Various types of Portland cement concrete used in pavement and dam constructions

Behzad Kalantari, Civil Engineering Department, University of Hormozgan, Bandar Abbas (Iran)

ABSTRACT

This article presents a study on two very common types of Portland cement concrete; (a) zero slump concrete or roller compacted concrete (RCC) and (b) usual conventional concrete. The study discusses the similarities and differences between this two types of cement concrete when used for pavement as well as used for dam constructions. The article also describes different steps to make or produce Portland cement concrete, and list of laboratory and field tests for the quality control (QC) of both types of concrete is also provided.

The article contains various subjects on both types of cement concrete including; common laboratory and field tests before and after concrete is produced, a general view of what the RCC is, a brief discussion on selection of concrete mix proportion (mix design), performance of roller-compacted concrete pavement (RCCP), mixing and placing of RCCP in cold and hot weather, curing procedures for roller-compacted concrete followed by dam construction using RCC technique. Also, it discusses factors affecting the construction of pavement using RCC over conventional type of concrete in-regard to economical advantage, ease of production, construction, and speed of operation, as well as its low maintenance.

KEYWORDS: roller-compacted concrete, slump, mix design, strength, durability

INTRODUCTION

Roller-compacted concrete (RCC) for paving is a relatively new construction technique that uses zero-slump concrete. This type of concrete is transported, placed, distributed, and finally compacted using heavy road-construction equipments.

In conventional concrete construction, a minimum quantity of free water is needed for a specified workability that reaches the strength and durability of the concrete. However, in RCC works, the free water content is determined by the field condition. The conditions on the field usually depend on parameters such as the ease of compaction, the process, and the ability of the concrete paste to support the vibrating roller without collapsing or bearing any imprint.

RCC for pavements is placed without form, finishing, or surface texturing. Therefore, large quantities of RCC can be placed with minimum cost, compared with conventional concrete. RCC for pavements is stronger and therefore is more durable than asphalt pavements. As for mixing, placing, and curing both types of concrete in either hot or cold climates, both concretes share the same types of concerns. Therefore, the techniques for handling them under extreme weather (hot or cold) are almost the same. However, for RCC, because of the large surface area, the care needed and precision procedures involved may be greater. The advantages of RCC techniques over conventional concrete include the lower cost, increased durability with minimum maintenance, and speed of construction.

LABORATORY AND FIELD TESTS BEFORE AND AFTER CONCRETE IS PRODUCED

Concrete is prepared from a mixture of poorly graded aggregates (coarse and fine), Portland cement (PC), and water. Other additives such as fly ash and different types of admixtures such as air-entraining agents, accelerators, retarders, and plasticizers also may be used to improve the concrete's capabilities for workability and/or strength.

Before concrete is produced, the components that make up concrete are tested for their qualitative performances. The aggregates for concrete are usually tested for gradation, hardness, specific gravity, absorption, and organic material impurities. PC usually is tested for consistency, initial and final set, soundness, and strength (with mortar). Water is tested at the source of supply for its purity and potability. Admixtures usually are considered acceptable on certification from the supplier (Broke et al.1986).

After mixing the components, fresh concrete is produced and transported to the field to be poured into its final place for hardening. Subsequently, a test for consistency, named the "slump test", is carried out on concrete samples. The apparatus for this test consists of a hollow cone-shaped metallic container, which is filled with concrete and tamped with a steel rod according to standard procedures. The cone is carefully and slowly lifted vertically, allowing the wet concrete inside it to slump (settle) under its own weight. Then, the degree of slump or settlement is measured (usually in mm).

Tables 1 and 2 describe the workability relationship to the slump magnitude and the recommended slump values for different types of construction, respectively.

After measuring the slump of the concrete, several samples (at least four) are taken in cylindrical or cubic moulds (made from cast iron or stainless steel) for strength tests, usually at ages 3, 7, and 28 days (at least one more sample as probable replacement for the other three samples is taken). Drilled cores or any non - destructive test also can be used in the field to check the quality of hardened concrete at later dates, if required.

