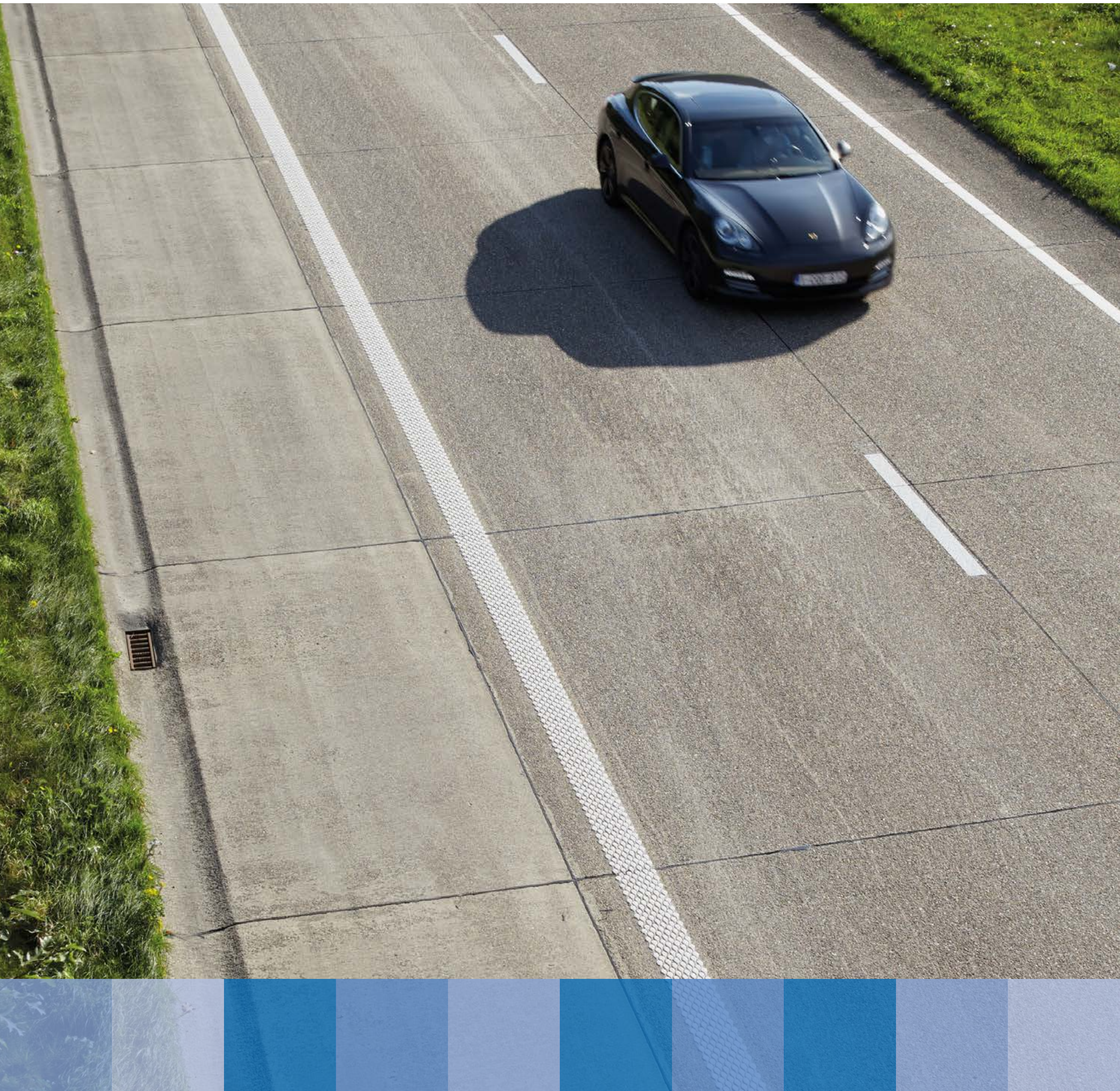
EUPAVE
EUROPEAN CONCRETE PAVING ASSOCIATION

Guide for design of “Jointed plain concrete pavements”



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1 INTRODUCTION

Jointed Plain Concrete Pavements (JPCP) are long proven to be the most common type of cast in place concrete pavements in the world. Specific to all concrete pavements, the phenomenon of cracking occurs when the concrete is exposed to several thermal and mechanical actions due to early-age shrinkage or expansion, temperature gradient, traffic stresses or possible soil movements.

The transverse joints of which it is constituted are essential to prevent the pavement from cracking randomly. Namely, the principle of JPCP is to intentionally locate the cracks at these joints and, in this way, control their location and width.

This method differs fundamentally from another type of concrete pavement called "Continuously Reinforced Concrete Pavement" (CRCP), which has no transverse joints, but a network of fine transverse cracks whose evolution is controlled by longitudinal reinforcement bars.

JPCP is suitable for a wide range of applications such as motorways, highways, main and secondary roads, agricultural roads, urban roads, squares, passages, bus lanes, industrial sites, car parks, etc.

The behaviour of JPCP subject to traffic load and weather conditions strongly depends on the following elements:

- transverse joints spacing;
- width of the JPCP;
- thickness of the JPCP;
- presence or absence of dowels in the transverse joints;
- presence or absence of reinforcement bars;
- bearing capacity of the base layer and subbase.

This publication provides a general overview of the basic principles of JPCPs, as well as an assessment of the influence of the aforementioned factors. In addition to many useful recommendations for the design and construction, this document does not fail to deal with different aspects such as thermal movements, different types of joints and reinforcements. Finally, this publication also contains a guide for the design of joint layouts according to the rules of art.

JPCP for a rural road and cycle path, Breugelweg, Pelt, Belgium

"JOINTED PLAIN CONCRETE PAVEMENTS (JPCP): EVER UNRIVALLED FOR A SUSTAINABLE ROAD PAVEMENT"

The principle of JPCP used as road pavement has existed for more than 120 years. The oldest known example is Court Avenue in Bellefontaine, Ohio, USA. In 1891, George Bartholomew, an immigrant and expert in cement and concrete, proposed to the city administration to pave the street in front of the City Hall with concrete. After a first conclusive experiment, permission to carry out the project was granted in 1893. However, the authorities were not particularly enthusiastic because they had never seen another example elsewhere. As consequence of that, George Bartholomew had to supply the cement himself and pay a $ 5 000 guarantee for a period of 5 years, knowing that the work total cost was $ 9 000. The deposit was returned unequivocal. Today, Court Avenue is still there and is still operational. While repairs have been necessary in recent years to preserve this historic site, during its first 50 years of existence, only $ 1 400 was spent on maintenance. On a technical level, the structure of the pavement is also particular. It is indeed a two-lift concrete pavement whose top layer is composed of aggregates up to 12 mm and characterised by a water/cement ratio of 0.45. The bottom layer is composed of aggregates up to 36 mm and has a water/cement ratio of 0.60. The strength of the concrete was about 35 MPa.

Commemorative plaque for the "oldest concrete street" in Bellefontaine.

JPCP is currently built around the world and covers all possible applications, ranging from lightly trafficked pavements, such as walking paths, bike paths and squares, to heavily loaded pavements such as highways, port areas and airport runways. For all these applications, numerous examples testify to the long life of these pavements, combined with very limited maintenance. Practically, their longevity can reach 40, 50,... up to over 80 years! E.g. motorway A11 from Berlin to Poland was opened September 1936 and has been in service till 2019-2020.

Thanks to the modern concept of transverse contraction joints, road surfaces have also become very comfortable. An appropriate surface finishing, such as exposed aggregates, grinding or the NGCS (Next Generation Concrete Surface), guarantees a low noise pavement type with low rolling resistance, resulting in a net reduction in fuel consumption.

The realization of a two-lift concrete pavement offers the possibility of maximizing the acoustic characteristics and ride comfort of the top layer, while using, for example, recycled aggregates in the lower layer of the pavement structure. In Flanders, Belgium it is allowed to replace up to 20 % of coarse aggregates with aggregates of recycled concrete of high quality in the bottom layer. From a technical point of view, however, it is possible to apply a higher replacement percentage (70 or 100 % of the coarse aggregates). In Austria, this technique has already been used since the beginning of the 1990s for the construction of highways made of two-layer concrete slabs.

The lighter surface colour of a concrete road also has the advantage of an albedo, or reflecting power, higher than black bituminous surfaces. The reflection of this energy ensures a slowing down of the greenhouse effect, which is equivalent to a reduction of 25 kg / m² of CO_2. In urban environments, light coloured surfaces can therefore reduce the effect of local warming and the risk of smog.

A more complete assessment of the environmental performance of a concrete pavement can be done using Life Cycle Analysis (LCA). Concrete achieves excellent results for many environmental indicators including: energy, water, smog, natural resources and ecotoxicity. The use of blast furnace slag cement in concrete compositions also limits the impact on the greenhouse effect. It is clear that the environmental footprint of a concrete road with a service life of 30, 40 years or more and requiring very little intervention for maintenance or renovation is positive, given the long-term savings over time on raw materials, transportation and energy.

Finally, long service life and low maintenance also have a positive influence on the total cost of the pavement in relation to its service life.

We can therefore conclude that jointed plain concrete pavements meet all the requirements of sustainable construction.

Concrete roads and platforms in industrial areas (photo left: A. Nullens for FEBELCEM)

2 STRESSES IN JPCP

Concrete pavements are subject to a variety of stresses that can be divided into two categories: traffic and non-traffic related stresses, the latter specific from fresh concrete (setting and hardening) as well as hardened concrete.

