Methods to assist the design of road surfaces with a reservoir structure :
To improve flood risk management

Fouad Loughreit
Laboratoire Méthodes - INSA de Lyon,
20, av. A. Einstein - Bâtiment 304,
69621 Villeurbanne CEDEX, France
E-mail : loughreit@urgc-hu.insa-lyon.fr

Reservoir road surfaces can be seen as equipment of the future, in that they have two functions in the same structure (circulation and hydraulic functions). They can thus be laid without immobilising land, which is very expensive and prized in urban areas. Furthermore, they enable the limitation of the flow or volumes of running water, and thus help control rainwater, resulting in better flood risk management.

The questions asked by drainage designers are : how can we design these structures in the best way? How are they going to work for different types of rain (rain from storms, prolonged winter rain....)? As for the public administrators, they wonder how a series of areas equipped with this type of technique (total flow management) would work. By solving this latter problem, we could really arouse interest in flood risk management.

Given the diversity of structures possible for reservoir road surfaces (regulated, non-regulated, draining surface, dispersion surface...), we suggest comparing design and simulation methods, taking into account the measurement and total flow management problems mentioned above.

So as to validate these comparisons and to give some directions concerning the use of one or the other methods, we use flow-metre measures on two different sites in Lyons. One of these sites is a car- park on a tertiary activity zone on the La Doua campus in Villeurbanne, the other a refuse dump in the Greater Lyons area in the town of Craponne. They are both interesting as they have different features. The first is non-regulated downstream and is used on a car-park for light motor-vehicles. The other is regulated and the traffic on it is made up of lorries. These sites will be described in this article.

INTRODUCTION

Porous pavements are useful equipment in that they have some functions in the same structure. They allow us to limit the flow or volumes of run-off water and can thus give better risk-management for flooding and pollution. Despite the usefulness of these techniques for urban storm drainage, few methods and even less softwares have been developed for hydraulic design and/or simulation for these constructions. A look at the current state of events shows the need to have quick and simple models at one's disposal for which results are easily interpretable.

In this article, we will present the results of a modelisation test on the functioning of these structures.

1. THE EXISTING APPROACHES

1.1. The very simplified approach

This approach consists of assimilating a porous structure to a retention basin and applying very simple methods (rainfall or volume methods) with steady out flow. They only allow us to solve the design problem, but not the functioning problem, nor the problem of their impact on the catchment. They do not take the flowing into account, nor the absorption of the flow into the road surface, nor the absorption of water flowing on run-off surfaces.

1.2. The mechanistic approach

This approach uses the classic equations to be found in fluid mechanics. The models, which come from them, generally try to represent the internal functioning of the structure but they are more difficult to use for the impact of this type of construction on a catchment, as the constructions are numerous and linked : piping network, overflow devices, retention basins, ...etc.

In France two simplified models of this approach can be found in two types of software. There is the one-dimensional model PORE (Raimbault, 91) and a two-dimensional one, CHAPOR (Dardab, 91). These two models use simple basic structure geometry. It allows us to calculate the change in the water-level in the structure and the exit-flow.

1.3. The conceptual approach

The main feature of the conceptual models is that they try to represent an overall view of some aspects of the behaviour of the system studied, without claiming to represent the "real" way in which the system itself functions, nor even trying to describe it accurately. They are often used in urban hydrology because of the low number of parameters. Amongst them, we can mention the reservoir models. These are the ones we used to modelise porous pavements as they allow design and simulation. Moreover they are user-friendly, do not require too many data and are often more solid than models in the previous category.

2. DEFINITION AND ADAPTING A CONCEPTUAL MODEL

Once we have reminded the reader of the basic equations for such a model, we will present the adaptation procedure in both cases.

The first case concerns pavements which are regulated downstream. In this hypothesis we only check that the functioning of the structure can be correctly represented by a reservoir model, in which the drainage law is given by a simple hydraulic relationship. The second case involves structures which are not regulated downstream, for which flow absorption is done by storing water in porous materials. In this case one must find adequate outflow relations laws.

2.1. Basic equations for the model

The model is based on the ability to solve 3 basic equations :

- an equation for volume conservation : $dV(t)/dt = Qe(t)-Qs(t)$
- an equation for storage (variation of the volume stored according to the water-level) : $V(t)=f(H(t))$ hypothesising a horizontal water-level
- outflow relations (variation of exit-flow according to the water-level) : $Qs(t)=g(h(t))$

in which V(t) is the volume stored at time (t) , Qe(t) the entry-flow, Qs(t) the exit flow, H(t) the water-level in the construction.

3. THE CASE OF POROUS PAVEMENT WHICH IS REGULATED DOWNSTREAM

In the model suggested, we used a drainage law of the type $Q(t)=Cm.H(t)^{\alpha}$ which we tried to adapt using an experimental site in Craponne, in the suburbs of Lyon, France. We have obviously firstly chosen $\alpha = 1/2$ because of the regulation device used (opening). To adapt Cm, we have optimised the peak shape and flow on the hydrograms compared to the measured hydrograms. We then tested a simple drainage law for the structure exit :

$$Q(t)=m.S.(2.g.H(t))1/2=Ct.H(t)1/2$$

where S is the cross-section of the opening, g the acceleration of gravity and m the contraction coefficient.

m was estimated in the laboratory on the regulation device placed at the structure exit

.

