AN OVERVIEW OF THE EUROPEAN PRACTICE WITH CONCRETE PAVEMENTS

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The scope of this Paper is to give a general picture of European practice with concrete pavements, particularly regarding the design, performance and rehabilitation of highway pavements. The main sources used are the National Reports submitted to the 17th PIARC World Road Congress held in Sydney, Australia, in October 1983, the conclusions of the Congress and the Report of the PIARC Technical Committee on Concrete Roads, which deals with a series of subjects, handled on an international basis. Emphasis is placed on the latest trends in the field. A wide range of subjects is considered within the objectives of the Conference.

The task of summarizing the variety of practices adopted by so many countries certainly necessitates being selective. Thus the information in this Paper can only be regarded as a general account of the activity in this field, but the references will help the reader to find the details that have had to be omitted. Throughout the Paper more emphasis has been placed on recent innovations or new developments than on the description of established practices.

During recent years concrete pavements have continued to draw an increasing interest in many European countries, some of them with a long tradition and experience of construction, while others have only recently been engaged in this field. The evolution of the relative prices of asphalt and Portland cements, the advances in construction methods and equipment, as well as energy and material saving or user cost considerations are factors underlying the trend towards a wider use of concrete for paving.

In recent years more attention is being paid to 4-R work and to maintaining existing facilities and to the use of concrete for paving secondary and urban roads. Freeway construction has generally slowed down due to the completion of some national networks, financial difficulties related to the widespread economic recession and a decreasing traffic demand.

The Technical Committee on Concrete Roads of the Permanent International Association of Road Congresses (PIARC) is a useful forum where members from 18 European countries and a few corresponding experts from the United States, Mexico, Japan, South Africa and Australia can effectively contrast their national experience, exchange information, analyse outstanding problems and finally submit syntheses on a series of relevant topics to the World Road Congresses organized every four years. The 17th was held in October 1983 in Sydney (Australia). Twenty two National Reports (18 from Europe) were presented to this Congress dealing with concrete pavements. The author, who acted as a General Reporter, has drawn heavily from the information presented there, as well as from reports and discussions of international symposiums and seminars held in Europe lately.

Design Methods

Most of the countries have established their own standards and practices for concrete roads. The latest European survey was presented by Dr. R. Sharp to the 4th Int. Symp. on Concrete Roads (London, Sep. 82). 121 questions covering from basic design requirements to construction and control were answered by 15 countries. Design methodology is based primarily on full-scale monitoring. However theoretical research continues in order to refine the available methods in some aspects such as the fatigue factor and the load transfer at joints. The damaging effects of traffic loads when combined with thermal gradients is also of concern in some countries with 130 kN maximum legal axle loads and large temperature variations.

Pavement Design Types

The most used design for concrete highways is plain concrete slabs of 4 to 6 m long; the trend is to reduce the joint spacings when dowels are not provided. In order to limit warping stresses, the slabs are generally not longer than 25 times the thickness of the pavements. Undowelled joints continue to be a main source of concern. This topic will be considered later.

Jointed reinforced concrete pavements are now very seldom used. They are more expensive than plain concrete pavements and their performance is not considered to be better.

Continuously reinforced concrete pavements (CRCP) are currently used in Belgium, mostly for heavy traffic. It has been found that reducing the amount of longitudinal steel from 0.85 per cent to 0.67 per cent considerably increases the number of cracks spaced at between 0.80 and 3 m, which is the most favourable crack pattern, and virtually eliminates cluster cracking (cracks spaced at less than 0.40 m). The cracking process takes a few years to develop and is faster if the pavement is laid in summer. A theoretical diagram has been drawn up showing the interaction of the various design parameters.

In Spain the good long term performance of CRCP with a longitudinal reinforcement no higher than 0.7 per cent has also been confirmed. An increase in the use of CRCP for new roads is reported from Britain, both as a running surface and as a road base with a lighter reinforced design (CRCB) carrying a bituminous wearing course.