2.1 NON-TRAFFIC RELATED STRESSES

2.1.1 Stresses in fresh concrete

The influence of fresh concrete stresses on the future pavement behaviour should not be underestimated. The appearance of uncontrolled cracks, the failure of the pavement, the loss of skid resistance and scaling of the surface are all defects which have their origin in the lack of care during the construction phase. Insufficient protection of the fresh concrete surface at young age is probably the most common of them. Directly after pouring, the concrete, which evolves from plastic state to solid state, is influenced by hygrometric and thermal phenomena, namely: hygrometric shrinkage, thermal contraction of concrete and uneven distribution of the temperature in depth of the concrete layer.

2.1.1.a Hygrometric or plastic shrinkage

Hygrometric shrinkage is specific to mixtures with hydraulic binders and occurs mainly because water evaporates from the mixture. This type of shrinkage is by far the most important during the plastic phase, which is before the end of the setting of cement, thus for about the first six to nine hours following the production of concrete. The unrestrained plastic shrinkage during this period can be up to ten times greater than the total drying shrinkage between

Random shrinkage cracks due to insufficient protection of fresh concrete

23 hours and 300 days of the same concrete at constant temperature and humidity (the unrestrained plastic shrinkage of unprotected concrete with low wind reaches around 3 mm/m, the total hygrometric shrinkage after setting is approximately 0.3 to 0.4 mm/m). Effective protection of freshly poured concrete against desiccation is therefore an absolute necessity to prevent any evaporation of the water through the surface in order to minimize plastic shrinkage.

2.1.1.b Thermal contraction

The temperature cooling which occurs during the first night following concreting causes a thermal contraction of young concrete cumulated with hygrometric shrinkage.

2.1.1.c Temperature gradient

Even before the setting of concrete is completed, a temperature difference can occur between the top and the bottom of the concrete layer. This effect is even more pronounced the first day because of the heat of hydration released during the setting period. In theory, it is recommended to pour concrete during the afternoon so that the heat of hydration and the nocturnal cooling compensate each other. In practice, however, concreting usually takes place early in the morning. The cooling can then cause a negative temperature gradient (the upper part is cooler than the lower part), resulting in the bending of the slab. This phenomenon is called the "built-in curling effect".

2.1.2 Stresses in hardened concrete

Hardened concrete remains subject to all the stresses experienced during the plastic phase but reacts differently to it. Added to this, is the thermal expansion and a possible movement of the base layers under the pavement (soil – subgrade - subbase – base layers).

2.1.2.a Contraction

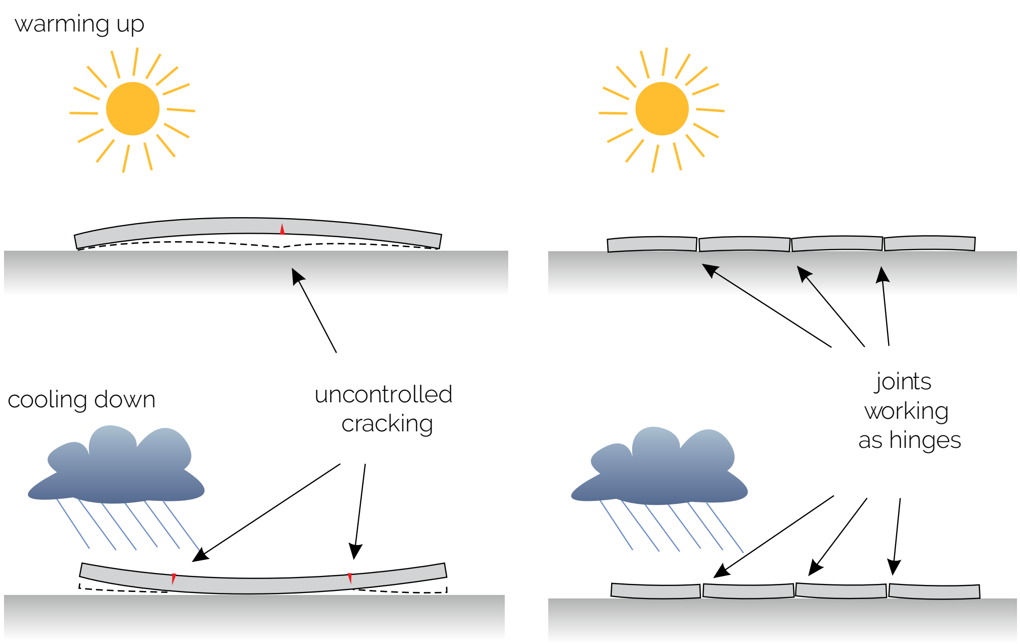
Hardened concrete continues to lose water, but to a much lesser extent because much of the water is already bound to the cement. Young concrete must therefore be protected for at least 72 hours by means of an effective curing compound. Evaporation, inevitable although limited, still leads to drying shrinkage. The latter can also be accentuated by the contraction due to pavement cooling.

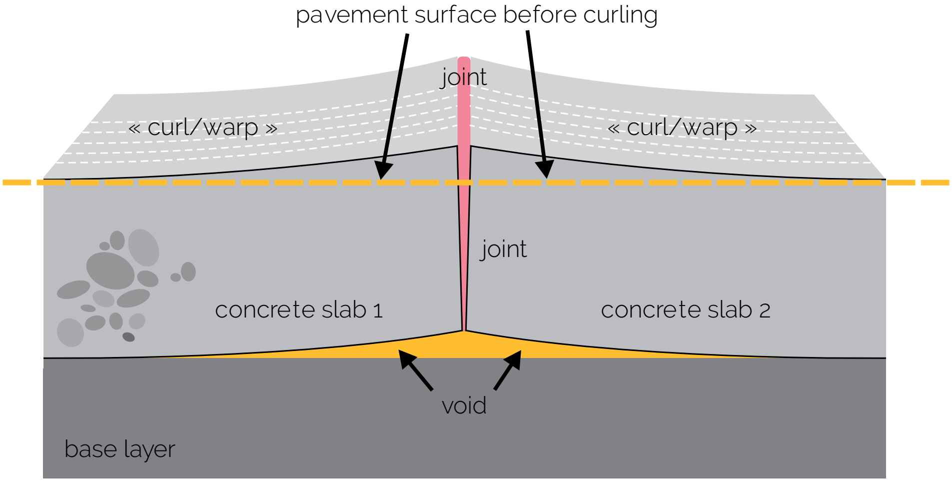
2.1.2.b Temperature gradient and curling

Variations of the outdoor temperatures cause a varia<tion of the temperature from the upper part towards the lower part of a JPCP, namely a temperature gradient which itself evolves as a function of the ambient temperature. Because of this temperature gradient, the upper and lower fibres will stretch or contract with consequent deformation of the pavement. In the event of an increase in the outside temperature, the slab will tend to curl downwards. However, this phenomenon is balanced by the weight of the slab, so that the tensile stresses appear below the pavement and are added to the stresses induced by traffic load. When the temperature drops, the upper fibres will tend to contract further and cause the pavement to curl upwards. The combination of lifted corners and heavy wheel loading results in top-down cracking at the corners. It is also possible to limit this phenomenon by avoiding, as far as possible, abrupt changes in temperature of the young concrete (protection of fresh concrete) and by producing sufficiently short sections.

Curling (or warping) stresses are the reason why the width of the JPCP must remain limited. In addition, the presence of transverse contraction joints in the pavement is essential.

Curling effects on hardened concrete





Schematic illustration of curling

"Curling" and "Warping" refer to the upward lifting or downward bending of corners of concrete slabs, creating an empty space under the pavement.

In the case of outdoor pavements, this occurs mostly under the influence of a temperature gradient in JPCP, due to a temperature difference above and below the pavement that varies during day and night.

In the case of an interior floor, the phenomenon is rather due to a difference in the humidity level above and below the concrete slab. This difference occurs when the surface dries out, referred to as drying shrinkage, while the humidity in the bottom of the slab remains constant.

Factors that accentuate the phenomenon of "curling" are:

- late or insufficient protection against desiccation of the concrete surface;
- sun and wind;
- high length / thickness ratio;
- sensitivity of concrete to shrinkage and thermal contraction;
- free slab edges or joints without load transfer;
- no friction with the base layer and therefore sliding surfaces.

2.1.2.c Thermal expansion

Increase in temperature causes slab elongation, which is usually neutralized by the concrete's self-weight and friction with the base layer. This expansion compresses the joints, resulting in compressive stresses in the concrete. This phenomenon is not a problem, as the concrete is very resistant to compression. In addition, it generates a prestressing action that opposes bending and tensile stresses, which is beneficial for the whole JPCP life. In most cases, expansion joints are not required, except when approaching adjacent structures or other types of pavement, or in the case of trajectories with reduced radii of curvature.

The amplitude at which the concrete expands or contracts as a function of temperature variations depends on the coefficient of thermal expansion of concrete α (m / m / ° C). The order of magnitude of α is 10^{-5} / ° C and is mainly determined by the nature of the aggregates. E.g., limestone has a relatively low coefficient of expansion of 8×10^{-6} / ° C, while that of porphyry (type of igneous rock) and gravel is higher and reaches about 12×10^{-6} / ° C.

A concrete with a low coefficient of thermal expansion is less subject to these deformations and will therefore behave better over time. From this point of view, it is therefore recommended to use a calcareous aggregate. However, limestone is an aggregate that is prone to polishing under the influence of traffic, which makes the pavement less skid resistant. The braking distance becomes longer and the safety on the road is impaired. The calcareous aggregate is therefore only used as a base layer of a two-lift pavement or for a pavement intended for low-speed traffic - for example in car parks.