Table 1 *Description of workability[a] and magnitude of slump (Nevile, 1999)*

Description of workability	*Slump (mm)*
No Slump	*0*
Very Low	*5 - 10*
Low	*15 - 30*
Medium	*35 – 75*
High	*80 – 155*
Very High	*160 to collapse*

[a] *Concrete, which can be readily compacted (densified), is said to be more workable*

Table 2 *Recommended slumps for various types of construction (*Irving, 2000)

Type of construction	*Slump (mm)*	
	Max.	*Min.*
Reinforced foundation and footing	*75*	*25*
Plain footings, caissons, and substructure walls	*75*	*25*
Beams and reinforced walls	*100*	*25*
Building Columns	*75*	*25*
Pavements and slabs	*75*	*25*
Mass concrete	*50*	*25*

ROLLER-COMPACTED CONCRETE (RCC)

RCC is a zero-slump concrete placed in layers called lifts using conventional earthwork machinery and equipments. In general, RCC has the same basic mix ingredients as conventional concrete (water, cement, and aggregates), usually without chemical admixtures *(8).* Studies show that by replacing the cement with fly ash (up to 35%), the strength of the concrete can be considerably increased. Fly ash in the RCC mix increases the quantity of fine materials, so it increases the water content required. Therefore, it improves the consistency and workability of the RCC, thus contributing to the increase in strength, which is a consequence of the pozzolanic reaction and the resulting improved microstructure of the material (Naik et al. 2001).

RCC may be used to construct pavements and dams. The main benefit of RCC over conventional concrete is its economic advantage, which arises from its quicker production, easier transportation, and uniform distribution and compaction techniques that result in a faster operation.

SELECTION OF THE CONCRETE-MIX PROPORTION (DESIGN MIX)

The selection of mix proportion is the singularly important process of choosing the suitable ingredients for concrete and determining their quantities, with the goal of producing a concrete with maximum efficiencies, such as strength, durability, and smoother consistency, as economically as possible. In addition, the quantity of cement, the most expensive component of concrete, has to be restricted to a minimum. This is true for the mix design of both RCC and conventional concrete. The preliminary work in designing the mix proportion for conventional and RCC consists of material testing and boundary gradation. The aggregate sizes are almost identical in both cases, except that for RCC, the maximum size of the aggregate may be larger. Aggregate sizes in the RCC depend very much upon factors such as the lift’s thickness, project requirements, and the cost involved. For conventional concrete mix design, having a specific W/C (water-cement ratio) and compressive strength for the 28-day age, along with the available mix-proportion charts and tables, would give a good estimate of the proportion in the designed mix. To achieve the required parameters for concrete, such as its compressive strength, the procedure may need some trial and error samples to be prepared in the laboratory for standardization.

RCC mixtures are proportioned at low water–cement ratios, ranging from 0.2 to 0.4. The mixture of RCC must be dry enough to support the weight of a vibratory roller and wet enough to allow adequately uniform distribution of the concrete paste throughout the entire mass during the mixing and compaction process. As for the conventional concrete mix designs, many methods are available for the RCC mix design also. These methods are usually classified into the following two major groups (Naik,et al. 2001).

●Mixture proportioning techniques for RCC to meet the special limits of consistency.

●Mixture proportioning techniques using the soil-compaction concept.

In the first approach, a number of trial mortar mixtures (cement + water + aggregates), different in W/C and S/C (sand-cement ratio), are proportioned and cast to meet a specified consistency. From the test results, a specific W/C is selected that meets the required strength and S/C. After determining the above-mentioned ratios, the proportion of coarse and fine aggregates is adjusted to meet the specified consistency.

In the second technique, the proportion of coarse aggregates is fixed according to the recommended gradation curves initially. Then, for the fixed or adjusted aggregate proportion, a number of concrete mixtures varying in their cementitious material contents (cement with or without fly ash) are prepared. For each sample that is prepared, a different quantity of water is assigned, so that every sample has a different water content (starting from the least water content for the first sample, more water is added in increments to the subsequent samples). For each sample, the compaction process is carried out according to AASHTO – T 180 D standards. After compaction of each sample is completed, the dry density curve is determined with respect to the water content. From this curve, the compressive strength is measured using the optimum moisture content (OMC). The mixture fulfilling the compressive strength requirements with a minimum proportion of cementitious material is then chosen. Table 3 shows an example (comparison) of two design mixes for RCC and conventional concrete.