In France also a definite interest in CRCP has lately become apparent beginning with the construction in 1983 of an overlay on a 10 km section of a heavily loaded freeway. This technique is also being considered for new construction and for the replacement of outer lanes on undowelled plain concrete freeway pavements.

Coming back to Belgium, which is at present the European country with the widest experience in CRCP, it should be stressed that the current bidding price is close to that of plain concrete with dowelled joints. CRCP overlays are preferred for main roads in Belgium because of their experience of the design requiring little maintenance performance, its long service life and reduced user costs. This satisfactory result should be linked to the use of an adequate design and a high level of construction control.

The use of prestressed concrete is exceptional nowadays. Special mention should be made of the construction since 1966 of about 700,000 m^2 of "zero-maintenance" pavements at Amsterdam Schiphol Airport (The Netherlands). This design has been applied to critical areas subject to very high static loads, to aircraft fuel spillage and to high temperatures of jet exhaust gases. The slabs are 0.18 m thick, 7.50 m wide and from about 30 m to max. 120 m long. They are prestressed longitudinally by 7-wire cables and transversely by ribbed bars, both reinforcements being placed in ducts which are grouted after stressing. The successful outcome in the Netherlands, where it is intended to extend this application in the future, is a proof of the practical possibilities of this technique into which many countries poured considerable effort in the past but which now appears to have been abandoned for road construction.

Steel-fiber reinforced concrete is currently only used on a limited scale and for specific applications due to its greater cost. Thin overlays, bridge deck surfacings, airport aprons and industrial floors are some examples of applications. A minimum crimped steel-fiber content of about 40 kg per m^3 of concrete provides a substantial increase in flexural and fatigue strength allowing a reduction of the slab thickness, which in turn gives rise to smaller warping stresses.

New Pavement Structures

In France, following tests started in 1978, the so-called thick slab pavement is being applied on freeways. The economic interest of this solution rests on the fact that the slab thickness is less than the combined thickness of the pavement and the cement-treated subbase of the conventional French design, making it a more economical and faster laying process. Furthermore, blended cements and fly-ash are used in the mix and the maximum aggregate size can be increased. On a recent freeway section the pavement was laid on a draining layer which was either 6/20 crushed stone 80 mm thick or a permeable non-woven geotextile 8 mm thick with a drainage capacity 100 times greater than the expected rainfall. The draining layer was laid on a very stable lime or cement treated subgrade.

Roller compacted concrete is also under development in several countries. The binder content with up to 40 per cent fly ash is generally about 13 per cent of the dry weight of the aggregate and has a low water content, reaching a strength approaching that of plastic concrete. It can be manufactured in a continuous plant, laid by finisher or simple grader and compacted by roller. With a conventional surface dressing treatment it can be immediately opened to traffic without suffering damage, provided it is thoroughly compacted. Shrinkage cracks occur about 10 m apart and show an acceptable load transfer. It constitutes a good solution for the construction of secondary roads and also for strengthening existing highways subject to traffic during the work.

Over the last 15 years Norway has been engaged in the development of thin pavements for tunnels where temperatures are very uniform. Plain concrete 100 to 180 mm thick with undowelled joints every 10 m is used to support relatively heavy traffic. Continuously reinforced concrete pavements 80 to 180 mm thick are also being tested.

Joints

Differences in criteria still remain over the design of the joints regarding dowel provision and sealing, and information is being gathered to establish whether it is possible to fix the threshold when dowels are needed for load transfer. National standards require dowelled contraction joints in countries like Austria, Belgium, United Kingdom, Switzerland and West Germany, whereas non-dowelled, skewed transverse joints are generally used for instance in Czechoslovakia, East Germany, France, Italy and Spain.

At undowelled joints, the load transfer by aggregate interlock between adjacent slabs is impaired at moderate and low temperatures and the repetitive action of heavy traffic (the maximum legal axle load in Europe is generally about 110-130 kN) will lead to significant slab deflections at the joints if the slabs are not well supported from below. Water penetration may lead to erosion of the supporting subbase or subgrade and finally to the faulting of the pavement at the joints, aggravated by the pumping action of traffic.

