Roller compacted concrete:
making concrete pavements available to the whole pavement building industry

The advantages of conventional vibrated concrete pavements are well known: strength, antiskidding properties, luminosity, fire resistance, durability, reduction of fuel consumption, minimal maintenance, more economical than other options in the long term. However, in most cases they must be constructed with machinery only suitable for concrete paving. Although present all around the world, the number of machines for mechanized construction of concrete pavements is largely exceeded by those used for asphalt paving, mainly finishers and rollers. Roller Compacted Concrete (RCC) is a hybrid technique allowing the use of asphalt equipment to achieve a pavement featuring properties (strength, durability) similar to those of vibrated concrete pavements. Although primarily intended for low speed applications such as industrial yards or secondary and residential roads, progresses in machinery and construction methods along near 50 years of experience have expanded the use of RCC pavements for carriageways with higher traffic volumes. Currently, for most applications where vibrated concrete pavements are used, RCC is also a feasible option providing excellent results.

Photo: TCMA

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WHAT IS RCC?

Roller Compacted Concrete (RCC) is a paving material which has similar strength properties and consists of the same basic ingredients as conventional, internally vibrated concrete for pavements—well-graded aggregates, cementitious materials, and water—but has different mixture proportions. The main differences are:

- the lower cement content allowing to obtain a consistency of the fresh material stiff enough to remain stable under vibratory rollers, yet wet enough to permit adequate mixing and distribution of paste without segregation;
- RCC has a higher percentage of fine aggregates, which allows for tight packing and consolidation by rollers and/or asphalt pavers provided with high density screeds;
- RCC is typically placed with an asphalt-type paver equipped with a standard or high-density screed, followed by a combination of passes with rollers for compaction. Final compaction is generally achieved within one hour of mixing.
- unlike conventional concrete pavements, RCC pavements are constructed without forms, dowels, or reinforcing steel;
- sawcutting has not always been used in RCC construction, but it is gaining popularity as a measure to maintain small crack widths and good load transfer. It is well accepted that tight cracks are more conducive to high load transfer, which is an important feature of pavement design. Moreover, joint sawing improves the aesthetics of the pavement, and sawn joints are less prone to distresses than naturally occurring cracks.

RCC should not be confused with cement treated materials intended for base layers, also called cement bound bases. The philosophy of all these mixes is very similar: a mixture of aggregates, cement (or a hydraulic binder) and a small content of water, allowing to be compacted by means of rollers; but, when compared with RCCs, they have a much lower cement content and consequently a lower strength. For pavement applications only materials with a mechanical strength in the range of that of vibrated concretes for structural uses (compressive strengths over 25 MPa at 28 days) should be called Roller Compacted Concretes.

APPLICATION AREAS

It can be considered that first modern examples of RCC pavements took place in Spain about 1970, in low volume roads [2]. Looking at heavy duty applications, Canada began their use in 1976, for the timber industry RCC pavements have been successfully used in almost all applications of vibrated concrete pavements:

- Heavy-duty applications
  - Ports and airports
  - Military installations
  - Intermodal facilities
- Light commercial industrial applications
  - Warehouses and manufacturing facilities
  - Commercial and industrial parking lots
  - Maintenance and storage yards
- Roadway applications
  - Highway frontage roads and shoulders
  - Minor arterials
  - City streets and local roads
  - Main highways and motorways

When used in high speed facilities, as main highways and motorways, RCC is most often covered with a wearing course of asphalt concrete, several centimetres thick, in order to attain a surface evenness meeting the requirements of these applications. Diamond grinding and grooving of RCC has also been used for this purpose. Aircraft parking areas have also been provided with a thin asphalt wearing layer to avoid any potential risk of loose particles entering a jet engine.

Poland: paper factory access

Mallorca: Industrial warehouse - Photos: CEMEX

ADVANTAGES

When compared with asphalt pavements, RCC ones present many of the advantages of conventional, internally vibrated concrete pavements:

- RCC can be designed to have high flexural, compressive, and shear strengths, which allow it to support heavy, repetitive loads without failure—such as in heavy industrial, mining and military applications—and to withstand highly concentrated loads and impacts;
- with specially adapted mixes, a low permeability of the RCC can be achieved, providing it excellent durability, even under freeze-thaw conditions;
- RCC eliminates rutting and subsequent repairs, except in areas of heavy tire chain or studded tire use;
- RCC provides chemical and rut resistance in industrial areas where point loading from trailer dollies is a concern;
- RCC resists abrasion, even under heavy loads and high traffic volumes;
- RCC mixtures can use both natural and manufactured fine aggregates;
- fine aggregates not suitable for asphalt pavements can be used in RCC;
- depending on the mix, and utilizing high-density pavers, RCC can be placed in lifts as thick as 25 cm;
- due to the light surface colour of RCC pavements, lighting requirements are reduced;
- RCC pavements have a high solar reflectance index, which reduces the temperature of the pavement and associated problems like the Heat Island Effect.

When compared with conventional vibrated concrete pavements, RCC also presents some extra advantages:

- RCC pavements are constructed with machinery easily available and that can be employed for other purposes;
- RCC is a faster form of construction;
- the lower paste content in RCC results in less concrete shrinkage and reduced cracking from shrinkage-related stresses;
- RCC requires a lower cement content to obtain a similar mechanical strength;
- the high stability of the granular skeleton of a properly graded and compacted RCC allows trafficking at very early ages. This property is very beneficial in works such as overlays of in-service pavements, emergency evacuation roads in case of disasters or some military applications.