Table 3. *A typical comparison between conventional concrete and RCC pavements mix design (*Norbet 2003)

Pavement Type	Max. Aggs. size (mm)	Unit Weight (kg/m^3)				Water content (%)
		Water	cements	fine aggs.	Coarse aggs.	
RCC	19	105	260	946	1254	5.4
Conventional Concrete	38	140	329	606	1356	7.8

PERFORMANCE OF RCC PAVEMENT

An RCC pavement (RCCP) is placed without form, finishing, or surface texturing. Therefore, large quantities of concrete can be placed rapidly with minimum labour and equipment. Because of its lower water-cement ratio, the RCCP mixture has strengths equal to or even greater than conventional concrete pavements, under the same conditions.

The surface quality and smoothness of RCCP are relatively not as perfect as those of the conventional concrete pavements because of the presence of zero-slump concrete. Therefore, the use of RCCP is often limited to heavy duty or industrial pavements such as port facilities or military warehouses. For highways and streets, RCCP can be used with a thin layer of asphalt (about 50 mm), which would normally cover the rough surface of the concrete pavement, thus ensuring a smooth road surface.

To avoid segregations and to promote uniform distribution during the handling and placing of RCC, in addition to obtaining a smoother surface, the maximum sizes for the aggregates may be restricted to be not greater than 19 mm, as is usually followed for conventional concrete used in regular or ordinary constructions.

Compared with conventional concrete, the RCCP mixes may contain larger-sized fine aggregates to ensure a uniform concrete mix with less surface voids. Several studies have shown that RCCP surfaces are vulnerable to deterioration, when subjected to cyclic freezing and thawing climates.

Test results have shown that the mechanical properties of RCCP, such as compressive strength, are similar to the results obtained for the conventional paving concrete.

Therefore, the design procedure to find the optimum thickness for both types of concrete is the same.

A significant factor that affects the strength and durability of both RCCP and conventional concrete is the degree of compaction or whether the concrete paste in its final place has been fully compacted or not. The higher the compaction degree (closer to the full compaction), the denser the product is, and therefore, the less permeable the concrete will be.

When permeability is decreased, aggressive agents such as seawater, acid rain, CO_2, and SO_3 cannot penetrate into the concrete, so the pavement will last longer (is more durable). Therefore, the durability of concrete, whether RCC or conventional, is directly related to its permeability, and permeability is directly related to the degree of compaction.

Studies have shown that the most important factor in construction operations is the field compaction. Each percent of voids retained in the concrete due to compaction deficiencies may cause the concrete to lose at least five percent of its long-term strength. Field compaction, therefore, has a direct impact on the concrete strength, durability, and quality of the pavement surface.

MIXING AND PLACING OF CONCRETE IN COLD WEATHER

Experiments have shown that the behaviour of fresh RCC in cold weather (According to ACI (1987), cold weather is defined as the time length of more than three successive days, when the average daily outdoor temperature drops below 4° C) is similar to conventional concrete. Low temperature slows down the hydration of fresh concrete paste. Studies have shown that below -10°C, hydration and gain in the strength of the concrete come to a standstill. Above 4°C, the mixed-and-placed concrete is expected to reach the specified ultimate strength, with proper protection and curing procedures. If concrete is placed at temperatures between -10°C and 4°C, the long-term strength may be lost by 50% (Choi et al. 2003).

Methods to protect fresh concrete during the freezing weather placement , which are practiced routinely for both conventional concrete and RCC, are as follows:

- Increasing the quantity of cement in the mix.

●Use of antifreeze agents and accelerators for conventional concrete (for RCC, no additive to the concrete paste is suggested).

●Heating the aggregates and the use of hot water.

●Providing an enclosure for the work area (for larger projects such as RCC sites, this method could be costly).

