Research Review Report on Effect of Specimen Size on Shear Strength of Soil in Laboratory Test

Maurya Suresh Seopal

January 20, 2023

केन्द्रीय मृदा एवं सामग्री अनुसंधान शाला
Central Soil and Materials Research Station

रिपोर्ट सं॰ 02/Technical Review Report/CSMRS/03/2021-22

TECHNICAL REVIEW REPORT ON MASS CONCRETE AND ROLLER COMPACTED CONCRETE

द्वारा
by

श्री मौर्य सुरेश शिवपाल, वैज्ञानिक 'डी'
Shri Maurya Suresh Seopal, Scientist 'D'

मार्च 2022
March 2022

ओलोफ़ पाल्मे मार्ग, हौज़ ख़ास
Olof Palme Marg, Hauz Khas
नई दिल्ली - ११००१६
New Delhi – 110016

ABSTRACT

This technical review report provides insight view of “Mass Concrete” in terms of thermal cracking and its control and “Roller compacted concrete (RCC)” as an alternate method to minimize the use of cement and reduce green house gas emission in the atmosphere.

All concrete generates heat as it cures. For thicker sections, specifically in dams, bridges, retaining wall, pier, large foundation etc., the heat cannot escape as quickly as it is generated. The trapped heat increases the temperature of the concrete and then become a vicious cycle. Due to this two main problem arises i.e., maximum internal temperature and temperature difference developed between the interior and the surface. This generates thermal stresses and leads to thermal cracking. Exceeding specified limits puts concrete at increased risk of severe cracking and therefore temperature monitoring is needed. To control thermal cracking, it is necessary to have real time measurement/monitoring of temperature at different key places, so that temperature difference are within the specified limits. Thermal control methods discussed in this report include optimal concrete mix design, insulation, concrete cooling before placement, concrete cooling after placement, and the use of smaller placements.

Building dams in today’s society is for more than one reason like water supply, irrigation, flood control, navigation, sedimentation control and hydropower. Multipurpose dams for the developing country are a great deal, due to a single investment boosting to economic and domestic benefits for the population. When the dam is constructed with concrete, it uses large amount of cement. This leads to high cost and a negative impact on the environment due to CO_2 emissions. Therefore alternate method like Roller Compacted Concrete (RCC) reduces the cost as well as minimizes the use of cement. Over the past decade improvement in construction method with advanced machineries has enhanced the final product while maintaining the speed of construction. This provides RCC its competitive edge. Today, RCC is used when strength, durability, economy and speed of construction are of primary needs. Roller compacted concrete has gain recognition as a competitive material for building new construction and also rehabilitating existing dams along with other types of structures.

Keywords: Mass concrete, thermal control, roller compacted concrete

CONTENT

List of Figures

TECHNICAL REVIEW REPORT ON MASS CONCRETE AND ROLLER COMPACTED CONCRETE

PART A: MASS CONCRETE

1.0 INTRODUCTION ON MASS CONCRETE

Definition: Mass concrete is defined as "any volume of concrete with dimensions large enough to require that measures be taken to cope with the generation of heat from hydration of cement and attendant volume change to minimize cracking" (ACI 207). The one characteristic that distinguishes mass concrete from other concrete work is thermal behavior.

Fig. 1. Mass concrete structure of Sardar Sarovar Dam on Narmada River

Brief Content: Mass concrete is usually associated with large, poured in-situ concrete structures such as dams, bridge piers, foundations to very tall buildings and other large volume placements which are at least 1.0 m deep. In many cases, mass concrete is unreinforced and therefore strong in compression but weak in tension. Mass concrete is basically concrete with a higher proportion of coarse aggregate and a lesser proportion of cement. Large size aggregates are preferred for mass concrete. Major difference lies between mass concrete and reinforced concrete is participation of reinforcement. Mass concrete is weak in tension. Reinforced concrete is mostly strong on both compression and tension. Reason behind it is the grip formed between the steel and concrete. Generally a ratio of 1:3:6 and 1:4:8 for foundations and mass concrete works are preferred. Volume of concrete in which a combination of dimensions of the member being cast, the boundary conditions, the characteristics of the concrete mixture, and the ambient conditions can lead to undesirable thermal stresses and cracking. Due to its low heat evolution property, Portland Puzzolana cement is used for mass concrete works, such as in dam construction and in areas where concrete will be exposed to extreme temperatures. An increase in temperature within the mass concrete causes an outward expansion during the initial phase of the setting. According to ACI 301, the maximum temperature in mass concrete after placement shall not exceed 160 °F (70 °C); and the maximum temperature difference between center and surface of placement shall not exceed 35 °F.

