Prof. Eng Francesca La Torre
University of Florence, Civil Engineering Department, Italy

Design and construction of concrete pavements for low volume roads

Abstract

Design and construction of low volume roads is often considered a minor issue even though the majority of the road network usually falls under this category (as in the Italian road network where 80% of the roads are "low volume" roads). On the other hand the very limited amount of resources devoted to these pavements both for maintenance and for monitoring is leading to very poor performances which contribute to the very high number of accidents which can be observed in urban areas.

Concrete pavements are often considered a valuable alternative to asphalt pavements only for heavily trafficked roads even though it is well know that concrete pavements con offer adequate structural capacity with limited maintenance. The key disadvantages of this technique are usually identified in a more complex design and construction. The selection of the proper design tools and construction techniques can nowadays fully overcome this problem and allow for a wide spread use of concrete pavements in low volume roads.

This paper will provide a description of the possible design tools that can be used for this type of pavements and the key issues that have to be considered for building a concrete pavement for low volume roads with a good performance in time.

Introduction

The growing attention to road safety world wide has enabled to highlight that the major problems arise in urban areas and in the secondary rural road network. The Italian accident statistics for the year 2003 [1] show (Figure 1) that 75% of the accidents occur on urban roads while only 16% of the accident involve the primary network (primary roads and motorways).

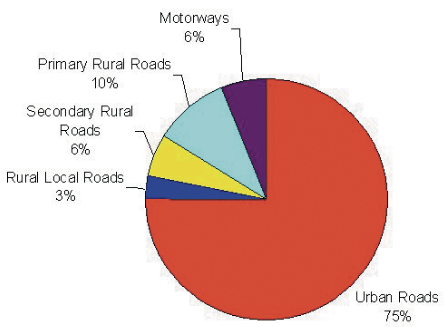


Figure 1: Distribution of accidents on the Italian Road Network – 2003

On the other hand the increase in traffic volumes and loading, together with the budget restrictions, are leading to very poor pavement conditions, mainly in urban areas and on local roads (Figure 2). There is therefore a strong need for more reliable and durable pavements for this type of roads and this is leading to a growing interest towards the use of concrete pavements.

A recent study published in 2002 by the Italian PIARC National Committee C7/8 (Road Pavements) [2] has highlighted the critical points of low volume roads pavement design in the following:

- even though only 20% of the traffic travels over these type of roads their extension is almost 80% of the entire Italian road network;
- even though the number of traffic repetitions can be low the axle load for each heavy vehicle can be quite high;
- low volume roads often shown a merge between a wide variety of different users from heavy gross vehicles to bicycles. In rural local roads also land trucks can be found;
- the budget for maintenance of this type of roads is often very limited;
- there is often a lack of information concerning the performance and conditions of this type of roads.

Figure 2: typical deteriorated pavement on a urban local road.

Concrete pavements can provide a very valuable solution for this type of roads as they offer a very good resistance to heavy axle loads and a generally lower maintenance, compared to flexible pavements. There is also a reduced risk of having a major deterioration, as a depression or a pothole, that can be a cause of danger for motorcycles and bicycles.

One of the key problems that can be encountered in introducing concrete road pavements in low volume roads is a generally higher level of complexity related to the design of this type of pavement structures.

To overcome these problems several tools have been developed in the latest years to provide simple methods for designing low volume roads.

It is finally extremely important to select the more appropriate type of pavement as some solutions (as the continuously reinforced concrete pavements) require a higher lever of expertise in the design and could lead to failures if not properly designed.

The type of concrete pavements which are generally considered preferable for low volume roads are [5]:

- jointed plain concrete pavements (usually without dowels);
- roller compacted concrete;
- concrete block pavements.

Concrete block pavements, which are often considered mainly for residential areas, pedestrian areas and parking lots have proven to be very successful for this type of roads.

The pavement laid in 1986 in the Town of Recoaro Terme (in the northern part of Italy) on a rural secondary road passing through the town centre is characterised by an AADT of 1230 vehicles per day with a 4% heavy gross vehicle and after 11 years of service (with only minor routine maintenance mainly related to the sand replacement) has been monitored to evaluate it's performance [6]. The results were extremely positive showing that the pavement could likely bear the actual traffic for other 20 years. Figure 3 shows how the concrete block pavement is performing after 11 years of service and the comparison with the adjacent flexible pavement.