To summarize, RCC has the strength and performance of conventional concrete with the availability of asphalt machinery. Coupled with long service life and minimal maintenance, RCC's low initial cost adds up to economy and value.

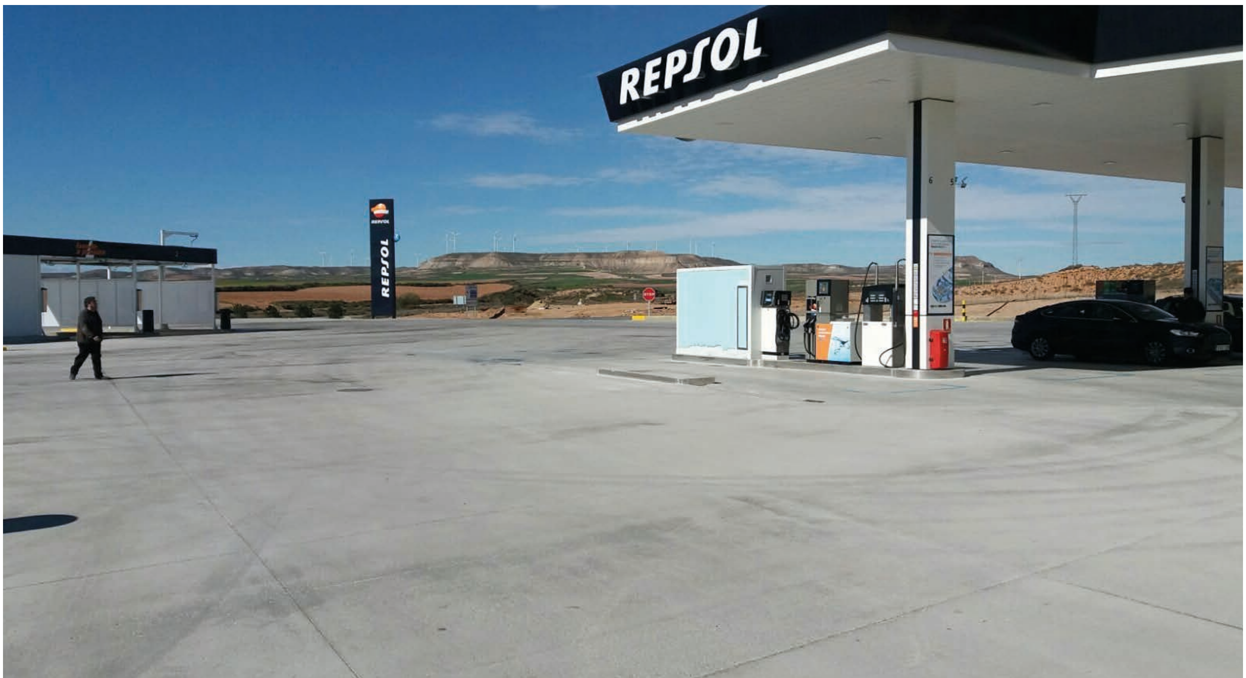
Turkey: Construction of a rural road in RCC
Photo: TCMA

POTENTIAL LIMITATIONS

There are some possible limitations and challenges associated with RCC pavements, such as the following:

- without diamond grinding, it is difficult to obtain a RCC's profile and smoothness desirable for pavements carrying high-speed traffic;
- the amount of RCC that can be mixed in a transit mixer or ready mix truck is typically lower than for conventional concrete, due to the dryness of the RCC mix. The use of central mixed concrete is therefore recommended;
- maximum thickness than can be placed in one single lift by asphalt finishers does not exceed 25 cm after compaction. Thicker pavements, as those required sometimes in airport or industrial facilities, must be constructed in multiple horizontal lifts that should be placed within an hour to ensure good bonding. The same applies to adjacent slabs in wide pavements which cannot be built in a single pass of the paver (unless a cold joint is planned). These delays can be increased using setting retarders;
- pavement edges are more difficult to compact, so most specifications require 96% modified Proctor density on cold joints instead of the 98% required on interior pavement sections. History has shown that properly prepared and consolidated cold joints perform very well;
- due to relatively low water content, hot-weather RCC paving requires extra vigilance to minimize water loss to evaporation;
- due to the dryness of the RCC mixture, admixture dosage requirements can be higher for RCC than for conventional concrete.

RCC pavement at a service station
Photo: CEMEX



RCC MIX DESIGN

Concerning aggregates, a general trend is observed towards limiting their maximum size to 16/20 mm or even less, in order to avoid segregation, as well as to facilitate the mixing process and to improve surface evenness. Fines passing 75 micron sieve are frequently limited. Normally, a large proportion of crushed material is used in order to obtain an adequate stability of the newly compacted material. The latter is especially important for overlay works aimed to be open to traffic as soon as possible.