In order to avoid this phenomenon the subbases have been strengthened and made more resistant to erosion by increasing the cement content up to 160 kg per m^3 as in lean concrete. Furthermore, pavement drainage systems are provided to ensure a quick outflow of any water trapped at the interface between slab, base and shoulder. With a very heavy traffic of about 5,000 trucks per lane with 100 kN max. axle loads (or 2,000 with 130 kN max. axle loads) it is generally regarded as advisable to install dowels, as has been done in some outer lanes of busy freeways in France. Incidentally, West Germany has found that if a cement stabilized subbase is provided, the number of dowels can be reduced by 45 per cent. This reduction is obtained by increasing the spacing of dowels in the areas least exposed to heavy wheel loads. In Spain a similar reduction has been successfully employed adopting a uniform spacing of 0.5 m.

European slip-form paver manufacturers have recently developed devices for placing dowels into the fresh concrete without affecting the surface evenness and the paving output.

Sawn joints are generally sealed although the service life of the poured sealants is seldom over 5 years. Many countries stress the importance of the width to depth proportions of the sealing groove configuration to control the strain in the sealant. Research is needed to improve the current specifications and the test methods on sealing compounds which are generally considered inadequate, both in respect of quality levels and long-term performance.

Unsealed sawn joints are also used in some countries. They perform well under traffic, either with dowelled pavements resting on an asphalt layer in severe climates or with undowelled pavements resting on a cement treated base in mild climates.

Joints formed in fresh concrete are generally limited to secondary roads, but it is the more general practice in Great Britain where pavements are mostly constructed using flint gravel aggregates which could not be sawn until the concrete is about 7 days old. Wet formed joints can prove a good solution but they are vulnerable to bad workmanship problems.

Subbases

Subbases increasingly consist of granular materials treated with cement and other hydraulic binders because they provide a more uniform and stable support for the slab plus being a good working platform for the paving process. In West Germany they even allow the traditional frost protecting layer to be omitted.

The practice of incorporating fly-ash into stabilized layers is becoming increasingly widespread with beneficial results.

The presence of the fly-ash assists the long term gain of mechanical strength and implies savings in cement content. This trend really falls within the more general framework of the recent innovations introduced to reduce costs and save energy. In the same context, the cement stabilization of marginal aggregates is under research in some countries. In Central and Northern Europe they would enable the use of local frost susceptible materials in place of scarce, good quality aggregates.

The move to more erosion-resistant subbases has already been mentioned, such as the slip-formed lean concrete used in France and in Spain to avoid pumping under heavy traffic. In a few Central European countries it is still customary to lay the concrete pavements over a thin bituminous layer, even when a cement treated subbase exists. Besides tradition, a protection against the infiltration of de-icing salts has been quoted as a justification.

The thickness of the subbase is usually in the 150-250 mm range.

Lateral Drainage

Lateral drainage of pavements for the fast elimination of the water trapped in the critical concrete slab-subbase-shoulder interfaces is considered an effective and beneficial practice. It is regarded as essential for roads with undowelled joints and for heavy traffic but it is also felt to be beneficial even when dowels are provided. Several countries systematically adopt drainage measures in newly constructed pavements, while others are testing different solutions with a view to identifying the most effective ones.

Drainage layer subbases are regarded by some countries as particularly well suited to wide roadbeds, such as in airport and multi-lane freeway pavements, whereas longitudinal drainage strips are a satisfactory system for two-lane carriageways.

Usually side drainage is effected through a porous concrete strip along the edge of the slab or hardshoulder with a slotted pipe drain at the bottom discharging through lateral outlets. Sometimes the drainage is left to the lower layers of the shoulder.

The installation of drainage trenches along pavements in service proved to be effective when pumping and faulting are only incipient. However, when this process has already developed and the subbase is erodible or the subgrade is water susceptible under a cracked surfacing combined with heavy traffic, side drainage should certainly be avoided since it is liable to accelerate the discharge of fines into the drainage system and lead to a worse situation.

Pavement drainage and erodibility of subbases are subjects of considerable interest in Europe. An International Seminar was held in Paris (March 1983) in order to state the progress already made and stress the matters calling for more detailed research. A paper on this is presented at this Conference by M. Ray and others.