Figure 3: the concrete block pavement in Recoaro after 11 years of service.

Definition of low volume roads

The first key issue in designing a pavement as part of a "low volume" road is to define which is the boundary between conventional pavements (designed for heavy traffics) and low volume ones.

There is no "uniformly accepted" definition of a low volume road. In some cases the distinction is mainly based on an administrative base (urban roads and local rural roads, as in the Italian Pavement Design Catalogue [3]). According to the study conducted by Hall and Bettis [4] a low volume road could be defined as having and average daily traffic (AADT) not higher than 500 vehicle per day independently of the actual heavy traffic which is travelling over it. This type of approach has to be considered carefully as these type of roads might carry very heavy loads, depending on their location and functions (as in the case of local roads in industrial areas or near caves). This AADT threshold for the design of low volume roads can be as high as 900-1000, according to Di Mascio [5]. Eugene M. Wilson, in his study on "Improving Safety on Low Volume Roads", defined low volume roads as those carrying under 5'000 average daily traffic (ADT) but at least 400 ADT [7]. It can be noted immediately that there is a wide spread of definitions, if these are given only in terms of AADT.

The new Mechanistic-Empiric Design Guide developed by NCHRP and AASHTO for the design of pavement structures [8] defines a low volume road as carrying not more than 750'000 heavy vehicles (trucks and busses) over its design life. This approach is in line with the previous AASHTO Guide [9] that identified the threshold for designing a flexible or rigid pavement with the "low volume road design procedure" in 700'000 to 1'000'000 ESALs (80 kN single axles).

It is therefore important, when using methods that classify low volume roads in terms of AADT or administrative classifications to check that the actual number of expected heavy vehicles is consistent with the ones assumed as a basis for developing the design procedure.

The design of concrete pavements for low volume roads

There are several tools available nowadays for designing concrete pavements for local roads. In general these are different for:

- conventional concrete pavements;
- concrete block pavements.

In terms of practical tools to be used the most commonly adopted are:

- design catalogues;
- design guides (empirical o mechanistic-empirical).

<u>Design Catalogues</u>

For designing conventional low volume concrete pavements the most practical approach would be to use a Design Catalogue. There are several ones available world-wide but the US Catalog of Recommended Design Features [10] and the Italian Pavement Design Catalogue [3] are the more interesting as they are both supported by an expert system software (in both cases available free of charge) that can assist the designer both for the structural and construction details design. The CEMPA software [11] is an expert system specifically developed for the design of concrete pavements, based on the Italian Pavement Design Catalogue.

This Catalogue covers the design of structures for local urban roads with overall traffic volumes in the design life between 400'000 and 4'000'000 HGV passes in the mostly trafficked lane. On the other hand local rural roads are not considered due to the very wide variety of different traffic conditions that can interest them. It is extremely important to keep in mind that, according to this Catalogue, bus lanes should not be considered as part of the local roads network and, for this reason, different structures for this type of pavements are given.

This Design Catalogue provide different solutions for different traffic classes and different subgrade resistances (which are given in terms of Resilient Modulus) as shown in Figure 4 and in Figure 5, referred to jointed plain concrete pavements (JPCP) and continuously reinforced concrete pavements (CRCP).

All the structures proposed are designed coupling the AASHTO Design Guide [9] (with a Reliability of 90% and a final Present Serviceability Index (PSI) value of 2) with a mechanistic design approach.

<u>Design Guides</u>

The design of road pavement has been conducted world wide with the AASHTO Pavement Design Guide [9] for several years. This included a specific section for low volume roads

Figure 4: JPCP pavement structures for local urban roads proposed by the Italian Pavement Catalogue

