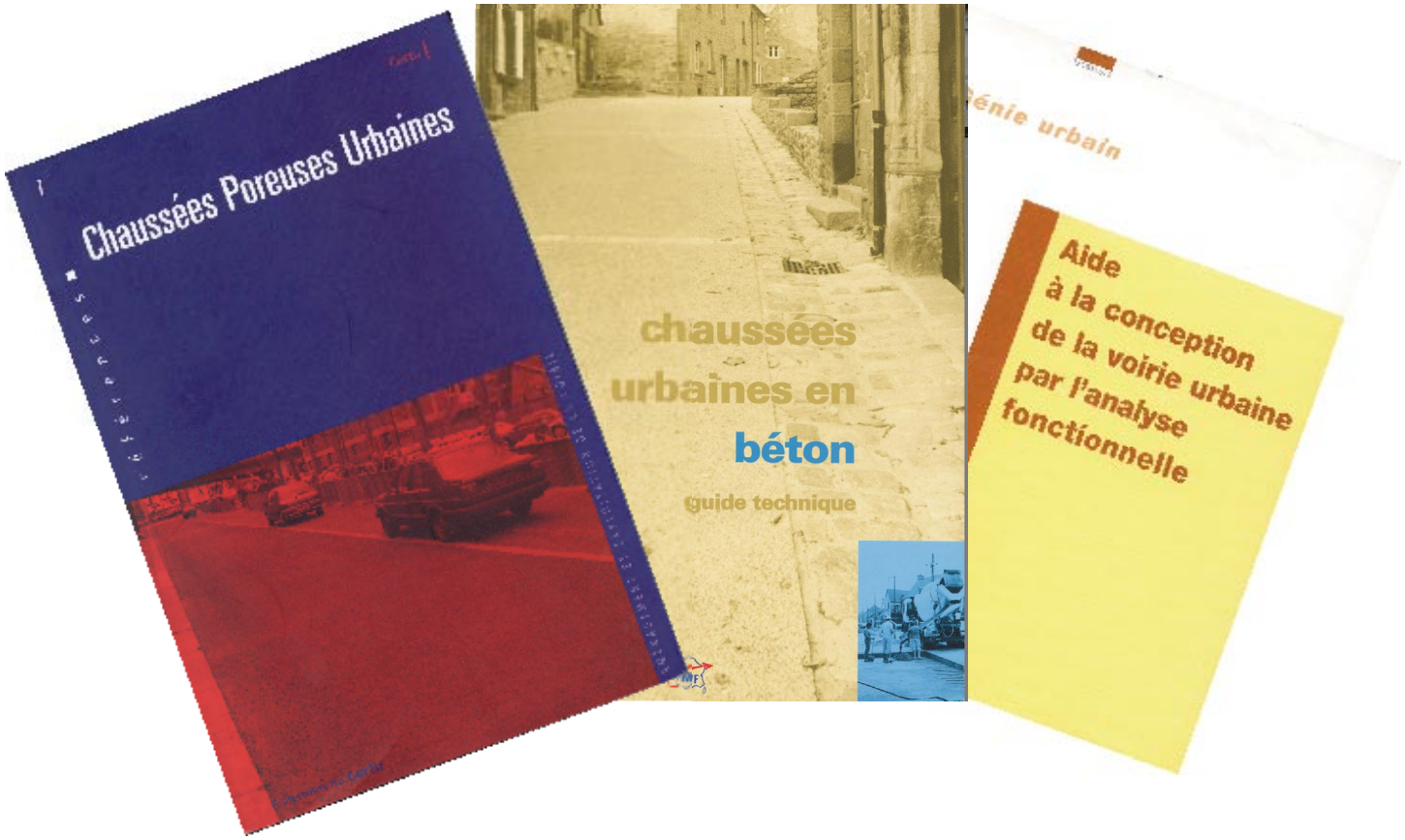


FIGURE 12 : CONCRETE TRAFFIC CIRCLE PAVEMENT STRUCTURES (Roadbed PF2)

