REMOVABLE URBAN PAVEMENTS: A NEW NEIGHBOUR-FRIENDLY TECHNOLOGY

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ABSTRACT

A Removable Urban Pavement (RUP) is a pavement that can be open and closed rapidly, with light facility, for an easy access to underground networks. It has the same difference with a conventional road as a window compared to a solid wall. No such a pavement seems to have ever been constructed, although the premises of the concept can be found in some military paths or industrial soils. A survey towards French city authorities shown the potential interest of the RUP concept in decreasing the public annoyance caused by pavement and network maintenance works.
Two cities, St Aubin-lès-Elbeuf (near Rouen, Seine-Maritime) and Nantes (Loire-Atlantique) accepted to host an experience of RUP, by providing a series of specifications applying to streets to be built in new residential areas. Then, original pavement designs were proposed, based upon precast, hexagonal concrete slabs over an hydraulic base course that could be easily excavated. Such a structure was successfully evaluated by mean of accelerated load testing using the LCPC facility. Two experimental sites will be then carried out in the coming months, the aim of which is to demonstrate the feasibility and interest of this innovative technology.

1. INTRODUCTION

Urban pavements have many functions, and cover many different types of utility networks (potable and storm water, power electricity, telecommunications…). As a perfect coordination between all operators is very difficult to achieve, these pavements are subject of frequent works, sometimes soon after construction or maintenance. These works are quite bothering for the human environment, causing noise, air pollution and traffic jams. Also, they have a detrimental effect on the architectural aspect of the streets. This is why the Ponts et Chaussées laboratories decided to carry out a R & D program aiming to develop a new technology: the removable urban pavement (RUP, see the Internet site quoted in the References section). Here, the idea is to design a pavement that can be open and closed within some hours, with a very light site equipment, restoring the initial aspect of the street and all its functional abilities.

After a quick look on previous works, the paper present the results of a survey directed towards urban roads authorities. Then, two RUP projects are presented, to be built in two French cities. The next development phases are presented in the conclusion.

2. BIBLIOGRAPHICAL SEARCH

An extensive bibliographical search was carried out at the beginning of the operation (Duffait et al. 2003). A number of classical or innovative techniques were found in the literature, as e.g.

- paving blocks pavements, some of which are to some extent removable. However, the time necessary to open and to close such streets does not fit with the goal of the RUP project;

- pavement based upon the use of large precast elements. But these elements are generally fastened together and/or stuck to their base course. Therefore, the removing operation remains destructive. One existing technique of RUP was found in this category, but in the context of industrial soils, only the surface layer being removable;

- steel plates are often used to allow traffic when works are in progress in a street. But this is always a tentative solution, dealing with no more than some square meters;

- military paths made up with light metallic elements, which can be rapidly applied to permit the passage of trucks and military vehicles on very soft soils. These pavements are really removable, but the transfer to the urban environment is not straightforward, since these pavements do not conform to most urban pavement specifications (as evenness, skid resistance, aspect and durability). Also, they are probably unaffordable in a civil context.

As a conclusion of this bibliographical study, it seems that no operational RUP technology can be found anywhere, as a concept of pavement designed to be readily open and closed in a non-destructive way, suitable to the context of streets in modern cities.

3. PRELIMINARY SURVEY AND POTENTIAL MARKET

At the preparation phase of the project, a number of city authorities were met. The aim of these meetings was to identify the potential advantages of the RUP technology, according to the average customer opinion. These advantages are listed hereafter, starting from the most to the least significant:

1. reduction of user and neighbour annoyance caused by maintenance work operations;
2. easy access to underground networks;
3. sustainable management of the pavement (possibility to repair or to change the functions of the pavement, with an easy recycling of the modular elements);
4. possibility to build ‘reservoir-type’ pavements that can be easily maintained;
5. possibility to incorporate networks and instrumentation in the removable pavement itself;
6. possibility to build permeable, noise-absorbing pavement with easy maintenance (in a factory);
7. easy management of horizontal marking.

The three first items led the authors to go ahead in the project and to think about practical applications. In the context of contemporary urban developments, four potential markets were identified through this survey:

1. downtown streets. These streets are generally characterized by a small lorry traffic, a low speed of vehicles, a complicate geometry, a high density of population and existing buildings around;
2. boulevards and urban highways. In this case, the shape of the pavement on a plan is straighter, and the traffic is more aggressive (higher speed and more lorries);
3. new residential areas. Here, new streets are to be built, so that the shape can be designed according to the pavement technology. The traffic is low, as for item #1;
4. tramway lanes (railway path transit tracks). This way of transportation is increasingly popular in French cities. As traffic disruption should be avoided as much as possible for public transportations, having a removable pavement would be of great interest. Also, to have a removable tramway path would lead the city authorities to let existing network in place, while nowadays all utility networks are moved prior any tramway line construction, which leads to tremendous and costly works. However, the design of a durable tramway pavement is still an open question, and the addition of a removability function increases again the difficulty of the problem.

