THE ROLE OF THE CONCRETE PAVEMENT

From the client's perspective, the role of the concrete pavement is to provide a hard, flat, wear-resistant surface with a texture and gradient that will allow him to conduct his business without hindrance. He has great difficulty in accepting that cracks are generally innocuous and finds them unacceptable from an aesthetic point of view.

From the designer's perspective, the concrete slab must increase the area over which the loads are transmitted to the base course to an extent where its bearing capacity is not exceeded.

FORCES ACTING ON THE CONCRETE IN PAVEMENTS

To satisfy the client's requirements the designer has first to identify the stresses and forces that will be imposed on the composite structure made up of base courses with a concrete slab as the top layer. These stresses may be listed as follows.

1. Loads imposed on the pavement surface will create compressive stresses as the concrete is "sandwiched" between the wheel of a vehicle or the base plate of a rack and the base course. This stress is not high and can generally be resisted by a relatively low strength concrete.

   The magnitude of the stress will be dictated by the area over which the load is applied and the magnitude of the load. The spacing of these loads is very important and the distance apart of vehicle wheels and the spacing of racks will affect the stress bulbs that form in the composite pavement to a significant depth.

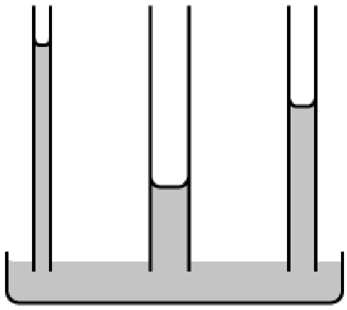
2. Bending stresses will be imposed in the concrete if the base course does not provide uniform support. A perfectly uniform base course will eliminate bending stresses but is difficult to achieve in practice; flexural stresses are, however, generally low.

   Repetition of application of loads will cause concrete to fail in flexure due to fatigue and it is necessary to estimate the number of times a moving vehicle will pass over a point on the pavement during the lifetime of the pavement. Fatigue is a common cause of failure of concrete slabs that have curled.
   Concrete that is capable of resisting some bending or flexural stress will add many years of service to a concrete pavement and is

sometimes (not often enough!!) the most important property of the concrete to be specified.

3. Tensile stresses are induced in the concrete due to the cumulative effect of surface tension forces in billions of microscopic capillaries that exist on the surface of the concrete. These stresses are imposed immediately after placement of the concrete in the plastic state and after hardening. If the concrete has not gained sufficient strength, it cannot resist these stresses and the concrete tears or cracks.

   These forces will be exerted on the concrete during its entire life as it responds to seasonal moisture cycles and will be exacerbated by thermal expansion and contraction. The effect of these forces will be much greater on exterior hard standing areas.

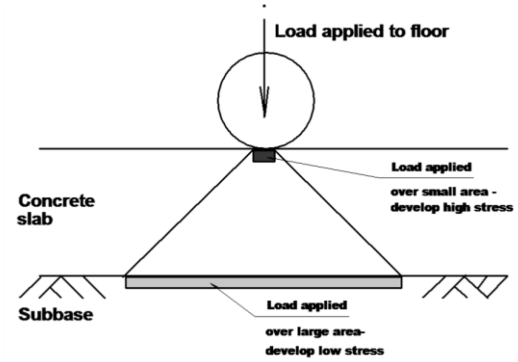


Capillary action tends to collapse the capillary

FORCES ACTING ON THE SUPPORTING LAYER

The supporting layer can be in situ material that has been suitably modified or imported material. Loads placed on the slab are generally resisted on this layer and the stress between the soffit of the concrete slab and the base course must not be allowed to exceed the bearing capacity of this layer.

The load is transmitted to the base course through a roughly conical section of concrete within the slab and the area over which the load is imposed on the base course is directly proportional to the square of the thickness of the slab. Even a modest increase in the slab thickness will increase the load carrying capacity of the pavement significantly.



Cone of Influence whereby load is transmitted to the floor

Loads on, and proper design of this part of the layer works is vitally important.

