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**A Broad Overview of Design and Construction of**

**Roller Compacted Concrete (RCC) Pavements**

**Introduction**

RCC is used in three principal areas and despite the same name being used, their differences are substantial. The **first area** is in dams/water retaining structures as an alternative material to clay in earth dams. Here it is characterised as having a low binder content, a compressive strength, usually of less than 10 MPa and permitting a range of aggregate sizes and gradings.

The **second area** is as a structural pavement layer. There the RCC has a high binder content and the compressive strength usually greater than 30 MPa. A detailed mix design is required and the aggregate size and gradings must fall within fairly confined limits. Here RCC provides the principal structural layer. Care should be taken as in international terminology RCC usually refers to base quality material which has a cement content of 12 – 14%. For subbase applications, as for concrete pavement subbases, the cement content is around 5% to produce 5 MPa lean mix rolled concrete. A better abbreviation may be Rolled Lean Concrete (RLC).

The **third area** of use is as the subbase for concrete pavements. Actually, to be strictly correct, this usage is called cement stabilization. Here the mix is designed to provide a maximum strength of 5 MPa in 5 days and no more than 15 MPa in 28 days. As a rule of thumb, cement content of 5% generally results in a suitable 5 MPa mix. As a subbase to a concrete or RCC base, it has no structural function and is used to:

* Resist erosion of the subbase and limit “pumping” at joints and slab edges;
* Provide uniform support under the structural concrete base;
* Reduce deflection at joints and enhance load transfer across joints (especially if no other load transfer devices are provided, such as tiebars or dowels);
* Assist in the control of shrinkage and swelling of high volume change subgrade soils.

This PIN gives an overview of the design requirements for the structural design of a RCC pavement layer as well as notes of the requirements for the RCC (and Lean Mix Concrete – LMC) subbases in for concrete pavement design.

**RCC Pavement Design**

The RCC pavement design follows similar procedure to that of jointed unreinforced concrete pavements with no dowels or tiebars in the contraction and construction joints. The main difference between RCC and conventional concrete pavements relates to the pavement construction, the spacing of joints and the appearance of the surface.

**Strength Requirements**

As the principal load carrying element in the pavement structure, the RCC should have a strength similar to that of the conventional concrete pavement. In general 32 MPa 28 day compressive strength.

In trafficked pavements the material failure criteria is the flexural stress capacity of the concrete being exceeded and not the compressive strength capacity. The design criterion is the flexural strength, but for reasons of convenience and time, compressive strength is used for construction control. A suitable conversion is ff = 0.8[fc]0.5.

**Mix Design (General)**

For structural RCC, it must satisfy the following:

1. It must achieve the specified strength;
2. It must contain sufficient water to allow the ingredients to mix properly and to hydrate the cement;
3. It must have a sufficiently stiff consistency such that after placing the material will not collapse or shear under the action of high-output vibrating rollers;
4. It must be capable of being paved and compacted without segregation of the mix components;
5. The mix proportions must be such that when compacted and cured the resulting pavement will have a durable, ie an abrasion resistant surface.

**Aggregate Properties**

The requirements of general properties and soundness for aggregates for RCC are similar to those used in conventional concrete pavement of similar strength.

Maximum aggregate size of 20 – 26.5 mm is typical, although up to 37.5 – 40 mm may also be suitable.

**Cementitious Binder Content and Type**

For both strength development and durability, in particular abrasion resistance, the minimum binder content of 300 kg/m3 is recommended. Foe best “paveability” cementitious contents of up to 300 – 320 kg/m3 are commonly used.

Due to the low w/c ratio and the high compactive effort used, relatively small additions of cement above the minimum amount recommended, will produce quite significant strength increases. Typically a Portland cement/fly-ash blend is commonly used with the binder containing up to 25% (sometimes more) of fly-ash. The spherical shape of the fly-ash particles adds to the paveability of the mix and ease of compaction.

**Moisture Content**

The w/c ratio and water content for RCC is substantially different from that of conventional concrete. The Moisture Content is determined as the optimum required to achieve maximum density after compaction in the same way as the OMC is determined for conventional crushed rock or gravel road materials. The same “Proctor” test method used for unbound pavement materials is also used for RCC testing.

In general, the OMC will be in the range of 5% to 7% by weight. This is well above of what is required for hydration of the cement. The above range is actually equivalent to 0.37 to 0.4 w/c ratio.

**Admixtures**

Admixtures may be used for same reasons as for conventional concrete. From experience, accurate and uniform incorporation of entrained air is a practical impossibility. Even with the absence of air-entrainment there has been no reported deterioration due to freeze-thaw. Under Australian conditions the absence of air-entrainment is unlikely to lead to loss of performance of the pavement.

As OMC is determined largely on the basis of achieving maximum compacted density by intensive rolling, the use of water reducing admixtures is also inappropriate to RCC.