The authors are aware that there are even more elegant solutions for an easy access to utility networks, namely multipurpose utility tunnels. However, these solutions are only affordable for important projects where many networks have to be built at the same time.

Based upon these general ideas, partners were searched among city authorities, wishing to build a RUP experimental section. To date, two cities accepted to join the project, and proposed streets in new residential areas, as the least difficult case among the four possible ones listed before.

4. THE ST AUBIN PROJECT

Saint Aubin-lès-Elbeuf is a city of about 8,500 inhabitants, located near Rouen, department of Seine-Maritime, France. Saint Aubin has a long tradition of innovation in civil engineering, and was the first city to decide to build a RUP in the framework of the present project. The reasons why St Aubin authorities decided to join the project were the following:
- need to push innovation in urban works;
- necessity to decrease the social pressure induced by civil engineering works in the urban context;
- sustainability of the RUP concept, which favours recycling of materials.
Also St Aubin was interested in building a PPP (Public-Private Partnership) around the construction of a RUP, since many stakeholders could benefit from such a technology (utility companies, cement industry etc.).

The opportunity was brought by the reconstruction of the Manopa area – an industrial area rehabilitated as a residential one.

4.1 Specifications

Table 1 - Specifications for the St Aubin RUP

Series of specifications	*Question*	*Answer*
General project	Dimensions of the street	Straight, 90x7m
	Joints	Possible
	Color, aspect	Surface material should be versatile (adaptation to the urban environment)
Basic pavement specifications	Subbase	PF2 according to French pavement design method (E-modulus = 120 MPa)
	Traffic (site phase)	50 heavy lorries/day, total 20,000
	Traffic (service phase)	10 heavy lorries/day, total 100,000
	Structural life-span, failure probability	30 years, 5 %
	Part of the pavement to be removable	All the street, without sidewalks
	Maximum dimensions of modular elements	2 m
	Maximum load at removal	1000 kg (unit weight of elements ≤ 800 kg)
	Minimum weight of the modular elements	100 kg
	Fastening technique during removing	Vacuum technique

Removability	Duration of the opening/closing process	Opening : 30 min Closing (base and top layers) : 4 hours.
	Type of material for base course repair	Self-compacting cementitious material (controlled low-strength material)
	Trench width	0.40 - 2 m
	Networks minimum depth	0.60 m
	Networks maximum depth	1.50 m

The street to be built is 90-m long. After discussions between the road authorities and the various utility operators, a set of specifications was written, according to Table 1.

4.2 Design

Due to the dimensions of the modular elements chosen, the option of precast concrete slabs was quickly taken. As for the shape of the slabs, it is well known that hexagons are better than rectangles, since the risk of angle failure is greatly reduced. This is why this shape is adopted. The slabs have to be mechanically independent in order to be easily lifted during maintenance operations. Therefore, only a soft polymeric water-proof joint, easy to remove manually, is cast in the joints. As in some traditional modular pavements, the slabs are put over a granular bed, for an easy positioning of the elements.

The base course has a structural function, but the wish of network operators was to have an easy-to-dig material. Then, a new material, called Structural Excavatable Cement Treated Material (SECTM) is needed. Three-dimensional finite element computations were carried out in order to evaluate the stresses induced by the traffic in the slabs and the base course. Allowable stresses were determined using the classical pavement design fatigue approach, and finally to determine the minimal thickness of the slabs and base course. As for the plain concrete slabs, a superior level of safety was searched, in order to avoid the risk of break under traffic and during removing/replacing operations. This led to a thickness of 20 cm, except around the edges where an over thickness of 1 cm was taken to ensure the contact between the slab and the granular bed. The computations lead to a total thickness of 60 cm for the base course consisting in two layers of 30 cm of structural cement-treated material (see next section). However, this thickness results from the standard application of the French design method, which is validated for stronger material. Itis likely that such a thickness of 60 cm is over conservative. In the future, supplementary investigations will be carried out, in order to reduce the thickness of the base course. The structure layout of the St Aubin project appears in Fig. 1 and 2.