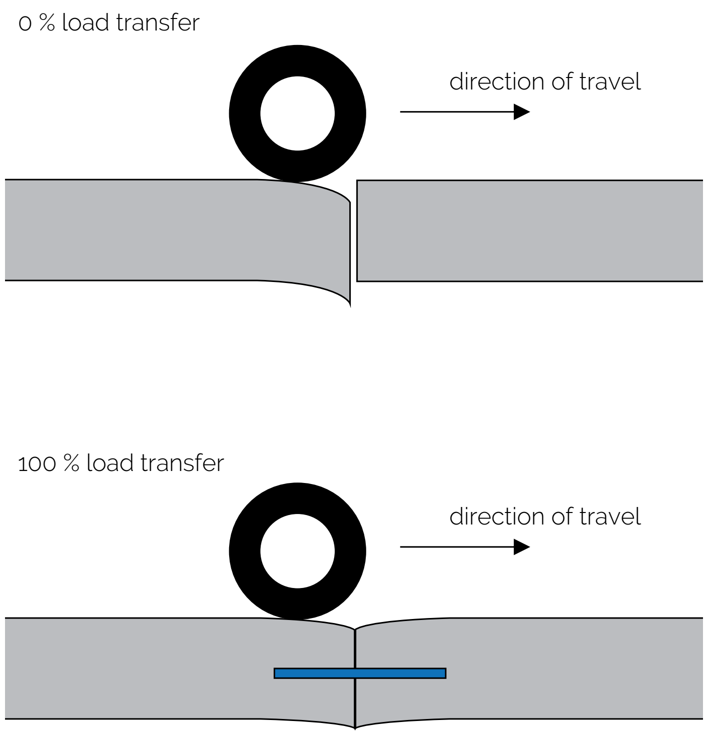
What does the coefficient α of 10^{-5} / ˚ C mean? Let us look at the case of a 10 m long pavement, having been implemented at a temperature of 5˚ C. On a hot summer day, the pavement temperature easily reaches 35 ˚ C. With a temperature difference ΔT = 30 ˚ C., the thermal expansion reaches 30 ˚ C × 10 × 10^{-5} / ˚ C = 3 mm. In case of expansion, the slabs work as a block and the displacement of each of them is cumulative. In case of contraction, each slab operates in isolation and a displaced pavement may not return to its original position. The calculation, it is true, is considered for a surface free of friction. In practice, a friction between the pavement and the base layer or the asphalt sandwich layer exists. The factual movements are therefore smaller. In addition, not the outside temperature should be considered but the temperature of the concrete, in the centre of the pavement.

2.2 TRAFFIC RELATED STRESSES

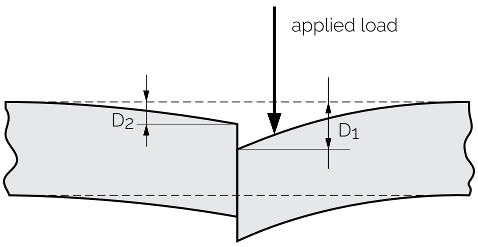
The calculation of the thickness of the concrete pavement is carried out at the places where the highest stresses (traffic load combined with thermal loads) are applied, namely at the joints and the edges of the pavement. High stresses can be avoided at the edges of the pavement by providing a sufficiently wide riding lane, widened at the edge of the slower traffic lane carrying the largest load.

Another important parameter is load transfer in the joints, from one slab to the next. This means that when a wheel load approaches the joint, the slab that is not subjected to the load, associates with the loaded slab and deflects. The principle is clearly illustrated in the figure below. In case of efficient load transfer, the stresses on the joints are considerably reduced and this can offer reduced concrete thickness.

The load transfer efficiency, also known as joint efficiency, can be stated as the



Principle of load transfer between two adjacent slabs percentage of the transmitted deflection across the adjacent slabs as depicted below. In practice, joint efficiency is measured by means of a Falling Weight Deflectometer (FWD) test, or in a simpler fashion, by a plate loading test (PLT).



Joint efficiency concept

Joint efficiency, J, can then be expressed as:

$$J = \frac{D_2}{D_1} \times 100$$

There are various recommendations and limits for the joint efficiency. Often, a minimum load transfer efficiency of 90% is required for jointed concrete pavements.

The load transfer is obtained by means of the following phenomena and measurements:

- the interlocking of the aggregates in the concrete at the joint below the saw cut;
- the presence of a rigid hydraulically bound base layer, which limits the deflection under the joint, in comparison with unbound base layers;
- the presence of dowels in the transverse joints in order to ensure the longitudinal contraction in the joint while ensuring vertical load transfer from one slab to the other. Dowels are mostly circular and smooth bars but also square shaped and plate dowels are available.

The interlocking of the aggregates in each other is especially efficient in case of high temperature - in the summer - when the joints are well closed, as well as when the travel speeds and vehicle weights are low. However, with joint openings beyond 0.6 mm, aggregate interlock becomes ineffective at transferring any load. Other measures to increase the load transfer are also recommended, especially as they prevent the so called "faulting" of the slabs at the joints level. Faulting occurs most of the time because of the pump effect when water gets entrapped between the concrete pavement and the base layers. Heavy traffic and unstable joints that deflect excessively under load cause the erosion of the base layer and the propulsion of fine particles from it upwards. Over time, an empty space is created under the joint, which causes the formation of a "fault" (difference in elevation with approach slab higher than leave slab) between the two slabs. In addition, this phenomenon increases the risk of cracking of the slabs, broken corners and spalling of the joint edges.

Faulting of a joint

2.3 FRICTION WITH THE SUPPORT - PLASTIC SHEET - ASPHALT SANDWICH LAYER

The contraction or expansion of the concrete is restrained by the friction with the support, which creates tensile stresses in the concrete that may lead to cracking and failure. One could therefore think that the friction with the support should be minimized, for example by placing a bond breaker such as a plastic sheet. This is a solution that is often used and can help preventing the fresh concrete penetration in the subbase/base layer as well, but also has a major drawback. Indeed, because of the sliding surface thus created, the first crack that appears may open completely. As a result, the following cracks won't propagate within the other cut joints. The pavement then moves in blocks of 3 to 5 slabs with, between these blocks, a widely opened joint. This affects the durability of the pavement and its comfort of use.

Application of a plastic sheet as a bond breaker (photos: S. Ghafari)

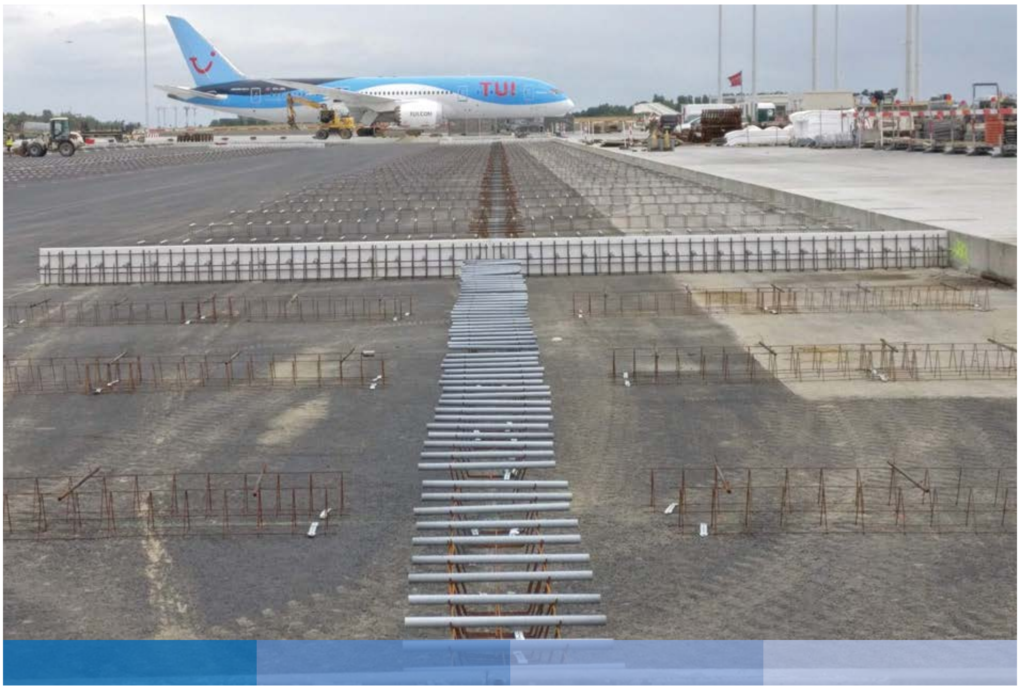
Too widely opened joint due to sliding upon a plastic sheet

Uniform and sufficient friction or even adhesion with the base layer is therefore preferable. Sudden movements due to temperature variations of the concrete at a young age should be avoided as much as possible and the slab length should be limited. In that case, due to its specific characteristics, pavement quality concrete will have no problem absorbing tensile stresses due to frictional movement, even at a young age. Friction with the base layer is therefore of no issue here.

Let's note that, if the base layer is likely to absorb water, it is recommended to wet it before concreting, to reduce the water migration of fresh concrete.

As an alternative to the plastic sheet mentioned above, an effective solution against the risk of "pumping effect", and thus against the faulting of JPCP, is to incorporate a sandwich layer of asphalt between the cement-bound base layer and the concrete pavement. This sandwich layer acts as a waterproof membrane and thus protects the base layer against erosion. In addition it creates a good adhesion between all layers, which is positive for the behaviour of the structure under load and which is also beneficial for the thickness design of the pavement.

For all these reasons, dowelled JPCP combined with an asphalt sandwich layer is a robust solution, ideal for heavily trafficked roadways.