Cement content is slightly lower than in the case of conventional vibrated concretes with similar mechanical strength requirements at 28 or 90 days. It ranges between 10% and 17% of total weight of dry components, values between 300 ± 30 kg per m^3 being the most usual ones. Mixes of cement and fly ash are frequently employed, as well as blended cements. In the latter, the proportion of active additions sometimes exceeds 50%. These cements are generally cheaper than ordinary Portland ones and present a marked delay in the setting process, this resulting in a less demanding construction. In addition, fly ash improves the workability of RCC and affects favourably its cracking behaviour. In regions with severe winters, silica fume, up to 10% by weight of the binder, is preferred to fly ash.

As for cement treated granular materials, water content usually is within the range of 4.5 to 6.5% of dry components. Two different approaches can be followed to proportion water. Most common are the compaction methods (also called soil compaction methods), as the modified Proctor test or those using a vibratory hammer. They involve establishing a relationship between dry unit weight and moisture content of RCC by compacting specimens by means of impacts over a range of moisture contents. The optimum moisture content is defined as the peak of the moisture- density curve. In consistency tests, e.g. the modified Vebe consistometer, an optimum workability is established, usually subjecting specimens of fresh material to the combined effect of a vibration and an overload on top of them. Other methods, such as the solid suspension model (or particle packing model) or the optimal paste volume method are also available.

There must be sufficient paste to coat the aggregate particles and give a closed structure; but it should be considered that too much paste causes the RCC to form a wave in front of the roller wheel, in addition to other problems

Plasticizers and setting retarders have been employed in some countries, the latter being customarily used in some countries to increase the workability period, that is to say, the time during which the material can be compacted without impairing its internal structure because the binder setting has not yet started. Some admixtures have also been developed that can be spread on the surface of the freshly compacted mix allowing it to be trowelled, brushed or tined.

MIXING AND TRANSPORT TO THE JOBSITE

Continuous-flow pugmill mixers, concrete batching plants and, in some cases, drum truck mixers have been employed. There is a general trend towards high output continuous plants with an accurate control of the cement added to the mix, since they may be easily transported and set up at the site and have a relatively large output capacity. When using a plant initially designed to mix cement treated materials, some modifications are frequently needed to accommodate it to the larger amounts of cement required for RCC. On the contrary, with concrete batch plants allowance must be made for a reduction in output, since RCC demands longer mixing times, at least 60 s. In all cases, it is necessary to reduce the free fall height of the concrete to avoid segregation.

Transport is usually performed by open-bodied tipping trucks. Moisture variations are critical in RCC; therefore trucks should be equipped with protective covers in case of adverse environmental conditions, such as in hot, or windy days.

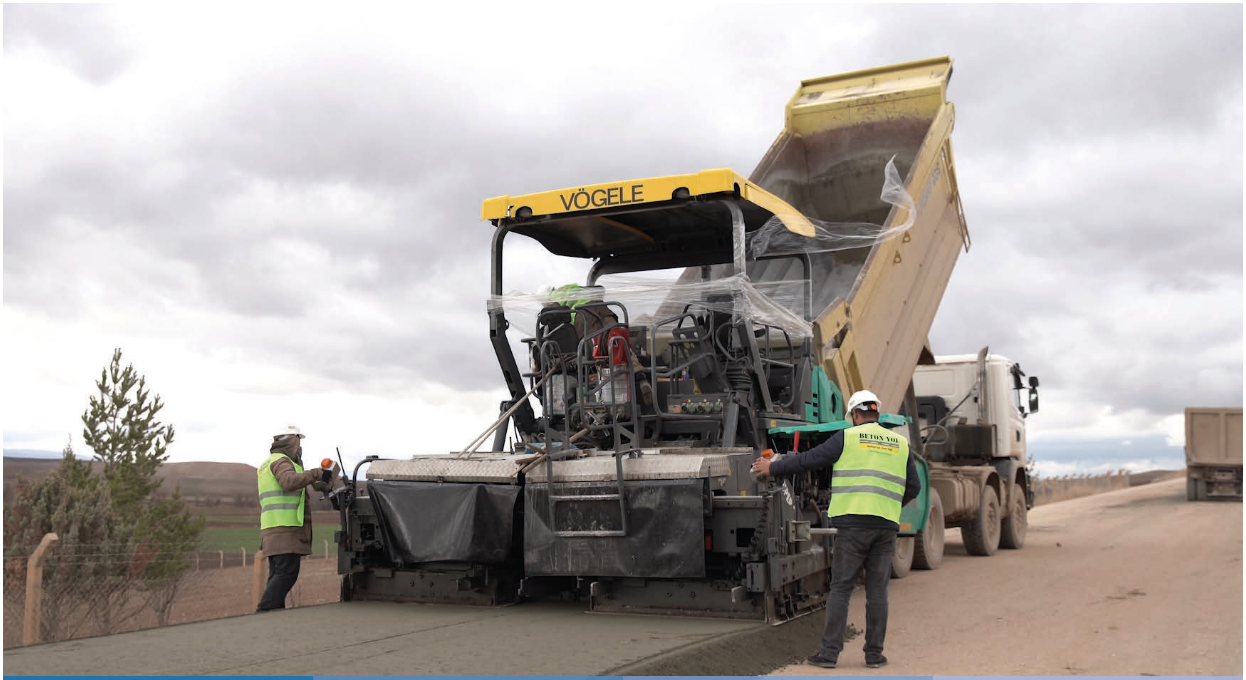
SPREADING

A large variety of equipment (figure 7) like graders, autograders or finishers has been employed for spreading the uncompacted material; but there is also a general trend towards the use of pavers ensuring a high precompaction of the mix, over 90% modified Proctor maximum density. Generally, finishers provided with a dual tamper system are employed for this purpose.