2.0 THE BASICS OF MASS CONCRETE

All concrete generates heat as it cures. The heat is caused by the hydration of the cementitious materials, which is the chemical reaction that provides strength to concrete. Like strength development, the majority of the heat generation occurs in the first few days after placement. For thin items such as pavements, heat energy escapes almost as quickly as it is generated. For thicker sections, specifically mass concrete, the heat cannot escape as quickly as it is generated.

The heat is trapped and increases the temperature of the concrete. As the concrete temperature increases, more heat is generated, which further raises the concrete temperature, becoming a vicious cycle. Eventually the concrete begins to cool because there is a finite amount of heat energy in the cementitious materials. The total amount of heat energy depends upon the quantity and type of cementitious materials.

The varying rate of heat generation and dissipation causes the interior of a concrete placement to get hotter than its surface. In other words, a temperature difference develops between the interior and the surface. This generates thermal stresses in the concrete (because the interior expands relative to the surface). Cracking immediately occurs when the tensile stress exceeds the tensile strength of the concrete. This cracking is referred to as thermal cracking. In most cases, thermal cracking is a durability issue because it provides easy pathways for air and water to reach the reinforcing steel and begin corrosion. In some cases, where thermal stresses are significant, the cracking may affect the structural capacity of the concrete. Thermal cracking takes many forms. On large foundation placements, it may appear as random map cracks. On walls, it may appear as a series of vertical cracks that are widest near the base. On beams, it may appear as uniformly spaced cracks perpendicular to the longest dimension of the beam.

Thermal cracking is one of two primary concerns for mass concrete placements. The other concern results from the concrete getting too hot. High temperatures change the cement hydration reactions. At temperatures above 70°C, unstable hydration products develop in some concretes. This is referred to as delayed ettringite formation (DEF). In concretes where DEF occurs, the unstable hydration products can eventually begin to expand within the concrete. This is a long-term effect that may not occur for months or years after the time of construction. In its worst form, DEF can cause significant cracking. To prevent DEF, the rule-of-thumb is to keep the concrete temperature less than 70 °C. Many concrete placements are relatively immune to the effects of DEF. Such placements include those isolated from water (for example, groundwater, rain, or ponding water) or some that contain cementitious materials with certain resistant chemistry (such as a higher proportion of fly ash or slag cement). Testing can be used to determine if the concrete is susceptible to DEF. Unfortunately, the concrete mix design and cementitious material sources are rarely known until the time of construction. When DEF can be shown to not be a concern, higher temperatures are justifiable; however, temperatures greater than 85°C can reduce the structural properties (strength and modulus of elasticity) of concrete.

3.0 CONCERN IN MASS CONCRETE

As explained above, the two main concerns with mass concrete placements are the maximum temperature and the maximum temperature difference. Specifications typically limit the maximum temperature to 160°F (70°C) and the maximum temperature difference to 36°F. Specifications also typically require calculations or a thermal control plan be developed to show that these limits will not be exceeded.

Some concretes are more tolerant to thermal cracking because they have a high tensile strength or contain aggregates with a low coefficient of thermal expansion. In such cases, higher temperature difference limits may be justifiable. It is suggested that 45°F (7°C) is an appropriate temperature difference limit for concrete with granite aggregates, and 56°F (13°C) for concrete with limestone aggregates. While this may be true, thermal modelling is often required to show that the higher temperature difference limit will control thermal cracking. These analyses typically utilize thermal modelling to define the temperature difference limit so that the thermal stresses do not exceed the tensile strength of the concrete and thermal cracking is prevented. Similar analysis may justify a higher initial temperature at placement.

4.0 THERMAL CONTROL MEASURES

Many potential solutions exist to minimize efforts needed to control temperature and temperature differences in mass concrete placements. These solutions are often referred to as "thermal controls". Each thermal control has associated costs and benefits. Thermal controls used currently include optimal concrete mix design, insulation, concrete cooling before placement, concrete cooling after placement, and the use of smaller placements.