Construction of JPCP on an asphalt course at Brussels Airport

3 JOINTS AND GEOMETRIC CHARACTERISTICS OF JPCP

3.1 FUNCTION OF THE JOINTS

As a reminder, joints are essential to prevent the concrete pavement from cracking randomly under the influence of contraction and expansion, temperature gradient, traffic and possible earth movements. The cracks are therefore located intentionally at the joints and, in this way, are controlled.

3.2 JOINT SPACING

It can be seen from the previous sections that the different types of loads have a significant influence on the determination of the dimensions of concrete pavements.

Whether the pavement thickness is defined by design calculations or based on design tables, the following practical rules can be applied: (L = slab length, w = slab width, T = slab thickness)

L / w ≤ 1.50 to 1.75

This rule imposes the shape of the slab being as square as possible. Any long narrow slabs behave like a beam and the risk of curling or excessive bending and consequent bending tensile stresses increases. However, this rule remains general and must be considered on a case by case basis. For industrial pavements, where the slabs are trafficked in two directions, square slabs – a ratio of 1 : 1 – are the best solution. For a walking path with a width of 1 m, a slab of 2.5 to 3 m long could be used. For bus-tramways, the strips between and next to the rails are often limited to a width between 0.80 and 1 m. In this case, the recommended slab length would then be 2.5 m. However, given the high load that buses represent, a (double) reinforcing mesh is necessary in this case.

L ≤ 25 T to 30T

This second rule establishes a relationship between the length of the slab and the thickness of the concrete pavement. With a factor 25 it can be considered as a strict, conservative and safe rule. If the first rule is fulfilled (square shaped slabs) some countries adopt the more flexible rule with factor 30. But for some applications such as roundabouts and bus lanes, increased thicknesses can be adopted in combination with limited slab lengths (L ≤ 20T).

L ≤ 5.00 m to 7.50 m

The third rule limits the length for unreinforced concrete pavements to a predefined value. Some countries are more conservative and limit joint spacing always to 5.00 m while others allow up to 7.50 m. Again, square shaped slabs can be made longer than elongated slabs.

Tramway with narrow concrete slabs between and along the rails

For pavements with no or limited traffic, such as walking paths, cycling paths and public spaces, the rules can also be less strict. However, when thickness is reduced to e.g. 14 to 16 cm, too long joint spacing can induce a risk of curling because of the limited dead weight and can lead to cracking of the pavement.

Thickness of the slab	Joint spacing
14 cm	3.50 to 4.00 m
16 cm	4.00 to 5.00 m
18 cm	4.50 to 5.50 m
20 to 26 cm	5.00 to 7.50 m

Recommended range of joint spacing depending on slab thickness with the lower figures corresponding to the safest options

Not only the length but also the width of the slabs must remain limited. For unreinforced concrete slabs: **w ≤ 4.50 m.** This is mainly related to the transverse curling effect due to which too wide slabs often cause longitudinal cracks.

Thicker concrete pavements, e.g. on airports, allow larger slab dimensions (photo: Betonhuis, NL)

3.3 TYPES OF JOINTS

3.3.1 Transverse contraction-bending joints

As its name suggests, the role of a contraction-bending joint is to limit the effect of both contraction (hygrometric shrinkage and thermal contraction) and bending (due to deformations resulting, among other things, from the temperature gradient).

To avoid any random crack pattern at the surface, transverse joints are created by initiating the cracks at specific locations, i.e. with the spacing determined in the preceding section. This crack initiator can be carried out in fresh or hardened concrete. If the concrete is fresh, a plastic strip is inserted with a vibrating device studied for this purpose. This technique was previously used in Europe on agricultural roads but has shown poor results over the years.

Nowadays, the most common technique for induced cracking is sawing joints in sufficiently hardened concrete.

Sawed cut as a crack initiator

For optimal result, the depth of these cuts is about 1/3 of the thickness of the concrete pavement (e.g. in Germany: 25-30 % for transverse joints and 35-40 % for longitudinal joints). In case fibre reinforced concrete, sawing depth is increased to 1/2 of the thickness. The width of the first saw cut generally measures 3 to 4 mm. The ideal time for sawing joints is usually between 6 and 12 hours after pouring the concrete but can sometimes be much later depending on the type of concrete and weather conditions. Obviously, it is necessary to wait until the concrete has hardened enough to access the sawing area.

The concrete must also be strong enough to prevent small aggregates from being ripped along the joint during sawing. The minimum compressive strength should be about 10 MPa. On the other hand, sawing must happen before the tensile or bending stresses in the concrete cause undesirable random cracking. Because of its multiple influencing factors, the optimal time should be determined by an expert. To name a few, some factors influencing the saw cutting time are: concrete composition, hardness of stones, type of cement, weather conditions, type of saw, the possible use of a retarding agent, etc.

The joints are then widened by a groove of 8 to 10 mm wide, depending on the type of seal. In case of widely opened joint cuts, the groove may also be wider than 10 mm. The edges of the joint can also be chamfered, which offers an expansion room for the seal when the JPCP is under compression. After inserting a joint backer rod, the joint sealing can be applied, preceded or not by an adhesive varnish. The sealing material may be a hot bituminous mass, a cold-applied product or a preformed synthetic rubber profile (usually made of EPDM) – see further in this document. In order to ensure a durable behaviour, the sealing of the joints is highly recommended. Yet, for lightly loaded pavements such as pedestrian areas and cycle paths, an unsealed and unwidened joint cut is often preferred.

Professional equipment for sawing of the joints, including suction of the slurry (photos: OAT)

“DOWELS”

For heavy-traffic roads, the use of dowels is necessary for load transfer and thus to avoid faulting at the joints.
The dowels usually are 25 mm (to 40 mm) in diameter and 500 to 600 mm long smooth-coated steel bars, which are placed mid-thickness of the pavement, parallel to the driving direction with a spacing of 250 mm to 300 mm between them. The transverse joint must be positioned in the middle of the dowels. The dowels are placed on steel baskets or vibrated into the fresh concrete. Care must be taken to place and keep the dowels in the correct position, particularly during the pouring of the concrete. Therefore, steel baskets must be securely fastened with crampons on a hydraulically-bound base or on the asphalt sandwich layer. Badly aligned dowels, both vertically and horizontally, will induce restraint and increase the risk of cracking.

Example of unsuitable and non-compliant dowels (corrosion, protrusions) and dowel baskets (deflection under the dumped concrete, displacement of dowels)

Dowel baskets fixed on an asphalt sandwich layer (top) and glued in a construction joint (bottom – photo: BKB-Infra)

In the case of unbound base layers, the fresh concrete can be dumped with a crane on the next row of dowels, so that they no longer can be displaced during the passing of the slipform paver. Dowel baskets can also be fixed with metal stakes or anchor pins in the unbound aggregate base.

The dowel bar inserting equipment (DBI) is usually quite accurate, but a clear landmark should still be indicated on the shoulder or side lane at the centre of the dowels, i.e. where the sawing will then have to be done.

Top: Fresh concrete dumped onto the dowel basket in order to avoid its displacement (photo: S. Ghafari) – Bottom: dowel basket secured with anchor pins

Automatic insertion of dowels in the fresh concrete (photo: Betonhuis, NL)

The dowels are specified in the European standard EN 13877-3 entitled "Concrete pavements - Part 3: Specifications for dowels to be used in concrete pavements". The minimum tensile strength required is 250 MPa and the durability must be declared by the manufacturer. It is also a harmonized standard, which means that the dowels must bear the CE marking.

The ongoing revision of this standard intends including performance based criteria by two tests:

- **a durability test according to EN ISO 9227:2017, i.e. a salt spray test with an immersion time of 240 hours;**
- **a pull-out test with measurement of the maximum bond stress in the concrete.**

Most dowels are made of steel, coated with a synthetic layer such as polyethylene. However, other solutions are available on the market e.g. hot-dip galvanized or stainless-steel dowels and also in other materials such as fibreglass reinforced polymer (FRP). In Europe, FRP dowels have already been used, for tram tracks and in container terminals, where the presence of steel could influence the magnetic field of automatic detection and guidance systems.

New types of dowels allow for both longitudinal and transverse movement of the concrete under shrinkage: square dowels with compressible sides or tapered plate dowels. Such free-movement joints will minimize the occurrence of joint cracks.

GFRP dowels for a concrete tramway (photo: Betonhuis, NL)

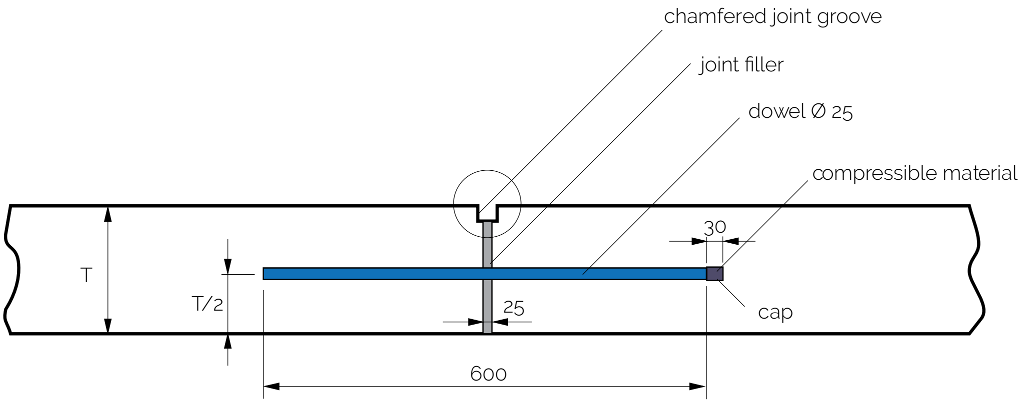
Plate dowels installed in a construction joint (photo: Danley, U.K.)