On the seven rainfalls tested, the results were satisfactory. The order of size of the design parameters (volume stored and maximum flow away) is generally speaking well respected, especially the flow, and the shape of the hydrogram is well reproduced. As for the time difference between each peak, the synchronisation is near-perfect).

Moreover we can see that for regulation as is such on experimental constructions, we can approximate Cm with Ct, the coefficient used in classic hydraulic laws.

3.1. Conclusion

If we make do with the small sample which provided these results, the drainage of a porous pavement regulated downstream could be assimilated to any other detention structure and the drainage laws are easily approximated with hydraulic laws which generally govern flowing through regulated areas. The time difference linked to the flowing in the porous media for small structures seems very small.

4. THE CASE OF POROUS PAVEMENT WHICH IS NOT-REGULATED DOWNSTREAM

Hydrological procedures are non-linear, but many hydrologists feel it is useless to insist on the subtleties for taking this non-linearity into account. Indeed the difficulty to implement a non-linear model has no connection with the degree of accuracy sought in urban hydrology. The problem of measurement accuracy (rain-flow) is undoubtedly more important than the effects linked to the non-linearity of the procedure studied.

4.1. Examining a linear model

We adopted the simplest model possible, supposing a drainage law :
$Qs(t)=C.H(t)$ which can also be written $Qs(t)=K.V(t)$.
The parameters C or K in the model depend on the features of the structure studied and those of the rainfall.

4.2. Adapting parameter K

We firstly studied the link $V=f(Qs)$ for three measurement sites. The linear link $V = K.Qs$ is generally not reached. The relationship $V=f(Qs)$ generally presents a hysteresis which is ignored by approximating it with a straight line supposing K constant.

The parameter K observed varies quite widely for the same construction. This variation shows the non-linearity of the phenomena. The improvement of the approximation $V=F(Qs)$ greatly depends on the shape of the rain, and it hardly has any influence on rain with a flat shape. We can also notice however a considerable change in the parameter K for rain with a marked shape. It therefore seems impossible to use an independent K coefficient for rain.

4.3. Copy of hydrograms observed with the help of the model

We firstly tried to show 25 hydrograms observed on the three different sites. We noticed that the general shape of the hydrograms was well respected, and the peak flows were generally correctly estimated. Moreover we saw that nearly all the peak flows calculated took place before the peak flows observed.

If we look at the readings normally taken at the design stage, the results are generally satisfying : indeed for the two sites of Villeurbanne and Bordeaux for which the inflow and outflow seem controlled, almost 90% of peak flows are calculated with a relative error under 15%. These results are not as good for the volumes stored in which only 75% have under 15% error. Concerning the synchronism of the hydrograms calculated and observed, as we have seen, the results are very variable, and it seems difficult to link them with the features of rain or at least the basic readings such as maximum intensity and total water-level.

Finally, for further information, the reader should look at Loughreit 96 in which this study is dealt with in great detail.

4.5. Conclusion

We think that the objective we were aiming at in this study has been reached, by showing that it is possible to adapt the linear model to a porous pavement, by producing satisfactory hydrograms, especially when near their maximum. Obviously a generalisation of the method remains to be done to be able to forecast hydrogram calculation from the features of structures and of the rainfall. This could only be realised through better knowledge of the physical phenomena which are really to be seen inside porous structures.

5. OVERAL CONCLUSION

As far as porous pavements regulated downstream are concerned, it is necessary to confirm the results obtained by trying other sites.

As for non-regulated surfaces, it is necessary, in order to make the model more user-friendly, to give a formulation of the coefficient K according to the data on the rainfall and the site. We are currently testing a correlation study between the site and rain parameters and the coefficient K in the model, using measurements available, to see if on this sample it is already possible to obtain permanent reliable statistics.
To adapt K, we are also trying to use general calculating codes from fluid mechanics in three dimensions. If these models turn out to be efficient, we could carry out statistical adaptations using numerical samples. The calculating codes cannot be used by the designers as they are too complicated (many data, difficult grid, too costly, etc.)

6. REFERENCES

(Dardab, 91) : Dardab C. ; "Hydraulic Design of Porous Pavements Using Finite Elements", (in French) ; Thesis, Bordeaux I University France ; 175 p. : 1991
(Encyclopédie, 96) : Chocat et al. ; "Urban Storm Drainage Encyclopedia" ; Eurudice 92, yet to come out ; Tec et Doc Lavoisier.
(Loughreit, 96) : Loughreit F. ; "Models For Helping in Design and Simulation of Porous Pavements", (in French) ; Thesis, INSA de Lyon France; yet to come out.
(Raimbault, 91) : Raimbault G., "Reservoirs Structures : Methods for Hydraulic Design" ; Document LCPC Centre de Nantes France; 18 p. ; 1991.