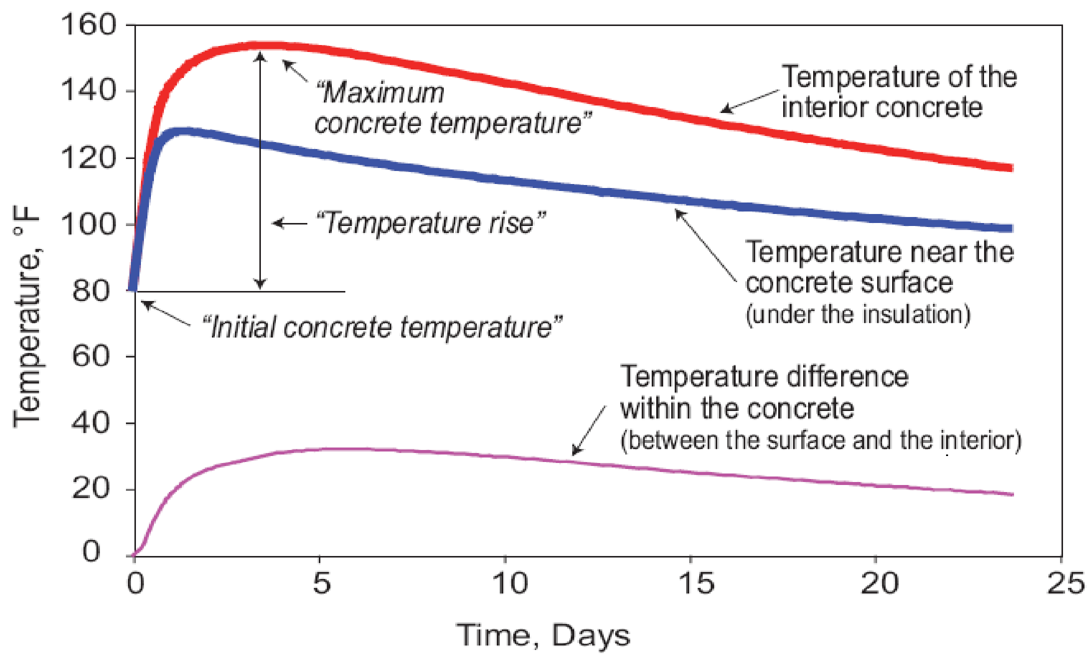

Fig. 2. Concrete temperature graph

4.1 Optimal Concrete Mix Design

Using an optimal concrete mix design is the easiest way to minimize thermal control costs. Use low-heat cement generally has the lowest heat of hydration. The concrete should contain fly ash or slag cement. Fly ash replace 25 to 40 percent of the cement because its heat of hydration is about half that of cement. Slag cement is often used to replace 50 to 75 percent of the cement, and its heat of hydration is typically 70 to 90 percent of cement. Both fly ash and slag cement decrease the early age strength of the concrete, but can greatly increase the long term strength. Testing should be performed to verify strength and durability. The water-to-cementitious materials ratio of the concrete should be as low as reasonably possible. This increases the efficiency of the cementitious materials (increases the strength-to-heat ratio), and decreases the likelihood of bleeding and segregation. The minimum practical water-to cementitious materials ratio is on the order of 0.35 to 0.40. Achieving a workable mix at this low water content requires the use of admixtures. Testing is recommended to ensure durable and peaceable concrete.

4.2 Insulation

While it may seem counter-intuitive to insulate mass concrete, insulation slows the escape of heat, which warms the concrete surface and reduces the temperature difference. In most cases, concrete insulating blankets are used; however, virtually any insulating material is often acceptable. To prevent thermal cracking, insulation should be kept in place until the hottest portion of the concrete cools to within the temperature difference limit of the average air temperature. For example, if a 45°F temperature difference is specified and the average air temperature is 20°F, insulation should not be removed until the hottest portion of the concrete cools down to 65°F. This may require that insulation be kept in place up to several weeks (especially on thicker placements). During this time, it may be possible to remove insulation temporarily to perform work. This can be done for a window of time when the temperature differencein the concrete is less than the specified limit.

Fig. 3. A bridge column uses surface insulation to minimize the temperature difference between the interior and the surface

4.3 Concrete Cooling Before Placement

The temperature of delivered concrete is normally about 10°F warmer than the average air temperature. To reduce its temperature, concrete can be precooled prior to placement. Chilled water can be used for mix water to precool the concrete by about 5°F. Shaved or chipped ice can be substituted for up to about 75 percent of the mix water to reduce the concrete temperature by up to 15 to 20°F. If extreme precooling is needed, liquid nitrogen (LN2) can be used to precool the concrete mix by any amount (to as low as 35°F). LN2 cooling requires highly specialized equipment to safely cool concrete and can be expensive.