3.3.2 Transverse construction joints

Transverse construction joints are located at any interruption points in JPCP during concreting, that is at the end of each daily production or in case of any interruption of more than 2 hours. They are also referred to as "end-of-day joints" and "cold joints" respectively. The contact surface between the old and the new concrete must be flat and perpendicular to the surface of the base layer. Fresh concrete can be cast against hardened concrete without the need for any joint profile. The joint should not be sawn here to avoid sawing right next to the joint. Concrete contraction will automatically form a joint at this location. To prevent any edge degradation, it is recommended, once the crack is visible, to mill a groove and seal.

At a transverse construction joint, no load transfer via the aggregates can be considered. For this reason, transverse construction joints must be dowelled, except for low traffic JPCP.

Dowelled transverse construction joints: drilling of the holes – anchoring the dowels with chemical glue (photos: OAT)



General scheme of a transverse expansion joint

3.3.3 Transverse expansion joints

The expansion joints are characterized by the presence of a compressible filler that allows the horizontal displacement of the JPCP.

Until about 1970, expansion joints were made between each concrete slab; the length of the slabs was then generally between 8 and 15 m. At that time, they served as well as contraction and bending joints. With time due to their fragility and the reduction of the slab length, these joints have been revised to become only contraction-bending joints as described in the above section. This adjustment has significantly improved driving comfort but has also played a key role in reducing maintenance costs for JPCP. Nowadays the number of expansion joints is drastically reduced. However, they are still necessary in some specific cases where compressive forces absorption is needed to avoid damage to adjacent structures:

- connection with engineering structures;
- connection with other pavements, for example at a crossroads or to make the transition to another type of pavement (asphalt or paving blocks). The expansion joint is here preferably located between the second and the third concrete slab;
- around fixed points, such as manholes, or when the concrete floor is in direct contact with a building. In these cases, it is also called isolation joint - see below.

In addition, the use of expansion joints is recommended in certain concreting situations, such as:

- at one end of a repaired slab or series of slabs when the temperature during concreting is low (< 15 ˚ C);
- on bicycle paths, given the increased risk of blow-ups due to the higher L/w ratio, approximately every 150 m in a straight line when the temperature during concreting is low (< 15 ˚ C);
- secondary roads and bicycle paths before and after tight turns (curvature radii < 250 m) to avoid lateral displacement of the pavement.

In terms of construction details, it is important that the filler is perpendicular to the surface of the pavement. Any skewed position of the filler is one of the main causes of buckling of the slab. The perpendicular position of the filler and holding it in this position during concreting, are in far from easy. A simpler solution is to make the expansion joint coincide with a construction joint, namely at a concreting interruption. The filler can then be placed against the vertical finishing surface. If dowels are needed, holes must be drilled through the filler in the existing pavement. The dowels must then be placed and glued in the drilled holes. Where dowels are not required, e.g. for bicycle paths or low-traffic streets, the joint width can be sawn into an existing pavement with a double cut over the full thickness.

Set up for a dowelled transverse expansion joint in a continuous paving job (photo: Betonhuis,NL)

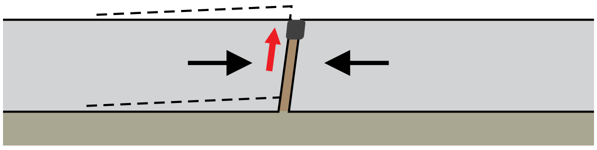
Dowelled transverse expansion joints at a construction joint (photo left: Betonhuis, NL)

Sawed cutout, allowing positioning the filler of the expansion joint

Another important issue is the size of the filler. Its length must be equivalent to the width of the pavement. If this is not the case, compressive stress concentration at the ends may cause cracking of the concrete. There must not be any concrete contact over the filler because in this case, the concrete will split off at the joint.

Possible degradation mechanisms for an expansion joint

a)



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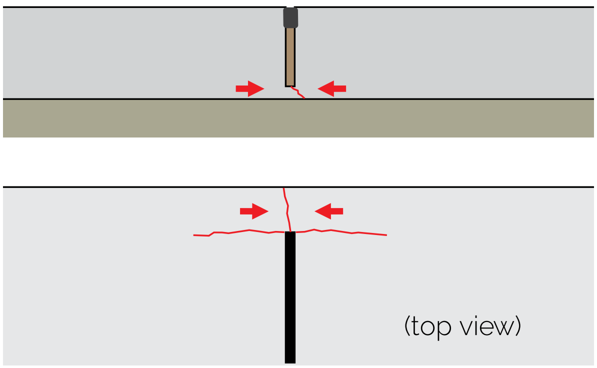

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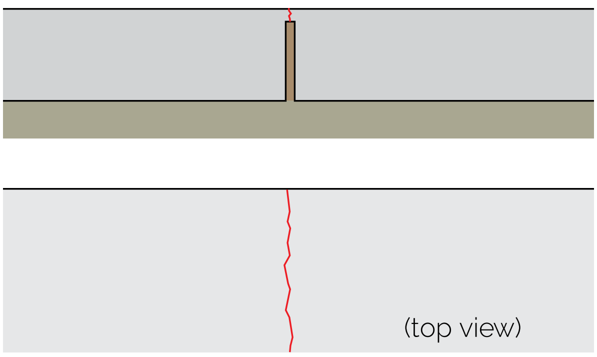

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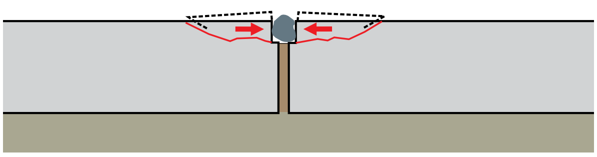
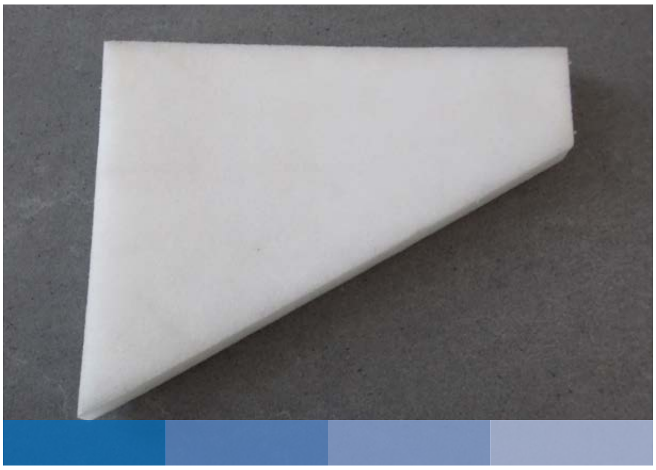


Joint failures due badly positioned filler plates in an expansion joint



Suitable materials for the expansion joint filler: on the left the cork agglomerate, on the right the high-density polyethylene foam

Fillers are made of rot-proof, compressible and elastic materials. After compression, they must also be able to recover their initial thickness. This is the case of cork agglomerate and high-density polyethylene foam (> 55 kg / m^3). Expanded polystyrene is not suitable for this application.

3.3.4 Isolation joints

An isolation joint is an application of a longitudinal (or sometimes a transverse joint) interrupted over the full height and which acts as the following:

a) prevents all existing joints from cracking in adjacent freshly poured concrete. In this case, the isolation joint does not allow much expansion of the concrete. It is then enough to provide a thin membrane inside the joint, for example an embossed PE film (250 to 500 µm), a bituminous membrane (3 to 4 mm) or a PE foam profile (foam tape - 5 mm).

b) provides interruption between two rigid pavements / structures to limit compressive force that could result in random cracking, splitting or uplift. This joint type can be applied against adjacent buildings, around manhole covers, drains, water nets or other built-in elements. In this case, the isolation joints can allow a slight expansion of the concrete. It is then advisable to use the same filler material as for the expansion joint (high density polyethylene foam), but possibly of a reduced thickness (e.g. 10 mm).

Examples of isolation joints along a channel and a vertical wall (Photos: Kebro, BE)

3.3.5 Longitudinal bending/contraction and construction joints

In the longitudinal direction, joints are made to allow the concrete pavement to hinge along the longitudinal axis and to limit stress due to the temperature gradient (curling in transverse direction). Two types of denomination exist:

- when a pavement is poured in a single concreting phase and is divided into two lanes by means of sawing, it is referred to as a longitudinal bending or contraction joint (its principal function will rather be to allow bending than contraction).
- when two contiguous lanes are cast in two concreting phases, it is then called a longitudinal construction joint.

The sawing depth must be at least 1/3 of the pavement thickness, just like for the transverse joints.

Sawcutting of a longitudinal joint (photo: OAT)

“TIE-BARS”

A longitudinal joint can be reinforced by tie bars (ribbed steel bars) which prevent the opening of the joint. In addition, the tie bars provide efficient vertical load transfer when the vehicles change lane.

Sliding and opening of the longitudinal joint in the absence of tie bars

Also free-movement longitudinal joints can be considered, using tapered plate dowels, working in conjunction with free-movement contraction joints.

In the standard EN 13877-1 "Concrete Pavements - Part 1: Materials", the tie bars have a specified diameter of 10, 12, 16 or 20 mm and a length of 800 mm. Specific requirements may be available in national annexes.

It is recommended to cover the central part of the tie bars with a corrosion protection layer, e.g. an epoxy or a polyethylene coating, in order to extend the service life of the structure.

The tie bars are placed at mid-depth of the pavement, perpendicular to the driving direction, spaced and at a distance from the transverse joint of about 750 mm to 1000 mm.