Set retarding agents have been successfully used to provide control and uniformity in the delay period between mixing the material and the time at which saw cutting the joints can commence.

**Thickness Design**

The general procedure for the thickness design for RCC pavements is the same as for conventional concrete pavements having the same strength. This involves the determination of the flexural stress in the pavement due to applied loads, applying the fatigue relationship based on the estimated load repetitions to the flexural strength of the RCC and ensuring that this modified value is greater than that calculated from the applied loads.

As with conventional concrete pavements the position of the design load within the individual slab influences the required thickness. The load may be placed in the interior of the slab (**interior loading**) or at the unprotected edge or joint (**edge loading**). For RCC due to its dry consistency the inclusion of load transfer devices such as dowels, tiebars and keyways, presents practical difficulties. Therefore, load transfer at a joint in RCC pavements will have to be obtained by aggregate interlock with some assistance in support from the presence of a bound subbase, where used.

**General Comments regarding Structural RCC and Stabilised Subbase**

1. Longitudinal and transverse joints are required.
2. Induced joint spacing is calculated to limit crack widths to 0.3 mm.
3. To counter edge loading stresses:
* Integral widening of the pavement by 600 mm has to be provided on the median side;
* For conventional concrete pavements fully keyed and tied “shoulder” of 1.5 m width has to be provided on the slow lane side, ie outside. This is not practical with RCC and the 1.5 m width has to be placed integral with the rest of the pavement.
1. The absence of edge loading provisions would require the RCC base to be 40 - 60 mm thicker than where shoulders are provided. (Because of the difficulty of providing proper edge support, the US Corps of Engineers designs all RCC pavements for the unsupported edge condition).
2. For fatigue performance, it is assumed that this would be similar to that of the same strength conventional concrete.
3. The subgrade for the RCC is designed similarly as for concrete pavements. The principal design parameter is the California Bearing Ratio (CBR). It is usual to use soaked CBR values.
4. For thickness design purposes all materials within one metre below the subbase are assessed to provide the Effective Subgrade Strength.
5. To calculate the Equivalent Subgrade Strength it is normal to add 150 – 300 mm of selected material (CBR >15%) on top of the subgrade depending on its quality. For the Effective Subgrade Strength for design, the actual subbase type and thickness is added from graphs containing bound material and Lean Mix Concrete (LMC). Details of the calculations are provided in PIN no 74.
6. The provision and design of the subbase for RCC follows the same lines as for concrete pavements. The mix is designed to provide 5 MPa in 7 days and a maximum of 15 MPa in 28 days. A minimum practical thickness of 150 mm is usually recommended.
7. The subbase is placed as “mass concrete” with no designed or induced joints. The low strength minimises unplanned cracking which is tolerated.
8. The RCC and subbase are separated by a debonding layer to also assist limiting reflection cracking from the subbase into the RCC and to allow joints in the RCC to move without excessive restraint by the subbase. It is usual to use two coats of wax emulsion, where the first also acts as the curing membrane.
9. The essential feature which makes the RCC different from conventional concrete pavements is the equipment and method used to construct the pavement.
10. Due to its dry nature it is generally unsuited for batch type mixing systems such as conventional wet-mix plants. (In Australia RCC has been mixed in mobile continuous mixing plants where the mixing of the material takes place in long-chamber, twin-shaft pugmills.
11. The haulage to the road site is by conventional tip-trucks. Agitator trucks are impractical due to the time it takes to discharge the nearly dry mix.
12. Placement is by purpose built pavers or modified asphalt pavers. Where applicable, internal vibrators have to be removed.
13. Compaction to maximum density is essential. Even a small percentage of voids in the RCC leads to a significant loss of compressive and flexural strength. For example, 5% voids results in 33% loss of reduction in compressive strength and 25% in flexural strength. 10% voids results in 55% loss in compressive strength and 45% in flexural.
14. In broad terms, the drying shrinkage of RCC is about half that of conventional concrete used in slipform or even fixed form pavement construction. Shrinkage of the 5 MPa cement stabilised layer would be even less.
15. Researchers have also shown that for a pavement thickness of 250 mm the joint spacing could be 20 times the slab thickness, ie about 5 m. Others have suggested that this may actually be 30 times the slab thickness, ie 7.5 m. After the mix design, actual shrinkage figures will be available for calculation of the realistic spacing of joints
16. It is not practical to try to reinforce RCC.
17. Even though pavers can place thicker layers, eg 300 mm, it has been shown that about 250 mm is the maximum for complete compaction.
18. It is quite risky to place RCC in two or more layers as ineffective bonding between the layers will prevent the total pavement depth acting as a unit, which in turn results in maximum flexural stresses being located at the bottom of the top layer.
19. RCC surface cannot be screeded or trimmed. Full scale field trials have demonstrated that for high speed roads the normal RCC finish is too rough and an asphalt wearing surface will be required.

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