A high precompaction improves surface evenness, since deformations of the material under rollers are reduced. On the contrary, graders give worse results concerning either output or precompaction; but they are the most suitable equipment for irregular layouts, as those found in many urban works.

When using finishers, it is very important that plant output allows a continuous forward motion of the equipment to prevent the formation of bumps and depressions on the final pavement surface.

Turkey: construction of a rural road
Photo: TCMA



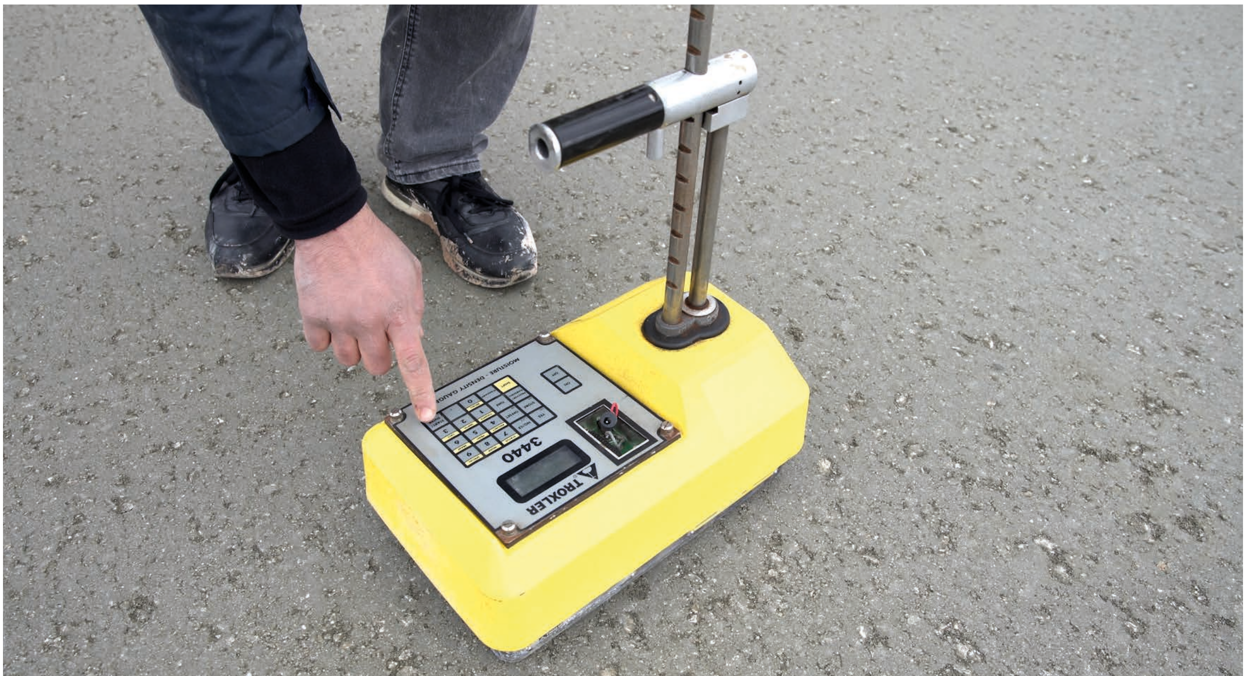
COMPACTION

RCC is usually compacted with a heavy vibratory roller, in many occasions combined with a rubber tyred roller. In the vibratory roller, it is recommended that static weight per linear centimetre width of the drive roll should not be less than 30 kg; whereas on the rubber-tyred roller the load per wheel should be 3 ton or higher and the contact pressure not less than 0.8 MPa. A common roller pattern consists of two static passes (one back-and-forth motion) on the fresh material to set it, followed by several vibratory passes, usually four or more, until the specified density is achieved. The compacting process is then completed with several passes of the rubber-tyred roller to close any surface voids or cracks. A rubber-coated drum can also be used both for the vibratory passes, until the required density is achieved, and for the finishing process. It also has the benefit of giving a surface with good friction. This roller pattern admits some variations. When tyred rollers are not available, several final static passes of the drum roller can be made to seal the surface. Good results have also been obtained with a mixed roller (smooth drum on the front axle and tyres at the rear).

Considering the strong relationship between RCC density and its mechanical strength, it is very important to perform the compaction adequately. A minimum density to be achieved is normally prescribed. Some specifications require an average density not lower than 97% of the maximum modified Proctor density, while at the bottom of the RCC layer this density must be not less than 95%.

In many works, it is compulsory to finish compaction within 60 or 90 minutes after mixing the materials. However, these terms can be increased with cements having a high addition content or when setting retarders are used.

Density measurement
Photo: TCMA



Thick pavements, in some cases up to 60 cm, are sometimes required for industrial facilities. When thickness exceeds 25 cm, RCC pavements are usually constructed in multiple layers to ensure adequate compaction of each one. In these cases, it is essential to obtain a good bonding between layers. This is usually accomplished by limiting the interval to place an upper layer to the workability period of the lower one; in addition, the surface of the latter should be kept wet.