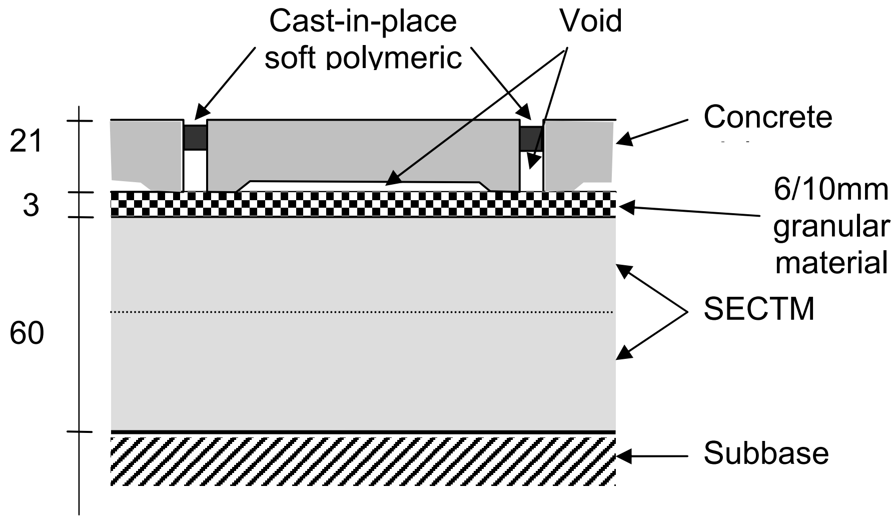

Figure 1 -The St Aubin RUP technology. Dimensions are given in cm.

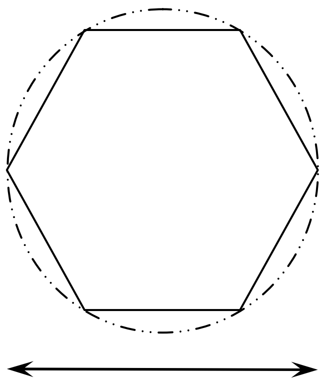

Figure 2 - Dimensions of the precast slabs

4.3 Development of a structural excavatable cement-treated material (SECTM)

The most innovative aspect of the St Aubin RUP probably lies in the nature of the base material. Here, what is needed is a structural material – characterized by a tensile strength, E-modulus etc. – which can be easily excavated with a light facility. In France, there is an experience with self-compacting materials used to fill trenches, summarized in a guide [Bonnet et al. 1998]. The critical property of these materials is the compressive strength, which must be lower than 2 MPa. However, in the RUP case, the self-compactability is not necessary, and the use of such a material for the total volume of a base course is not economically sustainable. Therefore, a new material had to be imagined.

The logics was then to chose a compacted cement-treated material, as the type of granular material which makes the best use of cement [de Larrard 1999]. A rather quick strength development was desirable, to allow a rapid opening to traffic and to avoid long term strength gain which would overcome later excavation works. Therefore, it was chosen to design the mixture by using a blend of Portland cement and limestone filler, excluding pozzolans, fly ash and all type of slow-hardening binders.

Mixtures were optimized using the LCPC approach [de Larrard 99], the only variable parameter being the proportion of cement in the binder. Three recipes were obtained, the characteristics of which appear in Table 2. Trial slabs with a thickness of 40 cm were layed down and compacted at LCPC Nantes, and were subject to excavation tests at 7, 28 and 230 days (see Fig. 3). The CTM2 recipe was then selected, as a material offering an acceptable compromise between strength and ability to be excavated.

Table 2 - Mix-design and properties of the three SECTMs

Recipe	CTM1	CTM2	CTM3
Cement dosage (mass %)	0.5	1.1	1.7
Specific gravity (dry)	2.24	2.35	2.23
Compressive strength at 28 days (MPa)	1.0	2.2	3.4
Splitting tensile strength at 28 days(MPa)	0.07	0.18	0.31
E-modulus at 28 days (MPa)	1 600	4 800	7 800
Number of shovel strokes to excavate 40 cm (at 28 d.)	3	23	> 40

Based upon the results of the study, the specifications for the St Aubin SECTM were the following: a compressive strength at 28 days lower than 2.5 MPa, a tensile splitting strength at 28 days higher than 0.16 MPa.

Figure 3 – Excavation of SECTM base course.