DESIGN OF THE CONCRETE PAVEMENT

Several properties of the pavement have to be designed and these are discussed below, keeping in mind the principles discussed above.

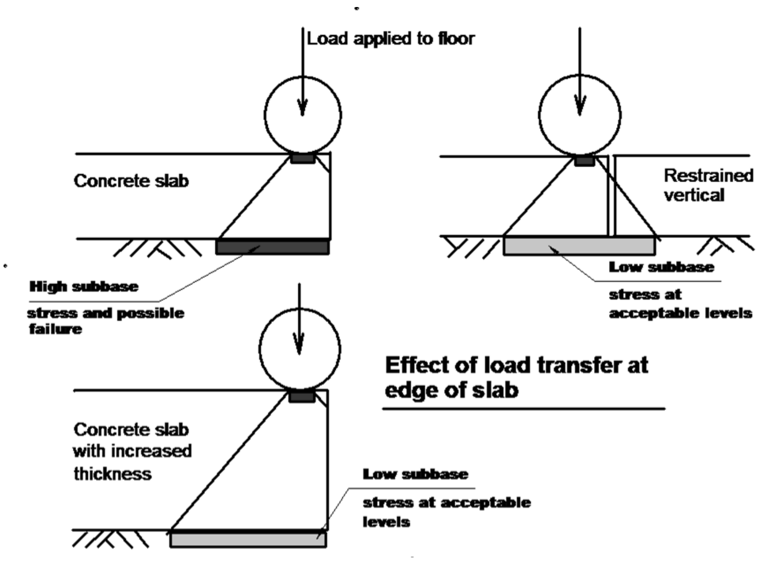
1. The design of concrete pavement thickness is usually done by using computer programmes or charts that are based to some extent on experiential and empirical relationships. Many of these design aids are available internationally and use the factors discussed above as variables required in the design.

   For factories using small forklifts or light rack loads it has become fashionable to specify a thickness of 150 mm and the few failures experienced bears testimony to the adequacy of this thickness. When dealing with container depots using straddle carriers or pavements on weak bases etc., a more detailed design is essential.

   The concrete thickness must be adequate to transfer the load to the base over a sufficient area so that failure of the base is not induced by overstressing. A problem occurs when a load is placed on the edge of a slab or at a break in the continuity of the slab i.e. at joints or cracks. The base area of the cone of influence is truncated, and the area over which the load is applied to the supporting layer is dramatically reduced. Failure of the base course is often the result, and loss of support will cause cracking in the concrete.

   A mechanism is therefore required where continuity of load support can be maintained across the discontinuity, and reliance is placed on aggregate interlock, keyways or dowels to prevent relative vertical movements and loss of load transfer. When the width of the opening caused by shrinkage exceeds about 1 mm aggregate interlock and keyway joints are no longer effective and only dowels are not affected. Effective dowel joints are, however, difficult to construct and accuracy tolerances are seldom specified.

Truncation of cone at discontinuity.



Severe faulting due to loss of load transfer capability in the crack

2. Compressive strength of the concrete is dictated largely by the wear or abrasion resistance required to resist the usage of the concrete surface. The concrete strength required for a reasonable industrial use is about 30 MPa but could be higher. Floor hardening materials could reduce the effects of abrasion and the required strength of the concrete.

   Other factors that reduce the effect of abrasion are the correct choice of aggregates and cement, the mix proportions of the concrete and good finishing techniques.

3. Perhaps design for the accommodation of shrinkage forces is the least understood and most poorly executed aspect of pavement design. Shrinkage forces are tensile and are generated internally by the material itself. These forces can be reduced but not eliminated and restraint to these forces by friction between the slab and the base, or incorrect placement steel is what causes cracking to occur.

Typical drying shrinkage crack running across several panels of a pavement

DESIGN TO ACCOMMODATE CONCRETE SHRINKAGE

Concrete shrinkage cannot be eliminated but can be reduced by an informed choice of materials and design of mix proportions, and will greatly reduce the risk of cracking. Most of the cracks that occur in a concrete slab forming part of a concrete pavement are due to poor accommodation of concrete shrinkage at design stage.

The following approaches may be taken to reduce the effect of shrinkage cracking.