Fig. 4. Liquid nitrogen cooling is sometimes used to reduce the temperature of the concrete prior to the time of placement

4.4 Concrete Cooling After Placement

After placement, there is not much that can be done to reduce the maximum temperature of the concrete. Removing insulation only cools the surface, which increases the temperature difference and the likelihood of thermal cracking. To avoid artificially cooling the surface, moisture retention curing methods should be used. Water curing (adding relatively cool water to the warm surface) actually increases the likelihood of thermal cracking. Using heated water for curing is typically not practical and is therefore not recommended. If installed prior to concrete placement, cooling pipes can be used to remove heat from the interior of the concrete. This increases the cost of construction, but limits the maximum temperature and greatly reduces the time that insulation is required. This method of thermal control is sometimes used on larger projects where an economical source of water is available such as a lake or river. Cooling pipes typically consist of a uniformly distributed array of 1 inch diameter plastic pipes embedded in the concrete. A pipe spacing of 2 to 4 feet on centre is typical.

4.5 Use of Smaller Placements

Larger sections can often be divided up into several smaller placements. Placing the concrete of a thick foundation in multiple lifts with smaller thicknesses can sometimes be an effective method to minimize the potential for thermal problems. However, the schedule delay between lifts, cost and effort for thermal control of individual lifts, and the horizontal joint preparation may offset the benefits.

5.0 MONITORING CONCRETE TEMPERATURES

Temperature monitoring should be performed to ensure that the thermal control measures are keeping the temperature and temperature differences within the specified limits. Monitoring also provides information so that additional insulation can be added to reduce the temperature difference, if it is too high. Commercially available systems such as plastic-sheathed thermocouples with an appropriate logger can be used to monitor concrete temperatures. Concrete temperatures should be monitored at the hottest location in the placement (typically at the geometric center) and at the center of the nearby exterior surfaces (at a depth of 2 to 3 inches below the surface).

PART B: ROLLER COMPACTED CONCRETE

6.0 INTRODUCTION ON ROLLER COMPACTED CONCRETE (RCC)

Definition: Roller compacted concrete, also known as RCC, is a composite construction material with no slump consistency in its unhardened state. It is placed with asphalt pavers to form a non-reinforced, concrete pavement. RCC successfully and economically combines strength and durability with ease of construction. Unlike conventional concrete, it's a drier mix, stiff enough to be compacted by vibratory rollers. Typically, RCC is constructed without joints. It needs neither forms nor finishing, nor does it contain reinforcement. It has achieved its name from the construction method where the RCC is placed with the help of standard or high-density paving equipment and then it is compacted or consolidated with rollers.

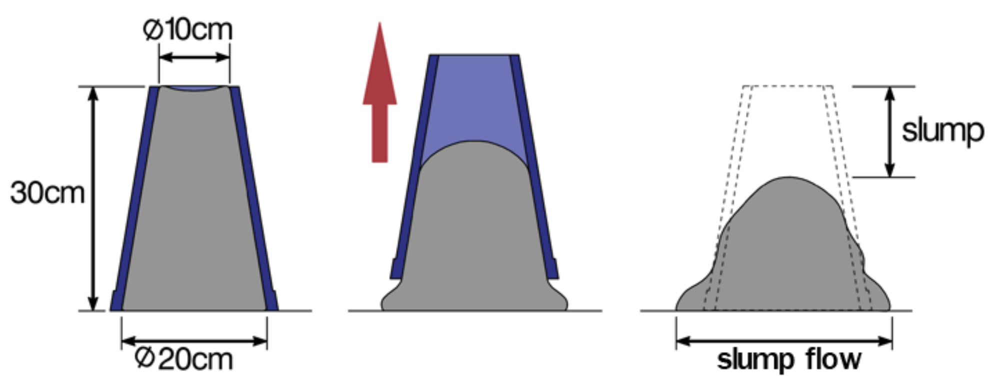

Fig. 5. The consistency of the concrete is tested with the help of the slump test

Compared to conventional concrete, the materials that are used for the RCC are usually of a wider range. When mixing the RCC the philosophy is to use adequate paste volume to fill the aggregate voids, without using more water than is needed for a decent workability. The hardened RCC and conventional concrete have similar properties, when it comes to durability and RCC can therefore be used for building dams. Constructing RCC dams is popular due to rapid construction process, reduced costs and smaller environmental impact due to less cement. (ACI, 2011)

Brief content: Roller compacted concrete is a zero-slump concrete consisting of dense-graded aggregate and sand, cementations materials, and water. Because it contains a relatively small amount of water, it cannot be placed by the same methods used for conventional (slump) concrete. Roller compacted concrete has the same basic ingredient as conventional concrete: cement, water, and aggregates. The basic difference is that roller compacted concrete is a much drier mix with practically zero slumps. It is drier, and looks and feels like damp gravel. It does not require any forms, dowels, reinforcing steel & finishing. Its production provides a rapid method of concrete. The properties of RCC mainly depend on quality of raw materials used, the cementations material content, the degree of compaction and the quality control measures. For effective compaction, the mix should be sufficiently dry so that it can support the load of vibratory equipment and on the other side it should be sufficiently wet also to allow adequate distribution of paste binder throughout the mass. Also, the method of compaction is different than the conventional compacted concrete and it is compacted by vibratory or pneumatic-tired rollers. The objective of mix design is to produce a roller compacted concrete mix that has sufficient paste volume to coat the aggregates in the mix and to fill in the voids between them.