Two-lane Principal Roads

Two-lane principal roads in concrete was one of the topics considered by the PIARC Technical Committee on Concrete Roads. Until recently, freeways and dual-carriageway highways received most of the attention in Europe but in many countries much current activity is centered on the construction or reconstruction of secondary roads that now have to support intense and heavy traffic. Here too concrete pavements offer technical and economic advantages in some cases.

A report has been drawn up summarizing the rather limited experience in this field. Whereas no special problems arise when a new facility is constructed or the traffic can be diverted, the rehabilitation of an existing road very often requires handling the traffic while the works are in progress and facing frequent restrictions imposed on paving.

The width of the rehabilitated pavement should be large enough to allow its construction one lane width at a time so that traffic can be controlled as alternate one-way shuttle working.

Construction of one lane at a time imposes limitations on the speed of execution. Only about 1 km of a lane can be kept closed at a time to traffic. If a hardening time of concrete of 2-3 days cannot be avoided, the average daily production is limited to 250-300 m.

Careful consideration has to be given to concrete delivery and the laying operation which may need particular machinery or construction methods. In some circumstances a fast hardening concrete has to be considered in order to open the pavement to traffic within 2 or 3 days.

Low-traffic Roads

Another expanding field for concrete pavements is low-traffic roads: secondary and rural roads, housing estates, farm and forest roads, etc. In most European countries this secondary network is 10 to 15 times greater than the main state network and its management is generally carried out by local public authorities or private collective entities. These roads should be designed with a relatively low construction cost and at the same time aiming at a long lasting pavement, requiring virtually no maintenance. The design traffic needs careful consideration.

It is impossible at the moment to compare the traffic between countries and to put forward a common classification. While the 80 kN standard axle is the most common, a 130 kN is allowed in some countries. Traffic can also be very specific to a particular sort of roadway. For instance, farm traffic is seasonal and variable in weight according to the agricultural production.

Traffic forecast of composition, weight and volume is also difficult.

The road width lies between 5 m and 7 m for village and housing roads, while a 3 m concrete strip is frequently laid on farm roads. Current pavement thickness varies from 160 to 200 mm for the former and from 140 to 180 mm for farm roads. Specific design methods are seldom used. An exception is France, where in 1981 a pavement design manual for light traffic was published.

A continuity of design between semi-rigid pavements with treated bases and concrete pavements has been incorporated through the flexural strength of the material. The thickness of the pavement is obtained from a nomograph taking into account the bearing capacity of the soil, the cumulative traffic expected and the flexural strength of the concrete (or treated material).

The subbase is often omitted with a good subgrade or for farm roads. Contraction joints every 3.5 to 6 m are either sawn or vibrated in fresh concrete with a crack-inducer of not less than a quarter of the slab thickness.

There are no rules for the dowelling of the joints, with a trend to relate this to the heavy traffic expected. The joints usually remain unsealed.

In order to allow the use of local materials and reduce costs, construction specifications are less stringent than those applied to main roads. The pavement is laid with concrete pavers and modified asphalt finishers, but also superplasticized concrete laid between forms and roller compacted dry concrete is being used in some countries. A simplification of the construction process without affecting the durability of the pavement is considered a requisite for the selection of a rigid pavement for minor roads.

Surface Texture

Surface texture is a matter of concern in Europe, particularly for freeways and other high-speed main roads where an adequate macrotexture is specified in order to guarantee a safe skid resistance in wet conditions. In some countries the traditional texture obtained by brushing was replaced in the 70's by transverse or longitudinal grooving of the fresh concrete. Different manual and mechanical means have been used. Transverse grooving facilitates the rapid expulsion of water sideways from under tires and lateral drainage of the surface water and considerably reduces the braking distances, but deep textures increases the running noise level and may affect the driver comfort, producing complaints from adjacent residential areas. Research carried out particularly in Great Britain and Belgium led however to generally acceptable solutions regarding groove dimensions and spacing. In Spain a longitudinal texture is currently employed by means of plastic bristles and steel tines, obtaining an initial surface depth texture by the sand-patch method of about 1.5 mm. Skid resistance is improved both regarding skid test coefficients and wet accident reduction with an acceptable noise level.