1. Grooves or saw-cuts may be made in the concrete surface to create weakened planes that will attract cracks. An advantage of this method of crack control is that the cracks are hidden from the client and aesthetic requirements are satisfied.

   The depth of grooves is important and generally taken as a third of the slab depth based on experience. A shallower groove may not form a sufficiently weak plane to attract the crack and a deeper groove will not provide a sufficient area of aggregate interlock to provide adequate load transfer.

   Timing of cutting of grooves is vitally important as shrinkage of concrete can occur within a few hours after placement and cutting of grooves is futile if a random crack occurs before the grooves are cut.

   Spacing and arrangement of the grooves is critical if cracks between joints are to be avoided. Movement restraint due to friction under the floor can affect the build-up of shrinkage forces, and a plastic membrane under the floor will frequently result in the forces being inadequate to form a crack at every groove which is cut.

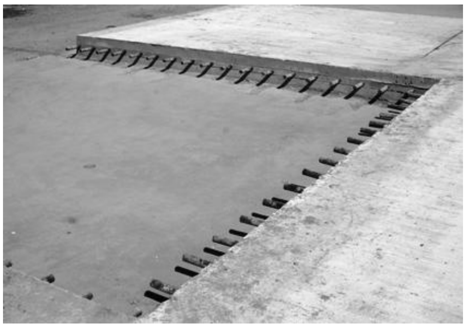
The cumulative width of the cracks that do form still has to accommodate the full shrinkage movement in the slab and can exceed the maximum effective width of 1 mm, rendering them incapable of load transfer.

Cutting the groove too late could mean that the concrete will crack first

2. Traditionally, the control of cracking has been done by the provision of a light steel mesh 50 mm below the surface of the concrete. The mesh will not eliminate cracking but does play a role in preventing drying shrinkage cracks from opening excessively. It is, however, well nigh impossible to place with any degree of accuracy, and poses a serious danger if it is continuous across joints where a weakened plane has been created, as it negates the effect. Shrinkage forces may not be strong enough to induce a crack at the reinforced saw-cut, and a crack may be induced at a location other than a saw-cut, which is undesirable. Cracks may be fewer in number and therefore wider, and incapable of load transfer by aggregate interlock.

   Modern floor design avoids the use of mesh wherever possible.

3. Design of joints to accommodate shrinkage movements must take into account the dual requirements of preventing relative vertical movements between the two sides of the joint, and allowing unrestrained relative horizontal movement. Care should be exercised not to lock-up joints with incorrect combinations of dowels and tie-bars, placed to provide vertical transfer of load.

4. Seasonal variations in the behaviour of concrete and the quality of locally available materials are frequently responsible for cracking and should be considered when planning.

REPAIR OF CONCRETE PAVEMENTS

Diagnosis of the failure of concrete slabs falls into two categories as follows.

1. Failures that could have been prevented by proper floor design such as joint spacing and type, and concrete design to reduce shrinkage, bleeding, abrasion and cracking.

2. Failures that could have been prevented by good site practice such as timeous cutting of saw-cuts, finishing, compaction and curing.

Many repair methods are available such as toughening of the concrete surface, or restoring load transfer across cracks or joints where it has been lost. Repairs are frequently less acceptable aesthetically and there is no substitute for proper design and construction for enhancing the longevity of a pavement.

CONCLUSIONS

The performance of concrete slabs that from part of a composite concrete pavement, has to take cognisance of the frequency and magnitude of loads to be applied and the inherent properties of the concrete.

The following factors must be considered and require the skills of the structural, geotechnical and materials engineer.

1. A thickness of the concrete slab that can transfer the loads applied to it so that the bearing capacity of the supporting layer is not exceeded.

2. The bearing capacity and composition of the supporting layer.

3. Design of joints so that their spacing and type does not induce cracks.

4. Concrete constituent materials and mix proportions that will provide sufficient strength to resist abrasion and minimise shrinkage.

The detail which should be included in the specification for concrete pavements needs serious consideration, as the focus for a constructor is generally on cost, unless specification dictates otherwise in the interests of quality.