RCC uses aggregate sizes often found in conventional concrete. However, the blending of aggregates will be different than that done in case of conventional concrete. Crushed aggregates are preferable in roller compacted concrete mixes due to the sharp interlocking edges of the particles, which help to reduce segregation, provide higher strengths, and better aggregate interlock at joints and cracks. Roller compacted concrete is one type of such concrete which has wide applications in the field of civil engineering construction in particular for mass concreting.

Advantages: Concrete leads as the most frequently used construction material in the world because of its innumerable properties. RCC has gained the attention of the paving industry in recent years and is becoming more popular day by day because of its low cost, rapid construction, and durable performance. The energy required to compact RCC mixtures to their maximum densities is much greater than for concrete of measurable slump. The largest difference between RCC mixtures and conventional concrete mixtures is that RCC has a higher percentage of fine aggregates, which allows for tight packing and consolidation. Fresh RCC is comparative stiff than typical zero-slump conventional concrete. Its consistency allows it to remain stable under vibratory rollers, yet wet enough to permit adequate mixing and distribution of paste without segregation. Sometime admixtures or materials like fly ash are used in concrete to reduce the water content and produce more dry mix. The main advantage of roller compacted concrete is that it can be constructed without the use of dowel bars and we can also make a construction which does not require construction joints. RCC can be used in many areas of construction like in dams, pavement construction etc.

7.0 APPLICATION OF ROLLER COMPACTED CONCRETE

RCC is placed by asphalt pavers and compacted by vibratory rollers and hardened into concrete. RCC for pavements is placed without forms, finishing, pointing, or surface texturing. Thus, RCC pavements can be constructed more rapidly and with less labor and expenses than traditional concrete. Because of the low water content used in the RCC mixture and resulting low water-cementitious materials ratio, RCC typically has strengths similar to, or greater than, conventional concrete.

7.1 RCC Pavements

RCC mixtures for pavements contain less cementitious materials than conventional concrete mixtures. RCC pavement is much quicker to construct than conventional concrete pavement. RCC pavements do not require joints, dowels, reinforcing steel, or formwork. Relatively large quantities of RCC pavement can be placed rapidly with minimal labor and equipment, enabling speedy completion of tightly scheduled pavements. RCC pavement is much stronger and durable than asphalt pavement. RCC will not rut from high axle loads, or shove or tear from turning or braking of operating equipment. It will not soften from heat generated by hot summer sun or material stored on RCC floors (for example, compost). RCC resists degradation from materials such as diesel fuel. RCC pavement offers a substantial cost savings over conventional portland cement concrete and asphaltic concrete pavements when used in heavy wheel load applications.

Fig. 6. Roller Compacted Concrete for Road Construction

7.2 RCC Dams

Dam is a huge construction that needs massive amount of concrete to build it with and that leads to high cost, so alternative methods should be considered to minimize the cost of constructing the dams. One method is building the dams with Roller Compacted Concrete (RCC), which by definition is a composite construction material with no-slump consistency in its unhardened state and it has achieved its name from the construction method. The definition for a no-slump consistency is a freshly mixed concrete with a slump less than 6 mm. The RCC is placed with the help of paving equipment and then it is compacted by vibrating roller equipment. The RCC ingredients are the same as for the conventional concrete but it has different ratios in the materials that are blended to produce the concrete. It differs when it comes to aggregates because both similar aggregates used in conventional concrete or aggregates that do not fulfil the normal standards can be used in the RCC mixtures.

Compared to constructing a conventional concrete dam, which is usually built in large blocks, the RCC dam are usually built in thin, horizontal lifts, which allows rapid construction. This reduces the amount of formwork and also the demand for man-hours are less due to the usage of machines for spreading and compacting, ultimately making it a cheaper method.

RCC has been increasingly used to build concrete gravity dams because the low cement content and use of fly ash causes less heat to be generated while curing as compared to conventional mass concrete placements. In dam applications, RCC sections are built lift-by-lift in successive horizontal layers resulting in a downstream slope that resembles a concrete staircase. Once a layer is placed, it can immediately support the earth-moving equipment to place the next layer. After RCC is deposited on the lift surface, small dozers typically spread it in 30 cm thick layers.