SURFACE FINISHING

Normally the surface is left as it is after compaction and is ready to use without any further finishing, also called "natural RCC finishing". However, some recent developments include other finishing methods, well-known for conventional concrete surfaces, such as trowelling, brushing and tining of the fresh concrete or diamond grinding of the hardened concrete surface. (read further in "Special applications and new developments").

CURING AND SURFACE AND PROTECTION

The reduced water content of RCC mixes puts great emphasis on effective curing. It must begin as soon as possible once compaction has been completed. If RCC is to be left uncovered, generally a water curing during one week is performed. Curing compounds or bituminous emulsions are employed. The latter is the normal practice when an asphalt concrete layer or a surface dressing is to be placed on top of RCC. If traffic is allowed to run on top of the emulsion, it should be protected with chippings or sand.

Latvia: RCC street in an industrial area
Photo: CEMEX

JOINTS

There is a trend towards jointing RCC pavements. Transverse joints are usually sawn within a delay largely depending on climatic conditions and the strength gain of RCC: from a few hours to several days. Wet formed joints are only used when a bituminous wearing course is placed on top of the RCC. In this case, joint spacing is short, trying to avoid reflective cracking

Concerning end-of-day joints, either longitudinal or transverse, it is mandatory to leave their edges as vertical as possible. Otherwise, ends of adjacent slabs risk blowing up with occasion of high temperature rises. Several methods can be followed to ensure this required verticality.

In most cases, joints in RCC pavements remain unsealed. When used, sealing products and procedures are in accordance with the same specifications applicable to vibrated concrete pavements.

Poland: paper factory access – view of the RCC surface

Photos: CEMEX

Poland: construction of a rural road – sawcutting of the joints

THE MARKET - EXAMPLES

United States

The United States are one of the countries where the utilization of RCC pavements is clearly increasing, in terms of area placed per year, types of applications, and number of projects per year. Just to provide an estimation, the number of works completed between 2011 and 2013 (172) is near twice those constructed between 2000 and 2010 (99). Average total surface paved yearly has increased from 750 000 m^2 in the period between 2000 and 2010 to 1 400 000 m^2 between 2011 and 2015. Industrial is the largest application type, but use in roadways is increasing, in some cases even in high speed facilities thanks to advances in methods to improve evenness and anti-skidding properties. Roughly speaking, the share between private and public owned projects is 3 to 1 in the last years.

Base layer for motorways and other high speed facilities

As pointed above, RCC should not be confused with cement treated materials, also called cement bound materials. For pavement applications only materials with a mechanical strength in the range of that of vibrated concretes for structural uses should be called Roller Compacted Concretes and allowed to be directly trafficked by a large number of heavy vehicles (trucks, container handling devices, etc) during the whole design period of the related facility.

However, where surface evenness and/or antiskidding properties are relevant (eg in high speed facilities), a wearing course of asphalt concrete, several centimetres thick, have been used in a number of RCC pavements to improve them-expressways and main highways to get an adequate surface evenness. In these cases, reflection of RCC joints and cracks at the upper surface should preferably be avoided. A great number of procedures, most of them originally developed for pavements with cement treated bases have been used, for instance, wet-formed joints shortly spaced (3 m or less), in order to reduce joint movements. This last procedure is not feasible when using asphalt finishers providing a high precompaction, and early entry saws should be employed as soon as possible to create joints at short distances.

To summarize, an asphalt wearing course improves smoothness and skid resistance, and the final result is least sensitive to the skill level of the RCC contractor. However, it supposes a higher cost and an increased construction time. In addition, the asphalt surface requires more maintenance than a properly constructed RCC pavement.

Low-volume rural roads and urban streets

First known modern examples of RCC pavements took place in Spain about 1970, in low-volume roads and streets. In general they have performed very satisfactorily. They were constructed by small local contractors, in a self-taught way. All these facts prove that RCC is a technique that can be easily mastered, since pavements are constructed with machinery usually available and that can be employed for other purposes. Moreover, this easy construction, together with reduced labour requirements and high production rates, results in important savings when compared with other possibilities.