Another procedure developed in Belgium and being applied since 1980 in some French freeways with slip-form pavers is that of spreading and partially embedding non-polishable stone chippings into the fresh concrete surface.

This mechanized finishing process allows the use of a slab concrete of polishable limestone aggregate, thus enabling a distinct treatment of the structural and the user affecting safety requisites.

A similar omni-directional texture can be achieved by the Danish technique, also used in Belgium, of chemical stripping. The surface mortar whose setting is delayed by a retarder is eliminated by brushing 24-72 hours later. This technique, however, requires a non-polishable coarse aggregate.

On a 1984 French freeway construction site the two latter techniques have been combined in which somewhat smaller size chippings were fully embedded into the surface with a vibrating screed. This was followed by a surface spray of a mixture of a retarding agent and a curing compound. The finished texture was obtained by brushing the surface the next day to expose the aggregate. A better riding quality is obtained thanks to this procedure.

With respect to old worn and slippery surfaces, besides the classic solution of longitudinal or transverse grooving, more economical surface dressing treatments using improved bituminous binders have been successfully developed and used in France on busy freeways. This technique, applied since 1975 and already routine, also enables the use of polishable limestone aggregate for the pavement, which is surfaced after some months of traffic.

Concrete Block Paving

The use of concrete block paving has grown considerably over the last 30 years in many European countries (the Netherlands, Great Britain, West Germany, Belgium, Denmark, France) as well as in Australia, South Africa and Japan.

Two international conferences were held (England 1980-The Netherlands 1984) on this topic and a state of the art report was presented at the last World Road Congress. Significant advances are apparent in specifications, standards and test procedures, manufacture of concrete blocks, structural design and construction practice, particularly regarding pavement quality and laying output.

Concrete block paving is suitable for a wide range of traffic loading from pedestrians through to the heaviest axle loads of specialized traffic, such as are used for port unloading and stacking containers. It is very adaptable to the urban scene where variety of appearance can easily be obtained by means of changes in colour, size and texture of the blocks. A particular advantage of block paving is that it can be taken up and relaid with relative ease for the insertion or repair of service pipes and ducts or their surface levels can easily be restored if deformed when laid on a ground subject to settlement. Their high surface wear resistance is appreciated where studded tires and steel chains are used in winter.

In addition to rectangular blocks a great variety of shapes are in use, with a thickness of 50-120 mm and more, depending upon the traffic to be carried. The blocks are typically placed on a layer of coarse sand, the whole superimposed on a subbase for which a variety of materials can be used. Sand is spread over the surface and vibrated into the joints between blocks providing the friction between adjoining faces that enables the pavement to develop its capacity to perform as a load bearing structure.

The design of pavements incorporating concrete blocks has generally developed as a result of experience. However the research carried out in some countries has been helpful in providing a better understanding of the performance of different structures and has produced reliable design methods both for lightly and medium trafficked pavements (U.K. Cement and Concrete Association; Amsterdam Road Department) and for heavy duty pavements (British Ports Association).

Design charts are now available for determining the total construction thickness of the pavement structure for a required number of load repetitions. It is important to get this right because excessive horizontal tensile strain in the subbase would lead to a serviceability failure by rutting or permanent surface deformation.

It must be stressed however that failures are usually not related to insufficient pavement block thickness, but to inadequate subbase materials, moisture susceptible subgrades with a lack of adequate drainage and poor workmanship.

Miscellaneous

Concrete surfacings are not so popular on bridge decks in Europe as in the United States. However it is a solution applied with success in some countries including the Netherlands, Spain and Switzerland. The bonded system is preferred and a good performance is linked to a careful construction process. In Belgium the continuity of the CRCP has in many instances been carried over engineering structures, avoiding the need for pavement anchorage terminals on either side.