The main economic advantages result from the following features of RCC dams:

- **Heat generation:** RCC is more favourable while taking into consideration the heat dissipation which always remains a vital issue for mass concreting structures.
- **Incorporation of spillway into dam body:** The spillway can directly be incorporated into the dam body which helps to accommodate large volume of water and which are in need of large spillways.
- **Low unit costs of RCC:** It reduces the heat of hydration and a significant portion of cement is usually replaced by locally available pozzolanic materials or fly ash. With higher rates of concrete placement, lower material cost and lower costs associated with post cooling and formwork. It makes it economical with low unit cost.

- **Use of shape of conventional dams:** Because the stresses in gravity type dams are low, the cross-sections of RCC dams are the same as those of conventional dams.
- **Speed of construction:** Large volumes of (low or high paste) concrete can easily be placed with heavy equipment, thus shortening the construction period of these dams.

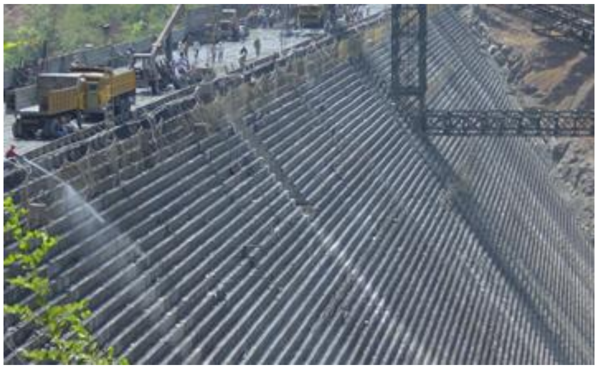

Fig. 7. Ghatghar Village, Maharashtra, India

Fig. 8. Downstream face of Beydag dam

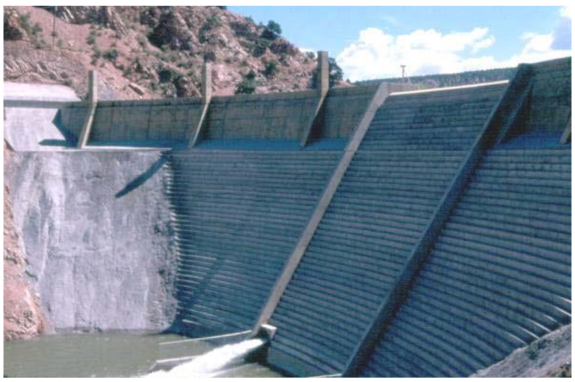

Fig. 9. RCC dam of Santa Cruz River in Argentina popularly known as Puerto Santa Cruz Dam

Fig. 10. Taum Sauk Dam Constructed Using Roller Compacted Concrete

7.3 In Repair and Rehabilitation Works

Roller compacted concrete can be used for repair of already constructed surfaces and they increase the performance and durability properties by providing a strong coating like finish with concrete overlay or a thin asphalt. Its usage can be applied for surfaces and rehabilitation of:-

- Damaged overflow structures
- To protect the embankments during overtopping
- To build buttress so as to strengthen heavy dams
- Reservoir liners etc.

Within the past decade, improvements in placing with equipment and mix design have resulted in smoother, tighter pavements with good surface appearance, expanding RCC's application. Today, RCC is used for any type of industrial or heavy-duty pavement. The reason is simple. RCC has the strength and performance of conventional concrete with the economy and simplicity of asphalt. Coupled with long service life and minimal maintenance, RCC's low initial cost adds up to economy and value. Depending on the desired thickness and width of the installation, the concrete can be laid very quickly from 60 m to 120 meters per hour

Its usage can be applied in other areas like:-

- Streets and local roads
- High-volume intersections/roads
- Industrial access roads
- Parking lots/ heavy storage areas
- Highway shoulders

- Airport aprons and taxiways
- Military facilities

8.0 MATERIALS USED IN RCC

The basic materials used to produce RCC include coarse aggregates, fine aggregates, cementitious materials water and chemical admixtures. The designer has to evaluate the actual material for the specific project and the proportion under consideration, design the structure accordingly, and provide appropriate construction specifications. The roller compacted concrete is constructed without joint sawing, formwork, finishing, steel reinforcement, or dowels. However, saw-cut joints can be easily created to offer an enhanced appearance and to help control cracking.