4.4 Trial of the RUP structure with the LCPC accelerated load testing facility

From Table 1, it is realized that the RUP structure should be capable of resisting to 120 000 typical lorry passages. Given the innovative aspects of this structure, it was decided to validate its concept and verify the thickness design by mean of the LCPC accelerated load testing facility in Nantes. Therefore an experimental RUP pavement comprising 19 slabs and 4 halves of slabs was built and tested by the LCPC carrousel, The fatigue test was performed using the French standard load configuration (twined wheel loaded at 32.5 kN/wheel), and the linear speed of 40 km/h.The test set-up appears on Figure 4. The slabs were put over a 3-cm thick granular bed, over a base course of 38 cm. A material close to the CTM3 given in Table 2 was applied. Later it was realized that this material was too strong to be easily excavated.

Several series of tests were necessary:
- to find a suitable method to place the slabs;
- to select a suitable material for the granular bed. The first tests were carried out with a 2-4 mm crushed material. However, the internal friction of this material appeared to be too sensitive to water: when water was sprayed over the pavement, the slabs quickly displayed a significant faulting. Finally, better results were obtained with a 6-10 mm material, which also ensured a better drainage;
- to select a suitable solution for the joints between slabs. The first joints tested were rubber prefabricated joints which had the tendency to be extracted when the model was submitted to the fatigue test. Such a phenomenon did not happen with a cast-in-place polymeric joint.

Figure 4 - View of the trial set-up

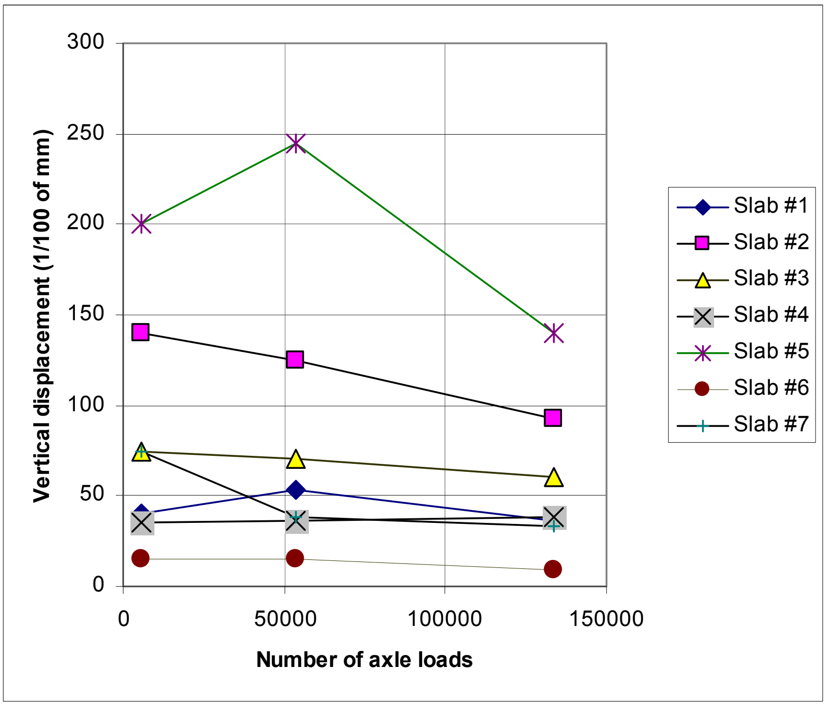

Figure 5 - Vertical displacement of the central slabs vs. number of fatigue loadings.

After these preliminary tests, the structure given in Figure 1 was tested, with a SECTM stronger than required (according to later tests). No failure nor other damage was obtained for any slab, nor for the base course. The surface layer was subject to a general settlement of 5-8 mm. The vertical displacements caused by the passage of the 65 kN standard load were measured before the test, after 50,000 cycles and at the end of the test; these measurements appear in Fig. 5. It can be noted that the structure is quite stable; moreover the loading cycles tend to decrease the level of vertical displacement.

After the full series of cycles, all displacements are lower than 1.5 mm (under the twin-wheel 65 kN load), which seems to be an acceptable value, especially in the context of a residential area where the speed of vehicles will be moderate. It is noteworthy that little noise was produced by the faulting motion of the slabs. The polymeric joints probably dissipate a part of the energy.

Another loading program was applied to the structure with a new SECTM complying with the specifications previously given. The behavior was the same, with a limited faulting of slabs. Furthermore, after completion of the 120,000 cycles, the slabs were removed and the base course was observed. No cracking nor any other type of damage was found. It is finally considered that the RUP structure is validated through this scale-1 study.