In the case of a longitudinal bending joint, the bars are placed on steel baskets or vibrated in fresh concrete. In the case of a longitudinal construction joint, they can be grouted and glued into drilled holes. In that case, sometimes shorter tie bars are used (700 mm) and the depth of the drilled hole can be limited to 25-30 cm. Another option is to horizontally insert the tie bars in the fresh concrete using hydraulic or pneumatic equipment.

Dowels (on the right) and tie bars (on the left) on a jobsite

Drilling of the holes for tie-bars in a longitudinal construction joint (photo: Betonhuis, NL)

Horizontal insertion of tie bars in the fresh concrete (photos: Betonhuis, NL)

The anchorage strength of the tie bar can be tested on site by a "pull-out test". A pulling force of 50 to 100 kN is applied within 48 hours for the bars glued in the drilled holes or after reaching a strength of 40 MPa for the anchor bars driven into the fresh concrete.

Another way to ensure the load transfer in a longitudinal construction joint is by doing a mortise and tenon joint ("keyed joint) or a sinusoidal joint, combined or not with tie bars. This is often prescribed for thick pavements like industrial platforms or airfields. However, problems may occur because of difficult consolidation of the concrete along this joint and consequently a risk for cracking along the joint. Therefore plane joints with tie bars are recommended. Additional or thicker tie bars can be used when extra load transfer is needed.

Another technique is to use tie bars that have been bent at 90° during concreting and straightened again before concreting the adjacent lane. This actually weakens the efficiency of the joint because the folding of the steel beyond its yield stress value reduces the load capacity of the bar. Hence this technique should be discouraged.

Longitudinal joints with mortise and tenon and sinus profile (not recommended practice)

3.3.6 Other types of joint systems

In addition to the conventional construction of contraction or expansion joints, several prefabricated systems are also available on the market. These are generally not used in road construction but rather for industrial floors.

These profiles have a straight cut or profiled (e.g. omega-shaped) section and can be inserted into the concrete with integrated connectors. The longitudinal profile is generally straight-lined and, in some cases, sinusoidal. Although they are often described as expansion joints, they mostly work as contraction joints. Given the possibility of concreting directly against these profiles, they can also be used as construction joints. As a reminder, only when a compressible material is used, the joint can be characterized as expansion joint.

Some important evaluation criteria for such profiles:

- the ability of properly compacting the concrete against the joint profile;
- the constant thickness of the concrete until reaching the joint profile. Any abrupt discontinuity in thickness can cause cracking;

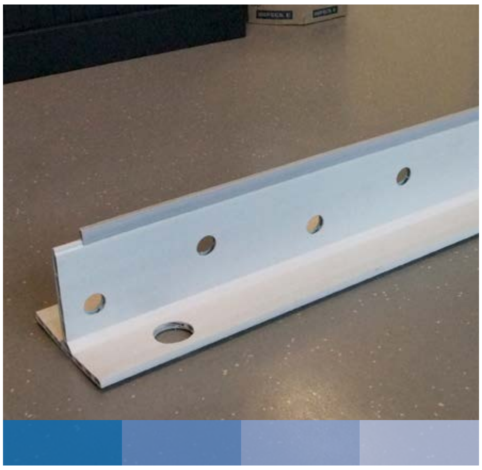
- in the case of an omega-shaped profile, a minimum of 6 cm concrete cover is required above and below the profile;
- the profile must allow an efficient load transfer. Some commercial profiles have been tested in this regard;
- the strength of the ridges must be ensured by a minimum steel thickness of 5 mm;
- the profiles can be provided with a metal protection of the edges of the joint;
- the systems must never be fully attached to the support on both sides in order to allow the joint to function properly;
- the profiles are not suitable for concreting using a slipform paver. Most of the time, they are used for pavement poured manually or with pumped concrete.

It is also important to know that some systems, suitable for interior floors, are not necessarily suitable for outdoor pavements.

Finally, other systems are also available on the market or can be custom-made to be used as formwork and consequently also as construction joints in a concrete pavement. Some examples below:

Omega-profile, mainly used for internal concrete floors (photo: Hengelhoef Concrete Joints)

Recycled T-shaped PVC used as a construction and contraction joint



Custom-made galvanized steel profile, construction joint – Project Pole Marexhe, Herstal, BE

Among the countless alternatives to sawing joints, the use of other materials such as concrete pavers, natural stones or wood can also take a prominent place in the architectural composition of concrete pavement. Here are some examples below.

Use of other materials for creating construction joints in decorative concrete pavements – from left to right: Jumièges, FR – Le Petit Quevilly, FR – Vilvoorde, BE

3.4 JOINT SEALING MATERIALS FOR CONCRETE PAVEMENTS

It is recommended to seal both transverse and longitudinal joints.

When sealing the joints with liquid materials (hot or cold poured), backer rods can be used. Backer roads are typically polyurethane foams in the form of a rope with a diameter of about 25 % greater than the joint width. The backer rods allow a proper sealant placement in the joint with the desired shape factor. Also, they prevent the adhesion of the sealant material to the two sides and bottom of the joint. These rods must be heat resistant to stay in proper shape when the hot joint sealants are poured into the joint.

Application of backer rods and joint sealants (photo: S. Ghafari)

The sealing materials can be divided into three main categories:

1. hot-poured sealants are the most commonly used. They consist mainly of bitumen, to which are added polymers and various additions;
2. cold-poured sealants can also be applied after mixing the components. They are elastic sealants based on polyurethane, polysulphide or silicones. These products are more expensive but have a longer lifetime (10 to 12 years for cold poured compared to 7 - 9 years for hot poured);
3. preformed compression seal of synthetic rubber.

These three product categories distinguish themselves by their plastic and/or elastic deformation capability which, under the conditions of use on pavements, can resist an acceptable service life (for example 5, 10 or 20 years) without breaking or coming off the edges of the joint.

Hot applied (top) and cold applied (bottom) joint sealing (photos: OAT)

Application of a preformed compression seal (photo: Robuco)

In some cases, it may be considered not to seal the joints. This is the option usually used for bike paths to ensure ride comfort. For outdoor decorative pavements, where a discrete joint finish is more suitable, it may be best not to widen the joints with a groove nor seal them.

But beware, in most cases and for moderate-to-heavy traffic roads, unsealed joints can have the following negative consequences:

- scaling and spalling of the edges of the joint that may be caused by the presence of hard, incompressible elements in the joint following pollution;
- water infiltration in the joint accompanied by the risk of pumping and washing away or erosion of the layers beneath (base, subbase and/or subgrade).

Joint cuts in a cycle path that will remain unsealed

4 REINFORCEMENT OF JPCP

Reinforcement of JPCP is not needed in case of a correct design, respecting all rules such as geometry of the slabs. When used anyway, it is often in the form of steel welded meshes and for the following purposes:

- structural reinforcement of concrete: the steel then resists most of the bending/tensile stresses;
- shrinkage reinforcement: avoid the appearance of cracks due to the various phenomena of shrinkage, contraction and curling of the young and hardened concrete.

Evidently, all reinforcements can only fulfil their purpose given their appropriate placement within the concrete section.
Since the traffic load results in tensile stresses in the lower part, the structural reinforcement must therefore be placed in the lower half, under the neutral fibre. Given the quality of the base layer (subgrade, subbase and base layer), this technique is usually not required in road construction. Indeed, with the appropriate thickness, pavement quality concrete develops enough tensile bending strength to resist any traffic load.

The shrinkage reinforcement, on the other hand, is placed in the upper part of the pavement, which is the zone affected by shrinkage cracks but also where the temperature and humidity variations are the highest.

If the mesh is positioned in the middle of the pavement, it will act as shrinkage reinforcement, although much less effective but more importantly, its structural effect will be inexistent.

The most commonly used meshes are those with a diameter of 8, 10 or 12 mm and a square mesh with a side of 150 mm.

For maximum efficiency, the shrinkage reinforcement should be placed in the upper third of the concrete section and must either stop at the contraction joints or be sawed through so that the joint can work properly, i.e. allow contraction between two jointed slabs. This may require an adaptation of the sawing depth.

On the other hand, the structural reinforcement in the lower half of the concrete pavement does not need to be interrupted nor sawn. The contraction crack will pass through the cut at the top and through the reinforcements to reach the bottom of the concrete slab. However, these cracks will not open as much as those of any unreinforced concrete and for this reason, it is recommended to interrupt the bottom reinforcement approximately every five joints or every 30 m.

Local reinforcement with a steel mesh (photo: Betonhuis, NL)

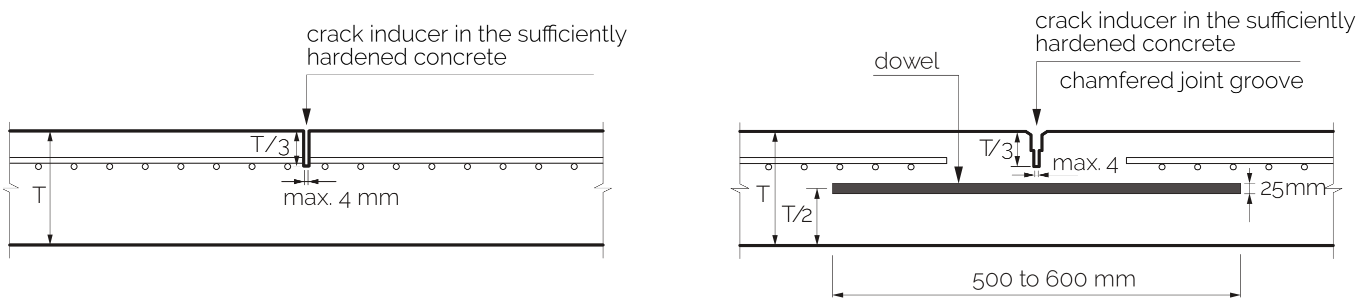
When meshes are combined with dowels, it is important that the meshes overlap the free ends of the dowels. The meshes can be interrupted or cross the joint. In the latter case, they must be sawn above the section of the dowels as described above, as they must themselves remain intact.