8.1 Coarse Aggregate

To produce high quality RCC, both the coarse and fine aggregate fractions should be composed of hard, durable particles and the quality of each should be evaluated by standard physical property tests. Compared to RCC containing naturally rounded gravel, RCC containing crushed stone generally requires more water to attain a given consistency and more effort to compact. However, it is more stable during compaction and usually provides a higher flexural strength. Owing to the low water content, the danger of segregation of RCC is high. In order to minimize segregation during handling and placing of RCC and to provide a closed and relatively smooth surface texture, the maximum aggregate size is often limited to approximately 20 mm.

8.2 Fine Aggregate

RCC mixtures are less susceptible to segregation during handling and placing when the fine-aggregate content is increased over that recommended for conventional concrete mixtures. In order to improve the smoothness of the top surface of RCC pavement and to obtain a closed surface, it is recommended that non-plastic fines passing a 75-µm sieve be in the range of 5 to 10%.ACI Committee 325 recommends fines content upto 8 %.

8.3 Cementitious Materials: Commonly used binding materials are as following:-

Fly ash: Cementitious materials content of a typical RCC mixture for pavement is about 11 percent of concrete by mass. The amount of fly ash is usually about 20-30 % by mass of the total binder content for typical highway pavement. Fly ash in RCC partially replaces portland cement and optimizes the amount of fine material in the mixture. It also improves placement characteristics. In addition, fly ash contributes to strength development due to its pozzolanic properties. When used to replace a portion of cement, fly ash generally decreases the water requirement of concrete mixtures having a measurable consistency. In order to increase the amount of fine particles, fly ash can also be used as a partial replacement of sand. Fly ash can be added when available aggregates do not contain enough fines. Use of fly ash gives the concrete enhanced properties such as decreased permeability and thereby higher seepage control. It has also the ability to control the heat gain effectively as well as it provides resistance against sulfates and sulfides.

Blast furnace slag and phospo-gypsum: Blast furnace slag and phospho-gypsum (a by-product of phosphoric acid production) is found to increase the setting time of RCC, thus allowing an increased time for construction.

Silica fume: Silica fume and super plasticizer can be used to improve strength and frost resistance of roller compacted concrete (RCC). The quality of RCC is directly related to the degree of compaction obtained and the dry density can be taken as a measure of compaction. It was found that the use of super plasticizer led to an increased dry density of RCC. The effect was even more pronounced when both super plasticizer and silica fume were added to an RCC mixture. When used alone, silica fume did not increase the dry density of RCC. The amount of silica fume is usually limited to maximum 10% by mass of the total binder content.

8.4 Water and Chemical Admixtures

Water quality for RCC is governed by the same requirements as for conventional concrete. Entraining a consistent amount of air in RCC is quite difficult, particularly with mixtures having no measurable slump. The formation of air bubbles is only possible if a sufficient amount of water is available. For an air-entraining agent to be efficient there must be enough water to form a film around each bubble. When the quantity of water added to the RCC mixture is significantly decreased, water tends, first of all, to cover solid surfaces. There is thus a competition for water between the bubbles and the solid particles. Below certain water content, the efficiency of the air-entraining agent is thus minimized, even at fairly large dosages. The water content of most

RCC mixtures is usually of the order of the minimum quantity required to entrain air. Attempts to entrain air in RCC mixtures can be successful if the air-entraining agent is premixed with the cementitious paste (a mixture of cementitious materials and water), a small portion of the coarse aggregate, and a super-plasticizer before adding the sand. The addition of a set-retarding admixture can also be effective to allow a delay of the rolling process without the formation of joints. However from durability point of view use of air entraining admixture is mandatory.

9.0 THE PROCESS

RCC owes much of its economy to high-volume, high-speed construction methods.

Mix: An RCC mixing facility, such as a pug mill, tilt drum, or dry batch ready-mixed plant, must have the mixing efficiency to evenly disperse the relatively small amount of water present in the mix.

Transport: Dump trucks transport the RCC mix from the plant to the conventional or high-density asphalt pavers.

Placement: The mix is placed in layers (or lifts) 4-8 inches thick. The concrete should be dry enough to prevent sinking of the roller equipment but it should be wet enough to permit the required distribution of binder mortar used.

Compaction: Compaction is the most important stage of construction because it provides density, strength, smoothness and surface texture. Compaction begins immediately after placement and continues until the pavement meets density requirements. Steel drum vibratory rollers are used to compact the RCC. The pavement must be cured to ensure proper strength gain. Once cured, the pavement is ready for use.

Surface smoothness: To improve surface smoothness and texture, an asphalt or concrete overlay is sometime applied as a riding surface for high speed traffic.