●Mixing and placing the concrete paste during the warmer hours of the day (use of solar radiation)and not during the windy weather, and compacting the RCC lifts as quickly and continuously as possible, so that each new lift acts as an insulation blanket for the lift below.

●Covering the exposed concrete with insulating materials is also an effective method to minimize the heat loss from the freshly placed conventional or RCC concrete.

For RCC, substituting ordinary cement with type *III* cement may cause the concrete to set up so fast that there would not be enough time to manage the transportation, spreading, and compaction.

If the exposed RCC lift does not reach its initial set (stiffening) within 24 hours, then it is suggested that the un - hydrated lift be removed and disposed.

MIXING AND PLACING OF CONCRETE IN HOT WEATHER

In general, there are two factors to be considered when dealing with placement of either RCC or conventional concrete in hot weather:

●Ultimate strength and

●Workability

Ultimate strength: The optimum curing temperature for concrete is between 10°C to 21°C. When concrete is cured at temperatures above 27°C, the early strengths (at 1, 3, and 7 days) are higher than the concrete cured at normal temperature. However, the ultimate strength is reduced. Studies show that when concrete is cured at temperatures from 32°C to 41°C, a drop of five to15 percent in the compressive strength (at 28 days) of concrete would result.

Because of the large surface area and small thickness, the heat of hydration is not a major concern while using RCC. However, the placement temperature will cause the water in concrete to evaporate so soon that the concrete will have a dry surface. The result will be a dusted surface, which will cause the RCC to be open to defects and thus reduces its durability.

Workability: Hot temperature makes the concrete paste less workable and difficult to place and compact, therefore the product obtained is short of the maximum specified quality. High temperature causes the water of RCC to evaporate. As the temperature is increased from 21°C to 32°C, the initial and final setting time are reduced by 20 to 30 percent (www.gearsinc.com 2007).

Studies show that as the ambient temperature increases above 32°C,the time gap allowed from the moment of mixing to placing the concrete should be reduced (say for example, from 60 min. to 30–45 min.)

Some of the techniques for conventional and RCC placement include :(Jaafar et al. 2006, Navile 1999, wwwcementorg.com.).

- Use of the least possible quantity of cement
- Use of low-heat PC
- Use of chilled water
- Use of ice chips
- Use of cooled aggregates
- Use of retarder, if permitted (additives may be used for conventional concrete, if tested and approved, but are not suggested for RCC)
- Use of water-sprinkled curing
- Use of cover against solar radiation
- Use of liquid nitrogen in extreme cases
- Night placement (night construction work)

CURING FOR RCC

As with conventional concrete, curing is very important in RCC. Because of its low water content, RCC has no bleed water; so the main concern in RCC is drying. If RCC is allowed to dry, the following results may occur:

- The concrete will experience drying, and
- The hydration process will not take place

When concrete dries, the surface of the concrete will show shrinkage cracking. Additionally, when hydration does not take place, the surface of the concrete is most affected, and therefore a weak or dusted layer is formed over the entire surface of the concrete. Therefore, the concrete becomes more prone to deterioration and has lower strength and durability.

To prevent RCC from drying, the surface of the concrete should be maintained moist for the minimum time required, which is usually between 3 to 10 days (Nevile 1996).

In addition, curing compounds can be used at the surface of the concrete to protect the concrete from drying. The curing compounds should conform to ASTM-C-309 provisions. It is also important to moisturize the RCC bed before placing the concrete paste to prevent moisture loss to the lower surface, which causes a shortage of water required for hydrating RCC.

DAM CONSTRUCTION USING RCC

RCC has been known to civil engineers since the early 1980's. Since then, the conventional concrete construction procedures for dams have been rapidly replaced by RCC techniques (www.gearsinc.com 2007).

The use of RCC for the construction of concrete dams has three advantages over conventional concrete. The first advantage is the economy, the second is the performance, and the third is the speed of project completion. As stated earlier, RCC can be placed easily with earth-moving equipments such as dump trucks, spread with bulldozers, and compacted using vibratory rollers. In the preparation of RCC, the rate of compaction may well reach up to 1000 tons per hour. For conventional dams, the process of transportation, pouring, and compaction is not only considerably slower than the RCC procedure but also requires more special equipments and skilled workers, apart from involving more precision and care.