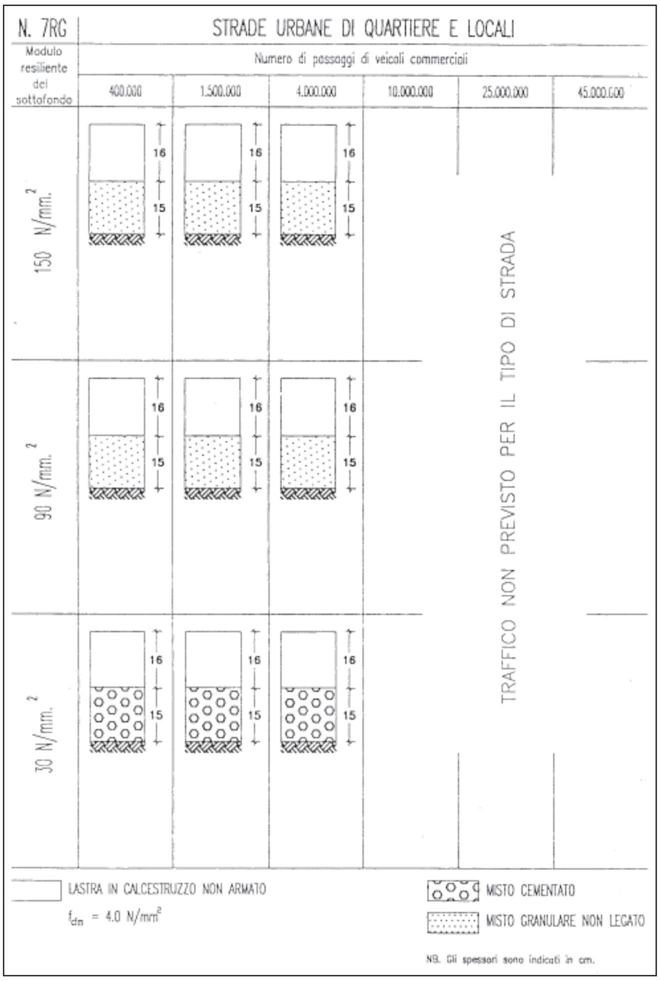
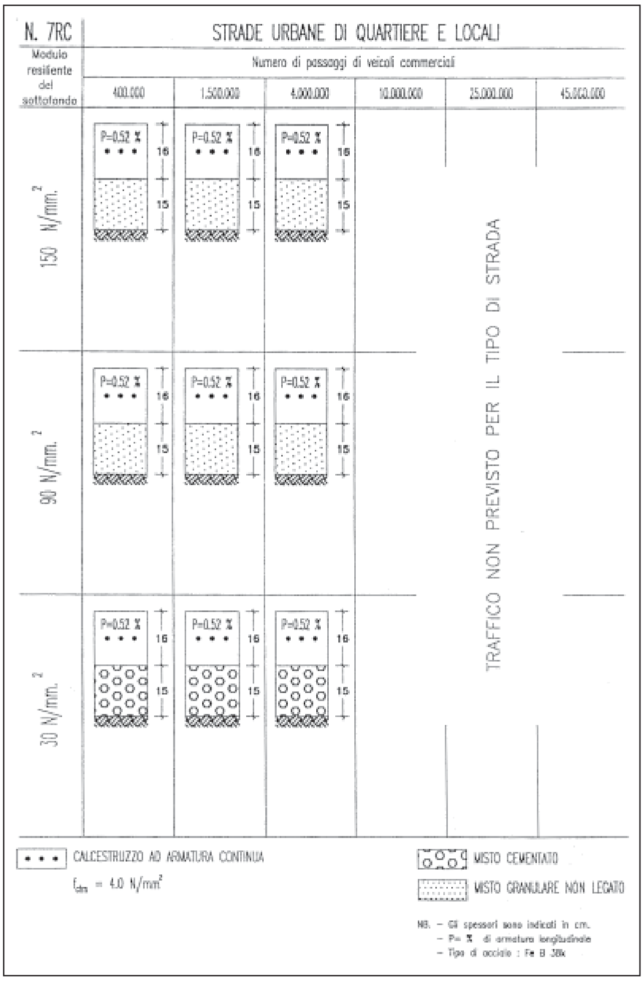


Figure 5: CRCP pavement structures for local urban roads proposed by the Italian Pavement Catalogue.



which was, for flexible and concrete pavements, an application of the procedure described in the Design Guide to a predefined set of input data in a sort of "catalogue" format.