Safety barriers, curbs and gutters, i.e. functional elements of the roadway made from concrete, are also being introduced or developed. They are precast or slip-formed, but again their use is generally not as extensive as in the U.S. In France a heavy concrete barrier for trucks (called LBA) has been tested. Designed with the same shape as the New Jersey barrier, it is however 1.50 m high, 0.85 m wide at the bottom and 0.20 m on the top. In that country, since 1984, precast concrete barriers can be moved mechanically from one lane to another by special equipment depending upon traffic conditions and repair work progress.

Concrete shoulders are beginning to be considered, and have been used on a limited scale. In Great Britain it has been the practice for many years to construct the pavement and the shoulder to the same design.

A new curing compound has been developed which, after only a few minutes, forms a sufficiently strong surface film on the concrete to withstand rainstorms. This compound, initially devised in East Germany, has been developed in Austria and in stormy seasons can substitute for the protection tents used in those countries.

Maintenance Strategies and Systematic Inspection

Maintenance strategies linked to standardized pavement structures are still rarely found in Europe. France is one of the few exceptions, where maintenance sequences for joint sealings, surface treatments and eventual reconstruction and strengthening are preestablished.

The application of pavement management systems is hindered by lack of performance data, and by the rapid development of new pavement structures rendering the performance models generated from old in-service pavements unusable. For instance, the better performance of modern non-dowelled slabs has already been confirmed when they rest on a lean concrete base, a lateral drainage is provided and the joint spacing reduced. However the ultimate performance of the thick slab pavement still remains difficult to forecast.

Data banks are only beginning to be set up and are generally at present only operational on a limited scale, such as on some toll-highways.

A series of high-efficiency apparatus for non-destructive monitoring and testing of the pavements is in use in some countries, such as France, Spain and Great Britain. They are very useful for a systematic inspection in order to adopt corrective measures when certain thresholds are reached. For example:

- The SCRIM for measuring skid resistance at a speed of 50-60 km/h.
- The GERPHO for photographing the pavement and adjoining shoulder at a speed of 50-60 km/h, giving a record of certain structural defects.
- The APL for analyzing surface evenness at a measuring speed of 72 km/h.
- A slab corner deflection measuring device with a high rate output, the collograph which continuously detects voids and the bond between courses and a modified deflectograph for measuring deflections and load transfer at joints.

The use of this different apparatus should supplement and not supplant visual inspection. Both provide a valuable contribution to decision making.

Repair and Rehabilitation

The importance of a systematic approach to the repair and rehabilitation of all pavement types is now fully realised and systems are now being introduced in some countries, though some engineers are to be found who are unaware that concrete pavements do need maintenance inspections and attention during their long service life.

In Switzerland the different types of failure have been analyzed, in each case giving the corresponding diagnosis and treatment. For the first time, European practice has been summarized in a Manual, edited by Cembureau.

There is room for improvement however regarding methods for evaluating the condition of existing pavements in order to plan 4-R measures. Many European highways are supporting a very heavy and intense traffic, with a high percentage of overweight loadings. Rapid action with protective and repair measures may defer or even obviate major rehabilitation work or reconstruction.

Recent advances are reported on local repairs of spalling, slab edges, pop-outs, cracks and joint edge spalls and on the fast reconstruction of one or several faulty slabs. Modified rapid hardening cements in high initial strength mortars with compensated shrinkage are in use, as well as polyester resins, rigid and flexibilized epoxy resins incorporating polysulphurs, etc.

The use of superplasticized concrete is widespread and in many cases the reconstructed area can be opened to traffic after only 24 hours. In Austria, since superplasticizers are available which can be added in higher amounts without leading to a decrease of entrained air, superplasticized concrete with a w/c ratio of only 0.35 is being used for special conditions. For instance, a flexural strength of 3.85 N/mm^2 was exceeded on a test section after only 14 hours. In West Germany high-initial strength superplasticized concrete has been used since 1976 for the reconstruction of damaged slabs in daylight work.

Concrete Overlays

Concrete overlays are increasingly being used in Europe to strengthen both rigid and flexible pavements. An International Seminar was held in May 1984 in Brussels (Belgium) organized by Cembureau where the latest experiences of eight countries were discussed. The subject was split into two parts: the so-called structural or thick overlay, of not less than 0.15 m; and thin overlays, which are at present being tested.