Steel meshes and dowels combined

The reinforcement meshes are sometimes replaced by steel fibres or structural synthetic fibres. This method is mainly applied for interior industrial floors and sometimes also for outdoor pavements, particularly in applications of thin white topping. The advantage of adding fibres is that they make the concrete all together tougher. This means that after the appearance of a crack, the structure does not collapse directly but has a favourable behaviour after cracking. In practice, this means that any crack in a concrete pavement remains better closed thanks to the action of steel fibres.

In practice, the applied dosage is between 30 and 50 kg/m^3 for steel fibres and 3 to 5 kg/m^3 for structural synthetic fibres. The shape and dimensions of the fibres also play a role. In conventional applications, galvanized steel fibres about 60 mm in length and 0.75 to 1 mm in diameter are mainly used. In terms of design, fibre reinforced concrete slabs may be slightly longer compared to unreinforced concrete. However, it is advisable to limit the slab length to a maximum of 7 or 8 m. In the Netherlands, some experiments have already been carried out on steel fibre reinforced concrete road sections up to 100 m long without joints. These achievements were designed based on concrete compositions containing 50 kg/m^3 of a mixture of different types of fibres.

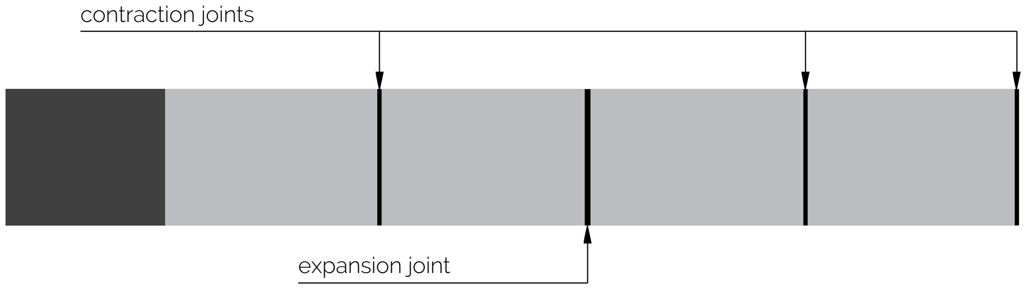
Schemes for the use of reinforcement meshes in JPCP, without and with dowels



5 TRANSITION TO OTHER PAVEMENTS

Where JPCP joins other types of pavement (asphalt, small elements), it is recommended to take the necessary measures to prevent the other pavement from being pushed away, e.g. in a situation of thermal expansion. As mentioned in § 3.3.3, one possibility is to place a transverse expansion joint between the second and third concrete slab.

Concrete-asphalt transition solution

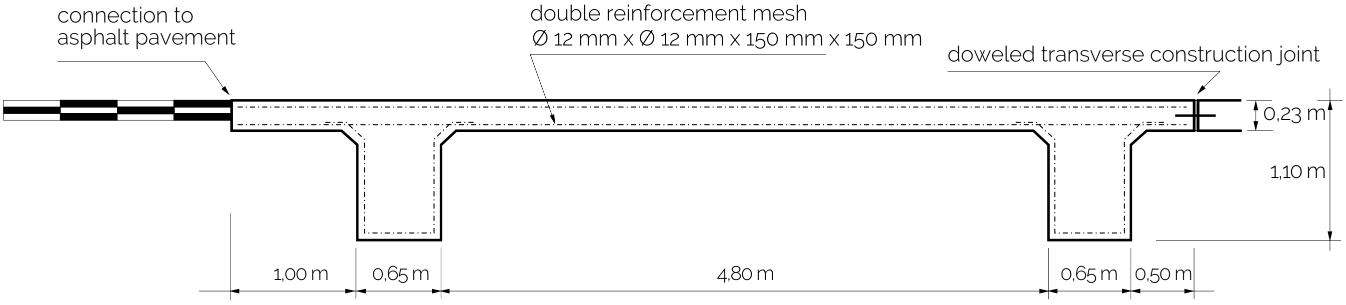


In the case of a concrete-asphalt transition, a "composite joint" is an alternative. It is approximately 250 to 500 mm wide and consists of a mixture of a particular type of bituminous compound and fine gravel. The capacity of such a compound seal is 10 or even 15 mm in expansion and contraction.

Composite joint at the transition from concrete to asphalt

Finally, it is possible to provide an anchoring abutment at the end of the concrete pavement, capable of neutralizing the movement. It may be a simple oblique thickening, or an anchoring abutment composed of one or more lugs. Pay attention to the fact that an abutment with a single lug has the risk of causing a kind of lever effect resulting in the detachment of the slab from its base. Due to the voids created, driving on the abutment zone will generate unwanted vibrations. It is therefore advised to make an anchoring abutment with minimum two lugs with double reinforced slab at its end.

Shortened anchoring abutment for transition between concrete and asphalt



6 JOINT AND REINFORCEMENT LAYOUT

The joint and reinforcement layout indicates the position and type of joints and all reinforcements. Although it is often considered to be the work of the contractor, the design of a qualitative joint and reinforcement layout should be part of the design phase. As such, a preliminary study of the joint layout makes it possible to anticipate the potential difficulties of construction and the adaptations are then easy. It should be noted that for spaces with a large surface or complex geometry, concreting phases must also be considered when drawing up the joint layout.

Here are some rules for drawing up the joint and reinforcement layout according to the rules of art:

- choose a main direction that will be considered as the driving direction, determining for the positioning of dowels and tie bars. As easy as it is in the case of a classic road, the decision can be more complex at a crossroads. In this case, the most frequently used roadway can be considered as the main direction;

- start by placing the joints at the most particular points (e.g., manholes, interruptions, connections, turns, etc.);

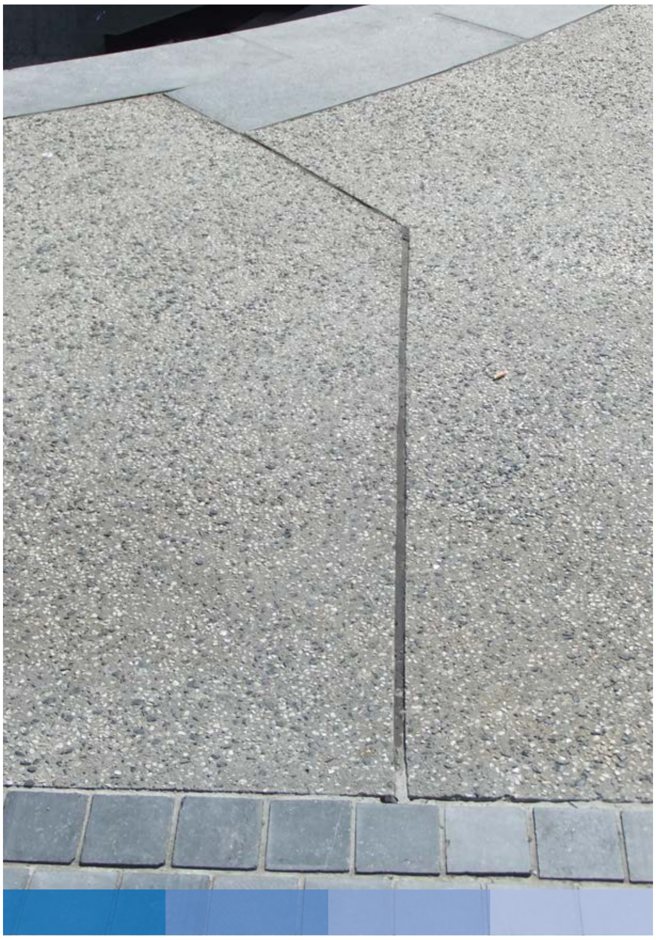
Sawn joints at manholes

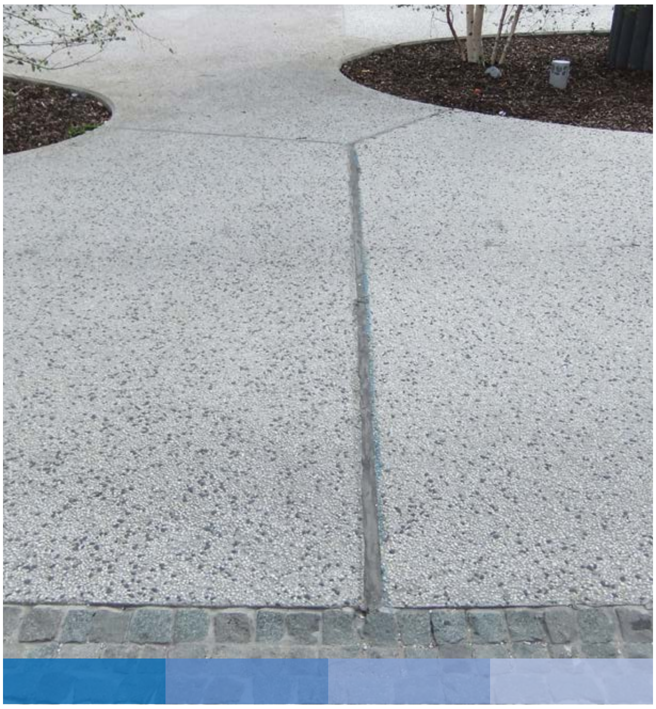
- do not saw more joints than necessary;

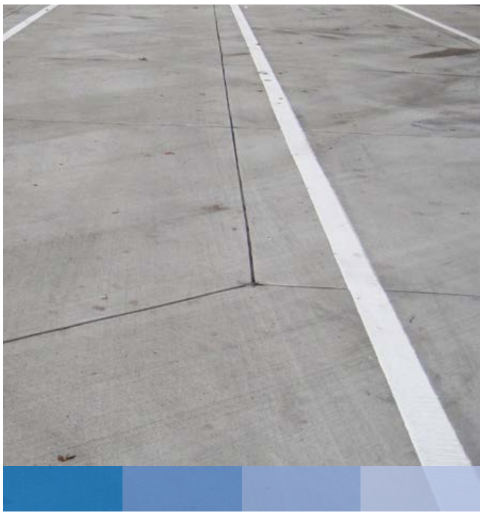
Too many sawings and acute angles can also cause unwanted cracks

- always avoid acute angles. This can be done by redirecting the joint perpendicularly to the edge of the pavement. This redirected joint, sometimes called "dog leg" joint, has a minimum recommended length of 40 cm. When it is not possible, a reinforcement mesh should be placed in the upper part of the slab

Various examples of correct joint layouts avoiding acute angles.