The same approach has been followed in developing the Low Volume Roads Section of the new AASHTO Mechanistic-Empirical Design Guide [8]. The application of the full procedure for the design of the pavement structures with the Mechanistic-Empirical approach is now more complex and requires the use of a specific software. For this reason the analytical approach has been coupled, for low pavement roads, with a set of JPCP solutions valid for predefined conditions which are:

1. all designs are based on the structural requirement for a design analysis period of 20 years. The range of traffic levels is 50'000, 250'000, and 750'000 trucks/buses in the design traffic lane over the design life;
2. two different sets of solutions are presented based on either a 50-percent or 75-percent level of reliability;
3. the designs are for environmental conditions corresponding to two broad regions of the U.S., a northern climate (as represented by the climate in the northern Illinois/Indiana area) and a southern climate (as represented by the climate in the Atlanta, Georgia area);
4. the designs are provided for five qualitative levels of subgrade soil modulus or support capability: Very Good, Good, Fair, Poor, and Very Poor. Water table levels assumed in design were 8 ft (2.4 m) in wet regions and 40 ft (12 m) in dry regions;
5. the maximum allowable distress indicators for the rigid pavement designs are set as follows:
   - smoothness (IRI) = max 200 in/mile (3.2 mm/m);
   - joint faulting = max 0.15 in (3.8 mm);
   - slab cracking = max 45%

   These values represent the average measurements taken along a segment of a roadway or street.

Even though the Mechanistic-Empirical Design Guide allows the definition of the concrete pavement slabs by means of this simplified tables it should be noted that these are always related to predefined input conditions.

One of the main reason for using simplified approaches, when designing low volume road pavements, is the lack of detailed information on the required input values (traffic, subgrade, climatic conditions, materials properties). The approach of the new AASHTO design procedure is "hierarchical"

Design Reliability: 50 percent								
Climatic Region	Chicago (freeze)				Atlanta (non-freeze)			
Edge Support***	No		Yes		No		Yes	
Granular Base Course	No	Yes	No	Yes	No	Yes	No	Yes
Relative Quality of Subgrade Soil	Low Traffic: 50,000 Trucks/Buses							
Very good	5.0 in	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Good	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Fair	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Poor	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Very poor	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
	Medium Traffic: 250,000 Trucks/Buses							
Very good	6.0 in	5.5	5.5	5.0	6.0	5.5	5.5	5.0
Good	6.0	5.5	5.5	5.0	6.0	5.5	5.5	5.0
Fair	6.0	5.5	5.5	5.0	6.0	5.5	5.5	5.0
Poor	6.5	6.0	6.0	5.5	6.0	6.0	6.0	5.5
Very poor	6.5	6.0	6.0	5.5	6.5	6.0	6.0	5.5
	High Traffic: 750,000 Trucks/Buses							
Very good	6.5 in	6.0	6.0	6.0	6.0	5.5	6.0	5.5
Good	6.5	6.0	6.0	6.0	6.0	5.5	6.0	5.5
Fair	6.5	6.0	6.0	6.0	6.0	5.5	6.0	5.5
Poor	7.0	6.5	6.5	6.0	6.5	6.0	6.0	5.5
Very poor	7.5	7.0	7.0	6.0	6.5	6.5	6.5	5.5

Figure 6: JPCP pavement structures for low volume roads proposed by the AASHTO Mechanistic-Empirical Design Guide (50% reliability)

Design Reliability: 75 percent								
Climatic Region	Chicago (northern)				Atlanta (southern)			
Edge Support***	No		Yes		No		Yes	
Granular Base Course	No	Yes	No	Yes	No	Yes	No	Yes
Relative Quality of Subgrade Soil	Low Traffic: 50,000 Trucks/Buses							
Very good	5.0 in	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Good	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Fair	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Poor	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Very poor	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
	Medium Traffic: 250,000 Trucks/Buses							
Very good	6.0 in	5.5	5.5	5.0	6.0	5.5	5.5	5.0
Good	6.0	5.5	5.5	5.0	6.0	5.5	5.5	5.0
Fair	6.0	5.5	5.5	5.0	6.0	5.5	5.5	5.0
Poor	6.5	6.0	6.0	5.5	6.5	6.0	6.0	5.5
Very poor	6.5	6.0	6.0	5.5	6.5	6.0	6.0	5.5
	High Traffic: 750,000 Trucks/Buses							
Very good	6.5**	6.0**	6.0**	6.0**	6.5	6.0	6.0	6.0
Good	6.5**	6.0**	6.0**	6.0**	6.5	6.0	6.0	6.0
Fair	6.5**	6.0**	6.0**	6.0**	6.5	6.0	6.0	6.0
Poor	7.0**	6.5**	6.5**	6.0**	7.0	6.5	6.5	6.0
Very poor	7.5**	7.0**	7.0**	6.0**	7.5	7.0	6.5	6.0

Figure 7: JPCP pavement structures for low volume roads proposed by the AASHTO Mechanistic-Empirical Design Guide (75% reliability)

which mean that there are different levels of accuracy required for the input data depending on the actual availability (the structural design will be more reliable if the Level 1, more accurate, input data are given but the user can reduce the input data requirements down to Level 3 where most of the input values are set by the system).