Based upon these successful tests, a call for tender was launched for the construction of a RUP in St Aubin. The SCREG company was selected, and studies were launched for the production of slabs in a prefabrication plant and for the production of SECTM in a central plant. The construction of the RUP is planned for april-may, 2006.

Table 3 - Specifications for the Nantes RUP.

Series of specifications	*Question*	*Answer*
General project Basic pavement specifications	Dimensions of the street	Straight, 86x7m + place 20x13m
	Joints	Possible
	Color, aspect	Top material should be versatile (adaptation to the urban environment)
	Subbase	PF2 according to French pavement design method (E-modulus = 50 MPa)
	Traffic (site phase)	10 heavy lorries/day
	Traffic (service phase)	1 heavy lorry/day
	Structural life-span, failure probability	30 years, 5-10 %
Removability	Part of the pavement to be removable	All the street, without sidewalks
	Maximum dimensions of modular elements	$0.5\ m^2$
	Maximum weight of modular elements	200 kg
	Minimum weight of the modular elements	100 kg
	Fastening technique during removing	Vacuum technique
	Duration of the opening/closing process	Half a day (plus network maintenance)
	Type of material for base course repair	Self-compacting cementitious material (controlled low-strength material)
	Networks minimum depth	0.70 m
	Networks maximum depth	2 m

5. THE NANTES PROJECT

5.1 Specifications

In Nantes, another new street in a residential area was proposed by the city authorities to experiment the concept of RUP. Here, the expected traffic is even lower than in St Aubin (about 10,000 passages of heavy lorry within the life of the pavement). The main difference in the specifications (see Table 3), as compared to those of the St Aubin project, lies in the difference in the slab dimensions. With smaller slabs, the effect of stress diffusion from the truck wheels to the base course is minimized. Therefore, the designers considered that the option of totally independent slabs was no longer valid for this project.

5.2 Envisaged solutions

Two solutions were studied. In the first one, 'semi-independent' slabs were chosen, which means that they were placed on recycled wood beams, the function of which was to avoid occurrence of joint faulting steps due to a settlement of the granular bed (see Fig. 6). This structure was tested at CER (Centre d'Expérimentation Routière, Rouen). It was found easy to construct and to remove. Under the passage of light vehicle, the behavior was satisfactory. However, under heavy lorries, slabs tend to fault by several centimeters. The problem could have been solved by changing the material put between concrete and wood (here, a geotextile). But time was lacking to optimize the system, and the second system was selected.

Figure 6 - The Rouen solution: wood beams covered with a geotextile sheet on which concrete slabs are positioned. The beams can be applied manually owing to their light weight.

This second one consists in connecting the slabs with each other, using concrete keys (see Fig. 7). The structure was designed at LCPC, and a thickness of 16 cm was first proposed for the slabs. A model comprising 31 slabs was built and tested by the Autun Regional Laboratory (LRA). It was then submitted to 1,290 passes of a deflectometer truck (French standard device for deflection measurement with a 130 kN single rear axle), which reproduces the effect of a heavy lorry.

Figure 7 - The Autun solution (slabs with connection keys)

The test led to a number of distresses: three connection keys failed under shear forces, and one slab angle was crushed. Based on these results, the structure was re-designed, using 3D-finite element modelling, and the slab thickness was increased up to 19 cm; steel fibres are also to be incorporated in the concrete to decrease the fracture likelihood, and to facilitate the removing process, in case where cracking would appear.

Finally, the city of Nantes decided to build a new model of 12 x 7 m, corresponding to approximately 155 slabs. This construction should take place during summer 2007. The behavior of this test section will be followed, in order to assess the soundness of this structure.

6. CONCLUSION

The concept of removable urban pavement seems to have a great future, owing to the interest of owners. Two experimental sites are scheduled in the coming weeks, based upon techniques of large precast concrete slabs. For the first one (St Aubin), the slabs are independent, which makes easy the removing and repair of the pavement. The design traffic is about 120 000 heavy lorries over the 30 years service life of the pavment. However, this structure would not be proposed for a higher traffic, especially if many heavy lorries are expected. In the second technique (currently used in Nantes), the removing process is more complicated. However, the stability under higher traffic should be better assured.

A monitoring of these innovative structures will be carried out by the project partners, and the opening/closing process will be tested in real conditions. Also, attention will be paid on the reduction of public annoyance permitted by this new technology, as compared to ordinary, non-removable urban pavement. This R & D operation, led by LCPC, should end next year by the writing of a technical guide, for the dissemination of this innovative technique.

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