Poland: construction of a rural road
Photo: CEMEX

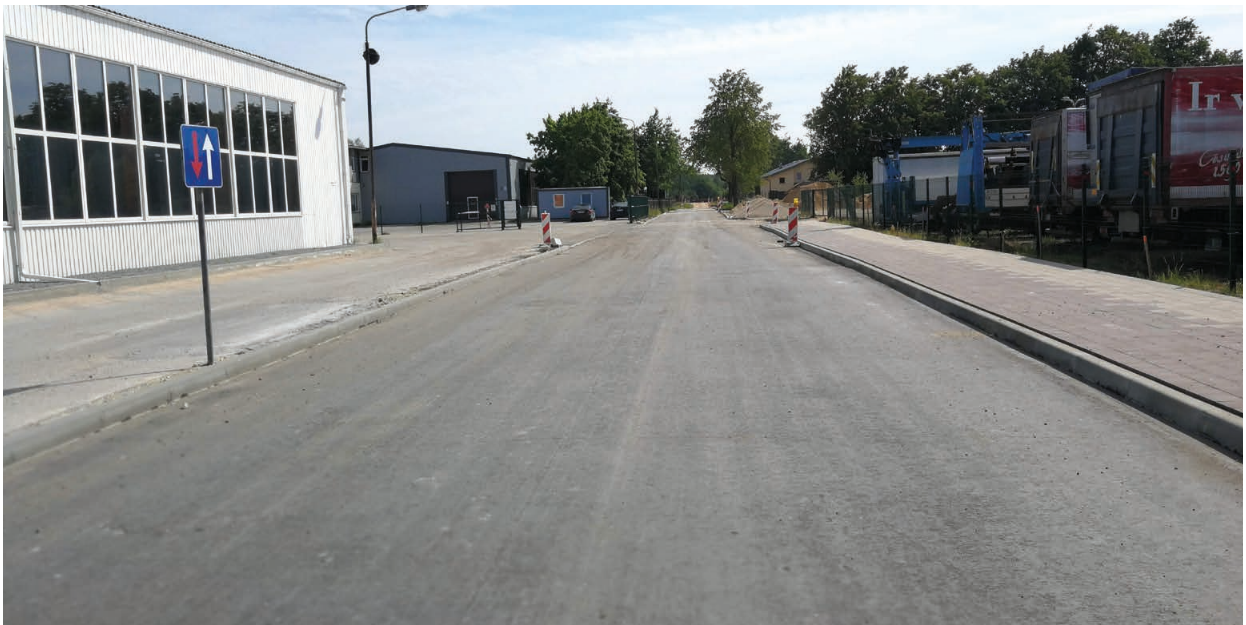
Worthy of mention is the overlaying of low-volume asphalt pavements badly deteriorated after 3 - 6 years in operation, especially when activities related to timber exploitation were involved. All the overlays were constructed by local contractors and have a thickness between 15 and 18 cm. RCC was produced in ready-mixed concrete batching plants, all the constituents being controlled by weight. In some cases, RCC was successfully hauled up to 80 km from the mixing plant, thanks to the use of setting retarders. Maximum daily productions have reached 430 m^3, in 10 hours, to build a stretch 720 m long. The combination of a reduced thickness and a strong support provided by the existing pavement has resulted in remarkable densities and mechanical strengths. Splitting strength values up to 6,2 MPa were obtained in some cores after several years in service.

Industrial and logistic facilities

In various European countries like UK, Poland, Latvia, Spain and others, a certain reintroduction of RCC applications is underway, making use of the wide availability of asphalt paving equipment in the market. Perhaps the largest use corresponds to industrial and logistics facilities, with the "natural" surface finish of the RCC. Large logistics fields of several hundred thousands of m^2 have been built recently in the UK.

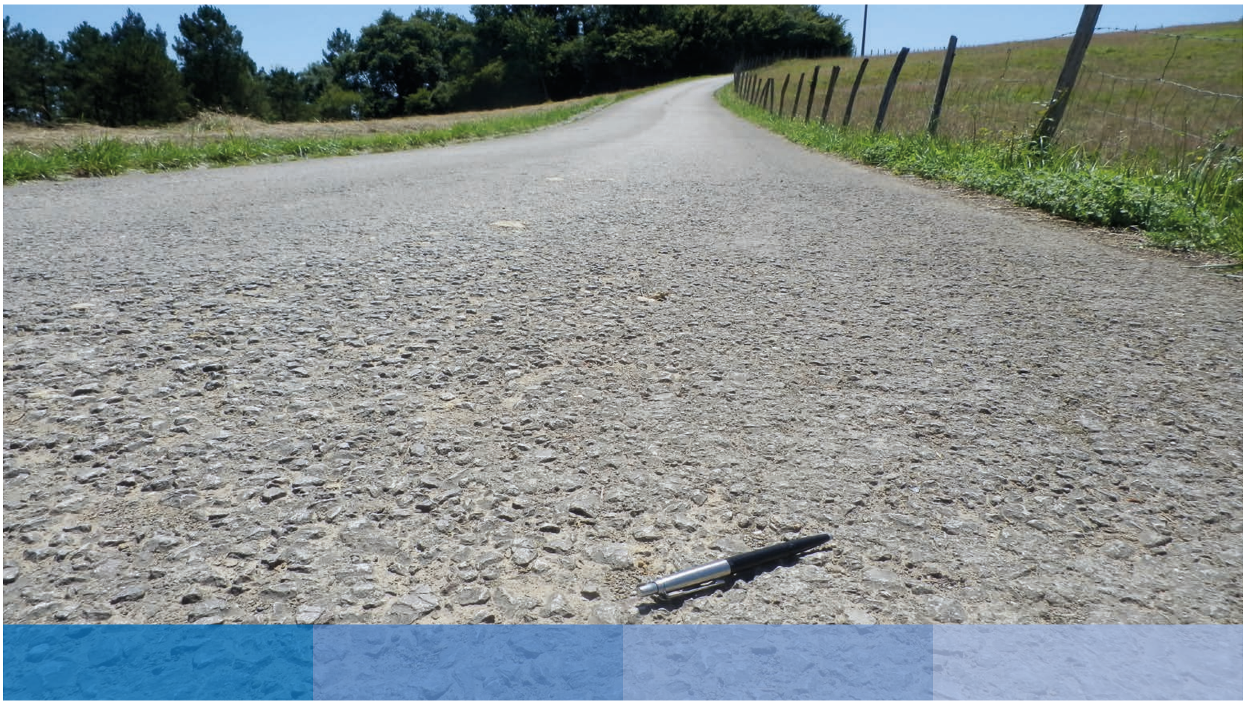
Also, a significate number of projects have been executed in the last few years, with thousands m^2 RCC built for secondary roads, industrial heavy traffic accesses and roads, service stations, large parking or storage areas, local and rural roads. Although it is a kind of rebirth of this application, it must be said that there are a lot of examples of the great durability of this paving solution, such as rural roads executed in the north of Spain in the 80-90s, currently in perfect working order after nearly 30 years operation.