For this reason it can be envisaged that in the very near future the full AASHTO Mechanistic-Empirical Design procedure could be used also for the design of low volume concrete pavements. As shown in Figure 8 this will enable to design the pavement (considering the actual input conditions), but also to predict the pavement performance in time and to perform life cycle cost analyses.

<u>Specific Methods for the design of concrete block pavements.</u>

The design of concrete block pavements usually require the application of specific procedures or the use of design catalogues specifically developed for this type of structures [12].

One of the most common approach is to design the structure with the AASHTO 1993 Design Guide considering the concrete block pavement as a flexible pavement with the schematisation shown in Figure 9.

To define the number of repetitions that the structure can bear the Structural Number (SN) is defined as follows:

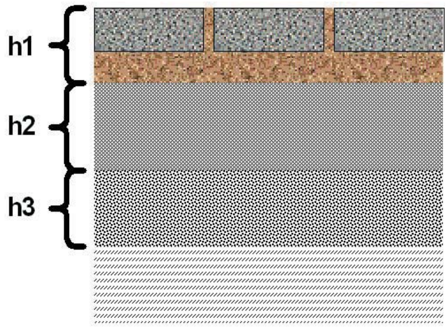


Figure 9: schematisation for the calculation of the Structural Number in concrete block pavement

$SN = a_1 * h_1 + a_2 * h_2 * m_2 + a_3 * h_3 * m_3$ [in inches]

where:

- a_1, a_2, a_3 are the "structural coefficients" that allow to characterise the different layers as in a "conventional" flexible pavement;
- m_2, m_3 are the "drainage coefficients" that allow to account for the moisture damage due to water accumulation in the structure.

The key issue in using this method for concrete block pavements is the definition of the a1 coefficient. A study conducted by Rada et al. [13] proposes the following equation for defining the structural coefficient as a function of the elastic moduli (Ebs, in psi) of the wearing course (concrete blocks and sand):

$$a_1 = 0.44 \cdot \sqrt[3]{\frac{E_{bs}}{45000}}$$

The same authors, in accordance with several other researchers, have shown that the properties of the wearing course of a concrete block pavement tend to improve with time due to an increase in the interlocking behaviour. If no other indications are available the Ebs value can be defi-