The process for dam construction using conventional concrete or RCC techniques is more important than the construction of pavements as far as the care and precision in work procedures are concerned. Moreover, if a dam is to be constructed by the RCC procedure, one of the concerns relates to the heat released due to the hydration process by the pouring of the concrete mass, which causes high thermal gradients on the interior and exterior of the dam surface; this results in thermal stresses and therefore, induces cracking (Jaffar et al. 2006).The cracks in dams are much more of a concern than cracks or possible defects in pavement construction.

Because concrete is a relatively expensive construction material and because the construction of concrete dams is usually costly, the RCC technique has been designed to reduce material and labour costs compared with the dam construction using conventional concrete.

CONCLUSIONS

RCC is a stiff, zero-slump concrete mix that has the same ingredients as conventional concrete. It is mixed, placed, and compacted using the same type of equipments that are used for asphalt pavement construction.

Because of its low W/C ratio, RCC products usually have strengths similar or even greater than conventional concrete. Usually, RCC, when used in pavement construction, is placed without forms, finishing, or surface texturing.

As far as the mixing and placing techniques for both RCC and conventional concrete in either cold or hot temperatures are concerned, the protective procedures are very similar. Only, these protective measures are of a larger size for RCC.

Curing is very important for RCC as is for conventional concrete. Therefore, it is fair to say that curing techniques for both types of concrete are identical, except that the preventive measures to protect the fresh concrete have to be greater in RCC (because of the large surface area that RCC usually occupies when compared to its thickness).

Because of the zero slump in RCC, in addition to being the least workable compared to conventional concrete, the surface texture of RCC usually has more voids when dried and hardened, which make it more vulnerable to penetration by detrimental agents and thus bring about less durability of the concrete. RCCs have been shown to be deteriorated as a result of cyclic freezing and thawing temperatures. To overcome this disadvantage, a thin asphalt layer (5-cm. thick) is placed over the RCC surface to protect it from the possible detrimental effects of freezing climates.

Fly ash makes RCC pavements more durable. However, no admixtures are recommended for RCC, except for some selected conventional concrete works.

In summary and conclusion, the main benefit of construction using RCC over conventional concrete construction is its economical advantage resulting from its ease of production, construction, and speed of operation, in addition to its low maintenance.

REFERENCES

Choi k.Ying,P.E,Neighbors Douglas,P.E,and Reichler D.Jamie,P.E., 2003.***Cold Weather Placement of RCC***,Journal of Materials in Civil Engineering . Doi: 10.1061/ (ASCE) 0899-1561,15:2(118).

Irving K. 2000.***Engineered Concrete-Mixed Design and Test Methods***, United States, CRC Press.

Jaafar S.M., Bayagoob H.K, Noorzaie J. 2006. ***Development of Finite Element Computer Code for Thermal Analysis of Compacted Concrete Dams***, Advances in Engineering Software.Doi:1016/j.advengsoft.08040.

Naik R., Tarun C., Moon Y.,Kraus N.R.. ,Singh S. S., Pennock C., Lorri R. Bruce **W.** 2001**.** ***Strength and Durability of Roller Compacted HVFA Concrete Pavements,*** Practice Periodical on Structural Design and Construction, vol 6, No 4, November.

Neville A.m.,*1999.* ***Properties of Concrete-4th edition***, Malaysia, Longman.

Norbet D., Nader, A. and Chris S. 2003. ***Improve managements of RCC Pavement Technology,*** *Department of Civil and Environmental Engineering. University of Alabama, Birmangham, USA, January.*

http:// www.gearsinc.com/prod04,Roller Compacted Concrete Projects.Aug.2007.

http:// www.usac.armymil/inet/usace-doc/armytm5-822-5ch17.pdf/Roller Compacted Concrete Pavements, Aug. 2007.

http://www.cementorg/basics/concrete products-rcc.asp, Roller Compacted Concrete.Aug.2007.