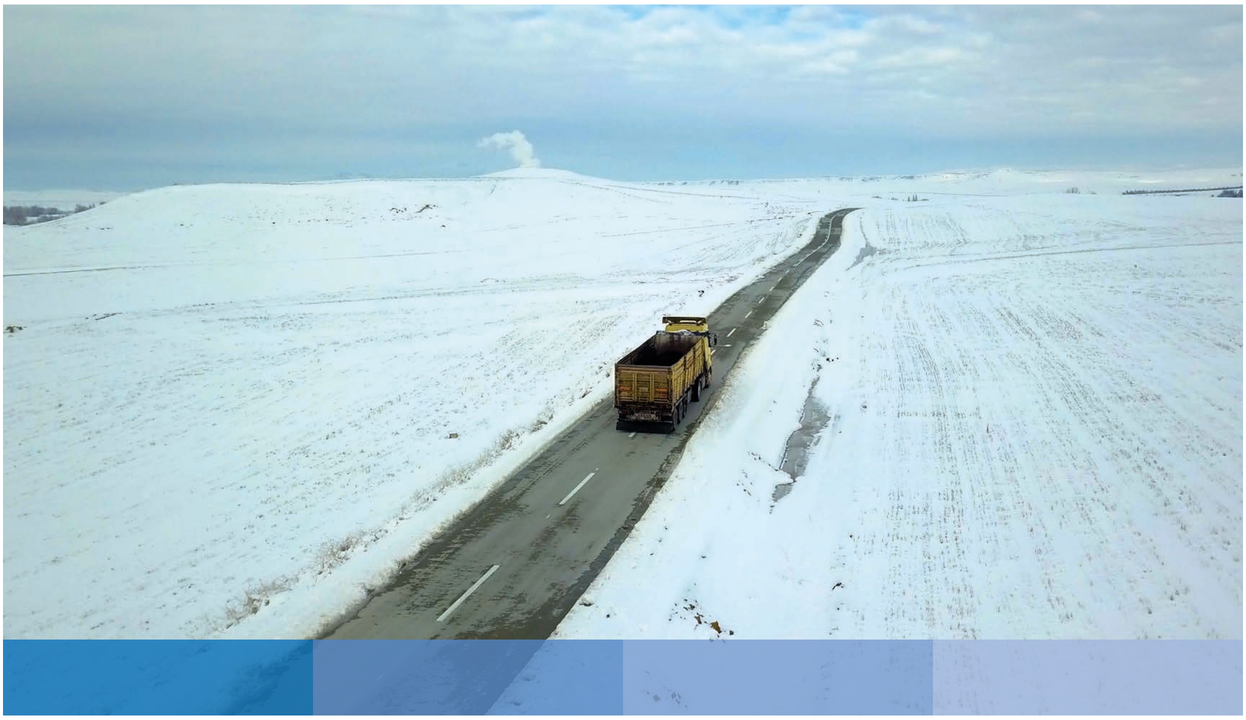
Latvia: RCC street in an industrial area
Photo: CEMEX



RCC is also used as a base layer with an asphalt wearing course on roads and streets, not only in urban areas but also in industrial estates.

Spain – Vizcaya: rural road built in 1991, in good condition after 28 years of service
Photo: CEMEX





Turkey: rural road in RCC
Photo: TCMA

Market development in Turkey

Since 2009 Turkey has also started with the use of RCC for urban road sections. A first pilot project took place in the Antalya Municipality and was sponsored by the EU 6th Framework project called "Ecolanes". The main objectives of the project were to develop, test and validate steel fibre reinforced concrete. Ecolanes aimed to use roller-compaction techniques as well as recycled materials in order to reduce construction costs, construction time and energy consumption. Recycled steel fibres of used tyres have been utilised for this purpose.

The first big-scale RCC application in Turkey was made by the Denizli Municipality. For the arterial roads with a heavy traffic flow, RCC was used for the base layer covered with an asphalt wearing course. The amount of RCC paved roads was estimated to be around 500 000 m². Later, RCC paved roads became an important choice especially for rural roads, due to certain advantages such as initial cost, early-age service and speed of construction. Today (2019), the number of cities that have applied RCC pavement is over 25, and the amount of RCC paved roads reached to about 1000 km.

SPECIAL APPLICATIONS AND NEW DEVELOPMENTS

Diamond grinding of the surface

The surface evenness of RCC pavements cannot be satisfactory for highway applications, especially if non high compaction finishers are used to spread the material, therefore requiring subsequent roller passes to achieve the required density. Concrete grinding can be used to improve both smoothness and skid resistance. In addition, rolling noise is reduced. On the contrary, total construction time and cost are increased.