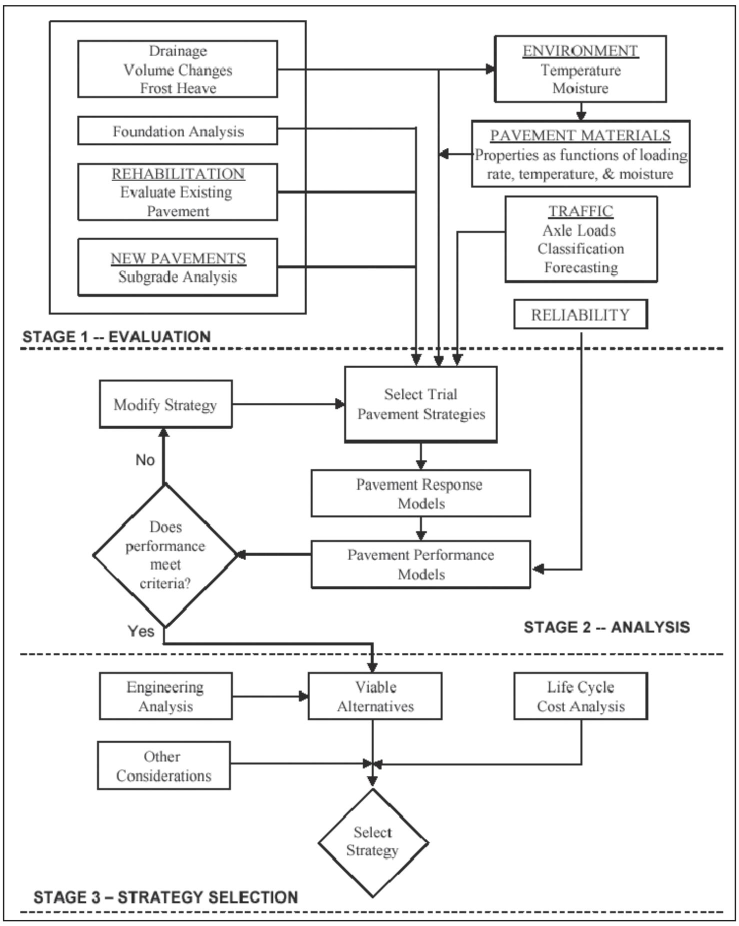


Figure 8: AASHTO Mechanistic-Empirical Design Guide approach

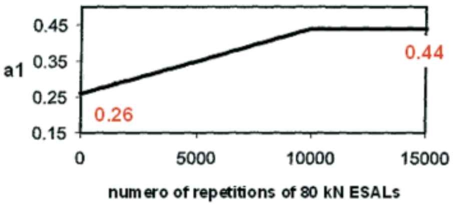


Figure 10: definition of the a1 coefficient for a concrete block pavement as a function of the traffic in ESALs according to Rada et al.

ned according to the diagram given by Rada et al. shown in Figure 10.

Key construction issus

The achieve a good performance in a concrete pavement for a low volume road it is important to define all the construction details specifically for this type of structures.

A comprehensive guide with details for the construction of low volume concrete pavements is the ACI 325.12 R guide by Zollinger [14] where the following issues are specifically tackled:

- subgrade support;
- drainage;
- properties of concrete paving mixtures;
- joint details;
- requirements for distributed reinforcing steel and load-transfer devices (where needed).

Zollinger highlighted the importance of adopting a proper spacing and layout of joints for city streets and local roads to achieve a good performance in time.

Concrete paving on low volume road can be made with different techniques but the more common is manual paving which can also be made with a Rolling Screed (revolving tube), as shown in Figure 11.

Figure 11: Roller Screed (Revolving Tube) paving technique for low volume roads

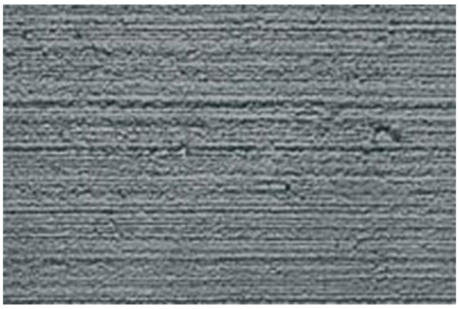


Figure 12: transverse broomed concrete surface

Figure 13: typical paving technique of a concrete block pavement

Figure 14: laying the sand roadbed of a concrete block pavement

Finishing of low volume concrete pavements is often a "broomed surface" which is obtained by a hand broom device that lightly drags the stiff bristles across the surface. It produces 1.5-3 mm deep striations oriented in the transverse direction with respect to the centerline of roadway (Figure 12).

Concrete block pavement are usually laid manually (even though mechanical techniques are actually available) without the need for specific paving devices (Figure 13). It should be noted, anyhow, that most of the good performance of a concrete block pavement is related with a proper laying of the sand roadbed (Figure 14).

Conclusions

Low volume roads cover a wide part of the road networks and the limited budget available often leads to a lack of maintenance and poor conditions. This can often lead to a very dangerous deterioration (with depressions or potholes) which can be a cause of accidents for motorcycles and bicycles which often travel over these pavements (especially in urban areas).

Concrete pavements can offer a good solution that can couple a proper structure with low maintenance requirements. The most common solutions for this type of applications are:

- jointed plain concrete pavements (usually without dowels);
- roller compacted concrete;
- concrete block pavements.

One of the major disadvantages of these type of structures, related to an increased complexity in pavement design which can be excessive for low volume pavements, has now been overcome with the development of design catalogues and easy to use design guides for low volume roads, the latest one based on the new Mechanistic-Empirical Design Guide developed by AASHTO, as well as easy to use expert systems.

Construction techniques are usually manual but it is important to define properly all the construction details to achieve well performing concrete pavements in low volume roads with special regards to joint spacing and layout.

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