Thick overlays have been in use since about 1960. Generally the pavement consists of short plain concrete slabs with or without dowels at the joints or a continuously reinforced concrete pavement. Thick overlays can in principle be applied to any existing paved surface with the necessary bearing capacity. The design starts with a detailed survey of the existing pavement, an analysis of its failures and a traffic forecast.

The overlay thickness is related to the expected traffic and to the condition of the existing pavement. CRCP are mainly restricted to use on freeways and principal roads. At present there is not a specific design method for overlays, but the available stress analysis models can be used. For instance in Belgium, with an axle load limit of 130 kN, the thickness of a dowelled plain concrete pavement is of 200-230 mm in the case of heavy or medium traffic and of 150-200 mm with light traffic. The corresponding figures for CRCP are 180-200 mm and 150-180 mm.

On old asphalt pavements the concrete can be poured directly on the old surface, provided the thickness of the slab is not too variable. Rutting greater than 30 mm depth is normally corrected by grinding. A bituminous levelling course is normally only laid where the geometric profile must be modified or the existing pavement is in a very bad condition. When laying CRCP, care should be taken to ensure that only small variations occur in the percentage of longitudinal steel, which should not be less than 0.5 at any point. To cope with concrete overthicknesses a steel elastic limit of 600 MPa is sometimes recommended.

On concrete overlay pavements, reflective cracking may occur over joints or cracks below. CRCP are considered to cope well with this problem. With plain concrete overlays, the old slabs are generally broken into pieces of about 1 m^2 and a bond breaking layer is used. Alternatively, the slabs may be 5 m long and lightly reinforced (2 to 3 kg/m^2 of steel). Breaking up the old pavement is generally considered a simpler and more effective procedure than mud-jacking to control block rocking.

Thin concrete overlays are currently being tested in some European countries. Unbonded overlays must be thicker than 100 mm in order to withstand the traffic-induced stresses. Steel-fiber concrete with transverse joints every 10-15 m, lightly-reinforced concrete slabs 10-25 m long and continuously reinforced concrete pavements with a thickness of 100-160 mm are under observation.

Bonded overlays 50 to 100 mm thick are constructed with steel-fiber concrete. The scarification of the existing concrete surface, the bonding grout, the use of a concrete with a minimum shrinkage, an appropriate curing and the matching of the joints are important features to consider.

Very thin bonded overlays with a thickness of less than 50 mm have been applied as the means of restoring worn running surfaces with apparent success. In Austria laboratory research and field tests have been carried out in order to fill in the ruts caused by studded tires still allowed in that country. For overlays with a minimum layer thickness of 35 mm, a superplasticized concrete with a water-cement ratio of only 0.35 and a carefully designed mix composition is used to minimize shrinkage and provide good workability and long-term durability. For overlays only 20 mm thick, a suitable latex-modifier is incorporated in order to reduce the modulus of elasticity and the shrinkage of the concrete. Intensive water-curing with water retaining cellulose fabrics is considered indispensable. A set of guidelines and check lists has been written based on the experience available.

Recycling

Although the use of quality aggregates is general practice in manufacturing pavement concretes, the use of lower grade local aggregates, waste materials and recycled concrete from old pavements continues to find applications.

In France since 1976 the reconstruction of the outer heavy traffic lanes of some freeways in the Paris area have involved the recycling of demolished concrete. Previously, the coarse aggregates thus obtained were re-used only in lean concrete subbases, but recently the crushed material has been employed in new pavements. The crushed material was utilized with the addition of about 20 per cent natural sand.

In the Netherlands a taxiway and an apron were constructed at Maastricht Airport in 1981 using crushed concrete as aggregate from the demolition of several parking areas. The recycled concrete consisted of 85 per cent reclaimed crushed concrete and 15 per cent natural sand.

Recycling of concrete pavements is however still seldom done in Europe, an overlay being generally cheaper unless the cost of the aggregates is very high.

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