Trowelling and brushing of surface

The surface texture of RCC after rolling, similar to asphalt pavement (while the colour is similar to vibrated concrete) cannot be adequate for high speed traffic circulating over 60 km/h. Admixtures are available to enhance the finishability or the antiskidding properties of the RCC surface concrete. It can be trowelled, broomed or tined as a conventional vibrated concrete. Trowelling can partially close up the surface and reduce moisture losses. Both brooming and tining improve skid resistance.

Fibre reinforced RCC

The specified density can be more easily obtained in the case of thin RCC layers. A method to reduce thickness is to include steel fibres into the material in order to both improve its flexural strength and control cracking. Several test sections have been built, proving that it is possible to distribute adequately the fibres into the RCC when mixing it. Their performance has been satisfactory.

CONCLUSION

For low speed applications, roller compacted concrete pavements can be considered a suitable technique, resulting in remarkable construction savings with regard to conventional concrete pavements, especially if specific construction equipment for the latter is not available. Also in motorways and main highways RCC provides an economical alternative, in spite of the fact that evenness standards usually require to diamond grind the surface or to place an asphalt concrete wearing layer. It is expected that, through new developments in high precompaction finishers, which reduce or even make unnecessary the passing of rollers, riding properties will be improved, eventually resulting in an expanded use of RCC solutions.

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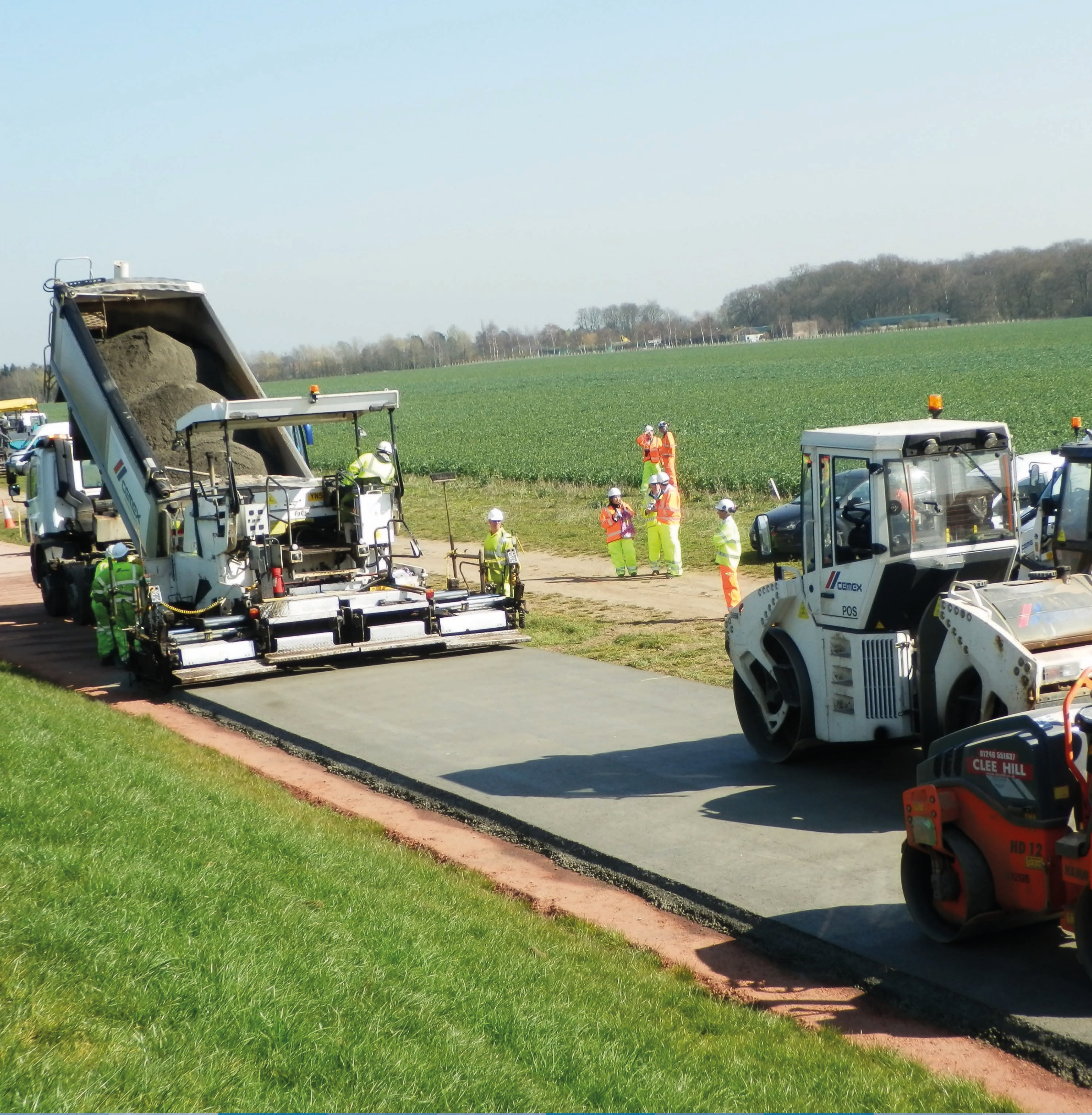

Construction of a RCC road in the UK
Photo: CEMEX

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