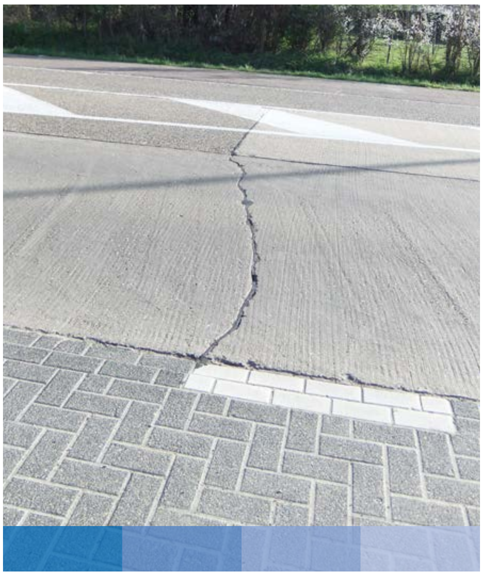




Joint lay-outs on motorway parking areas in Austria and Germany (photo on the right: Betonhuis, NL).

- provide a reinforcement mesh in the slabs of irregular shape;
- avoid placing dowels in the joints of a same slab if they are not parallel; the movement can only happen in one direction and a risk for blocking of the joint exist, followed by a crack starting from the corner
- consider the existing joints in order to avoid sympathy cracks or implement the necessary measures (placement of isolation joint at the level of the old transverse joint along which the concreting is carried out)

Sympathy cracks initiated by a joint in an adjacent slab or water gutter

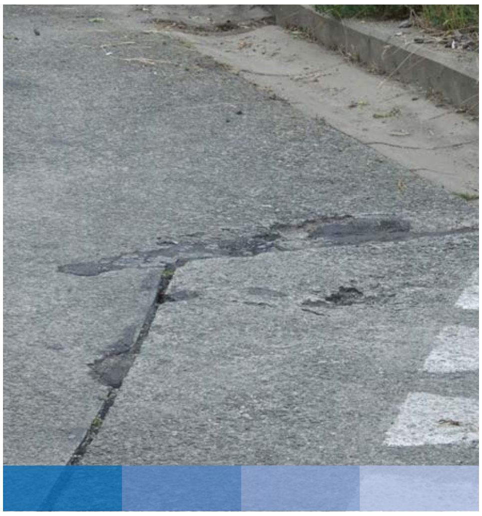


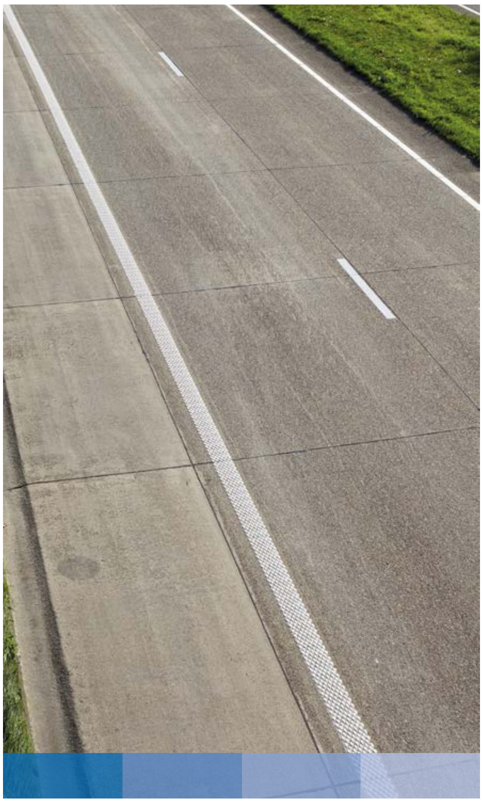
Joint in the road matches the position of the joint in the concrete barrier

Charleroi, Place de la Digue: to avoid sympathy cracks in this staggered joint layout, isolation membranes were placed along the longitudinal joints

- while drawing joints layout, consider the concreting phases or impose them during the construction phase;
- for the positioning of the longitudinal joints, take the heavy traffic pattern into account so that these joints are not directly under load. Widened lanes and a correct position of the road marking avoid systematic loading of the longitudinal joint and consequently reduce the risk of joint deterioration.

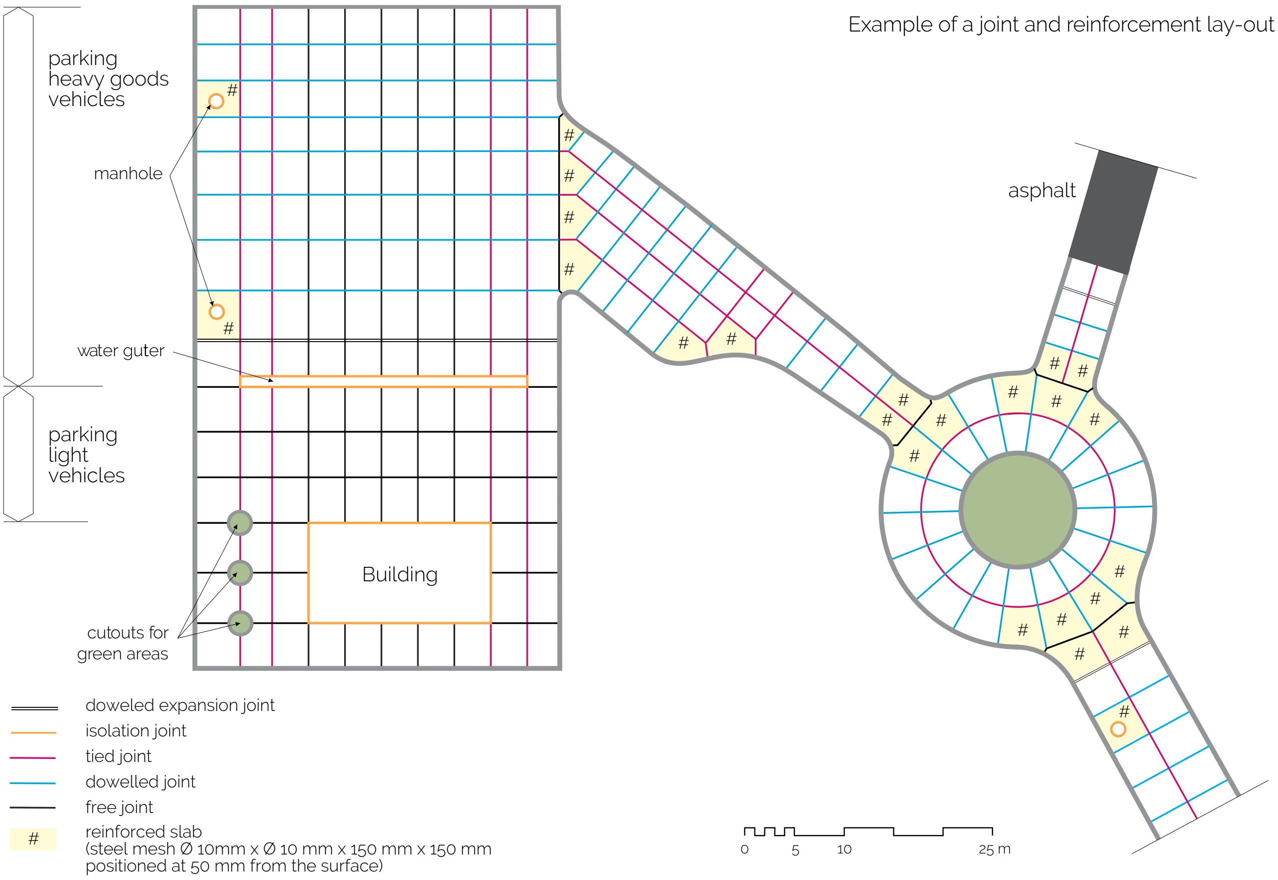
Joint damaged at a roundabout due to heavy load from heavy traffic





Example of correctly positioned longitudinal joints and road marking (photo: A. Nullens for FEBELCEM)

Example of a joint and reinforcement lay-out



7 CONCLUSION

The concept of JPCP has been known for decades and remains the most used type of structure within concrete road pavements. In addition to the thickness design, necessary attention must be given to the positioning of the different types of joints, dowels, tie bars and, if necessary, reinforcement meshes. Experience has shown that JPCPs located in urban, residential areas should be designed with dowels in order to ensure comfort and absence of vibration.

When the basic rules of modern design are respected and the construction is carried out in a professional manner according to the rules of art, JPCP offers the necessary comfort as well as the reliability and durability that we can expect today from concrete roads.

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Photos: FEBELCEM unless otherwise mentioned

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April 2020