10.0 BENEFITS AND FEATURES

- **Strong:** RCC has high flexural strength from 3.5 to 7 N/mm^2 and high compressive strength from 27 to 69 N/mm^2. RCC also has high shear strength and low shrinkage benefits.
- **Low initial cost:** RCC is competitive with alternative pavement options on a cost basis.
- **High durability:** Resists rutting and does not deform under heavy concentrated loads. Supports heavy, repetitive loads without failure, resists deterioration from spills of fuels and hydraulic fluid. It does not soften under high temperatures.
- **Low maintenance:** Fewer associated costs as compared to conventional concrete.
- **Fast construction:** With no forms or finishing and minimal labour, RCC is placed quickly. The low water-to-cement ratio and zero slum consistency of the mix allows for quick strength gain. Fast return to service in case of pavement for traffic movement.

- **Quick return to service:** RCC pavement can often be opened to local traffic in as little as 4 hours after placement and can accept heavy traffic 24-48 hours after placement.
- **Simple design/Construction:** No steel reinforcing or dowels required, aggregate interlock provides excellent load transfer eliminating need for dowels.

PART C: CONCLUSION

11.0 CONCLUSION

MASS CONCRETE

Mass concreting is used for massive structures such as dams, bridges, retaining wall, pier, large foundation etc. Generally, the concrete mix design is the most effective way to minimize the impact of heat in mass concrete. Minimizing the risk of temperature related damage is a fundamental part of every mass concreting project. There are two main temperature related issues to monitor for: maximum internal temperature and temperature differential. Exceeding specified limits puts concrete at increased risk of severe cracking and therefore temperature monitoring is needed. Thermal control plans describe the temperature monitoring procedures which should be strictly followed on site. Cooperation between the designer, specifier, and contractor on mix design, insulation, and cooling is the key to build durable structures successfully with mass concrete.

ROLLER COMPACTED CONCRETE

Building dams in today's society is for more than one reason like water supply, irrigation, flood control, navigation, sedimentation control and hydropower. Multipurpose dams for the developing countries are a great deal; due to a single investment contribute to economic and domestic benefits for the population. When the dam is constructed with concrete, it uses large amount of cement. This leads to high cost and a negative impact on the environment due to CO_2 emissions. Therefore alternate method like roller compacted concrete reduces the cost as well as minimizes the use of cement.

Roller compacted concrete (RCC) has gain recognition as a competitive material for building new and rehabilitating existing dams along with other types of structures. Over the past decade improvement in construction method to enhance the final product while maintaining the speed of construction, provides RCC its competitive edge. Today, RCC is used when strength, durability, economy and speed of construction are primary needs.

12.0 REFERENCES

1. ACI 207.2R. (2007). Report on Thermal and Volume Change Effects on Cracking of Mass Concrete, American Concrete Institute, U.S.A
2. ACI 207.1R. (2005). Guide to Mass Concrete, Reported by ACI Committee 207
3. ACI SPEC-301-16. (2016). Specifications for Structural Concrete, Reported by ACI Committee 301
4. ACI 301-99, Specifications for Structural Concrete, Reported by ACI Committee 301

5. https://www.commandcenterconcrete.com

6. Zhonghe Shui, Rui Yu, and Jun Dong. (2019). Activation of Fly Ash with Dehydrated Cement Paste

7. ACI CODE-318-11(2011). Building Code Requirements for Structural Concrete and Commentary

8. Delatte, N. and C. Storey. 2005. Effects of density and mixture proportions on freeze-thaw durabilityof roller-compacted concrete pavements. *Transportation Research Record: Journal of the Transportation Research Board* 1914: 45–52.

9. Luhr, D.R. 2006. *Frost Durability of Roller-Compacted Concrete Pavements: Research Synopsis*. Publication IS692. Skokie, IL: Portland Cement Association

10. Adaska, W. 2006, *Roller-Compacted Concrete (RCC)*. PCA Research & Development Information, Serial No. 2975. Skokie, IL: Portland Cement Association.

11. Marchand, J.; R. Gagne; E. Ouellet; and S. Lepage. 1997. Mixture proportioning of roller-compacted concrete: A review. From *Proceedings of the Third CANMET/ACI International Conference: ACI Special*

12. American Concrete Institute Committee 214. 2002. *Evaluation of Strength Test Results of Concrete.* ACI Report 214R-02. Farmington Hills, MI: American Concrete Institute.

13. American Concrete Institute Committee 325. 2002. *Guide for Design of Jointed Concrete Pavements for Streets and Local Roads.* ACI Report 325.12R-02. Farmington Hills, MI: American Concrete Institute.