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Design of Roller Compacting Concrete Pavement

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***Abstract*—**The quality of concrete is usually defined by compressive strength, but flexural strength is the most important characteristic of concrete in a pavement which control the mix design of concrete instead of compressive strength. Therefore, the aggregates which are selected for the pavements are affected by higher flexural strength. Roller Compacting Concrete Pavement (RCCP) is not a new construction method. The other characteristic of this method is no bleeding and less shrinkage due to the lower amount of water. For this purpose, a roller is needed for placing and compacting. The surface of RCCP is not smooth; therefore, the most common use of this pavement is in an industrial zone with slower traffic speed which requires durable and tough pavement. For preparing a smoother surface, it can be achieved by asphalt paver. RCCP decrease the finishing cost because there are no bars, formwork, and the lesser labor need for placing the concrete. In this paper, different aspect of RCCP such as mix design, flexural, compressive strength and focus on the different part of RCCP on detail have been investigated.

***Keywords*—**Flexural Strength, Compressive Strength, Pavement, Asphalt.

I. Introduction

IN order to use RCC, a combination of modified materials in concrete must be considered. The instruments used in RCC are the same as conventional concrete. In RCC, using dried material with cement to reduce the moisture that allows the roller to compact it. On the other hand, the cement and other characteristics are similar to normal concrete. Therefore, RCC pavements can directly tolerant the loads on the finished surface that such a possibility does not exist in the ordinary concrete.

The first report of RCC construction in pavements related to Scotland in 1865, while the use of concrete vibration started 50 years later [19].

A valuable contribution in the RCC pavements has been made in the 70s by increasing the price of bitumen and the use of alternative materials in pavements increased. The first new examples of RCC pavements were in Spain, about 1970, on low-traffic roads [1]. This type of pavement (RCCP) in Canada began to use in the timber industry in 1976 [2]. After 1980, at least 10 other countries (France, USA, Norway, Sweden, Finland, Denmark, Germany, Australia, Argentina and Japan), built RCC pavement more than 100,000 m2. By the end of 1990 total surfaces of this type of pavements were made 12000 000 m2 that about 10,500,000 m2 of the pavements were on the highways and main roads. For improving the smoothness of the surface, a layer of asphalt on RCC is located [3].

There are many reasons for the widespread use of roller compacted concrete pavement, such as, the ability to use it with commonly available devices that eventually cause to lower cost. Furthermore, the simple process of RCC pavement and lesser labor cost with high production rates, leads to significant savings in compared to other types of pavement [4]. As expected, RCCP has some drawbacks. Flatness of surface on the high-speed roads is not satisfactory, to solve this issue, performing a layer of asphalt, is required.

II. Martial and Mix Design

To prevent separation and facilitate mixing process, the size of the coarse aggregate should be 22 mm or less.

Mix sand should be used only if the smoothness of the pavement is less important. The important factor in the mix after compaction is the ability to earn high internal consistency [19].

III. Pavement Design Methods

In most countries, pavements remain uncoated; RCC pavements are designed in the same way like ordinary concrete. RCCP often perform without coating, especially in low-traffic roads and also in industrial areas. In some countries such as France, to protect RCCP and sliding resistance a coating layer is being used [5]. When a few centimeters of asphalt concrete placed on RCCP, the thickness is reduced in contrast to the same amount of ordinary concrete [6].

Most of the weaknesses of the RCC pavement are on the longitudinal edge of the road, because the compaction at these parts due to the lack of lateral support is not done correctly. Therefore, for overcoming this problem the road needs to be wider.

IV. Mixing and Transport

Generally, using permanent concrete plants with high production increases in recent years and it can be easily used for RCCP [8]. Transportation usually is done by open body trucks. Moisture content in RCC is very sensitive, so trucks must be equipped with protective coverings during unsuitable environmental conditions, such as cold or stormy days.

V. Distribute

During periods of warm weather, sub-base surface layer should be wet immediately before the distribution of concrete. On the other hand, distributing materials is not permitted on

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frozen layers [9]. To ensure the proper density of all the layers, the total thickness of RCCP should not exceed 25 cm [3].

VI. Density

Using a simple roller can ensure maximum density up to 90% [10]. Usually a heavy vibrating roller, in many cases, with a rubber wheel roller can satisfy the compaction. The vibration roller weight is recommended to be more than 30 kg per cm per wheel width. However, each wheel load must be at least 3 tons and contact pressure must be at least 0/8 MPa (Fig. 1) [11]. The pattern of roll includes two roll crossing (reciprocating) on the new material to form the layer. By several passes, usually four or more, the required density is obtained [8].

The condensation process continues until all of the cracks or holes in the surface being closed. If a rubber wheel roller is not available, steel wheel can be used to seal the surface [12]. Successive roller passes should be adjusted continuously to prevent the formation of depressions.

Fig. 1 Roller compacting

RCCP with the appropriate versatility has uniform deformation. If the RCCP is wet, its surface seems shiny and RCCP under pressure of rollers have elastic behavior. If the RCCP is very dry, its surface will appear dusty, therefore, it is essential to strictly limit the variation in water content.

Rollers, especially in the case of vibrating, should not be turned off when the materials are fresh because it causes ripples in the finishing surface. In many countries, the density of the layers is mandatory to finish in 60 to 90 minutes after mixing the material. Despite, in the presence of high amounts cement additives, such as retarders, this time can be increased. Thick pavement in the industry area can reach to a maximum thickness of 60 cm, in special condition.

When the thickness exceeds 25 cm, RCC pavements are usually implemented in several layers for ensuring the density of each layer (Fig. 2). In these cases, adhesion between the layers is very important. The substrate surface must be usually kept moist, however, in some projects in the US and Canada, application of an adhesive cement slurry was used successfully [13].

Fig. 2 Thickness of layers

Where RCC pavement construction is done in several lines, determining a suitable pattern of rollers to prevent the cold joints and longitudinal cracks is necessary [14].

Generally, 0.3 to 0.5 meters of the first line strip remain without compact. The compaction of outer edges is important. To obtain good results, need to place additional constraint, like a curb in the city streets. Otherwise, the density and strength will be reduced.

By using the shoulder of the road, it is recommended for compact together with the layers of RCCP. The pattern of compacting achieved with a roller passes over the seam by using two-thirds of the wheels on the concrete layer and the remaining placed on the shoulder [15]. Then, the roller is passed over a layer of RCCP, only to compact it against the shoulder. In hot weather, it may be necessary to keep the material moist and spray water on the surface.

VII. Joints

Usually, cracks in RCCP cannot transfer loads because it is more than pavement's tolerant. Therefore, the implementation of the joints is required. The necessary joints width should be less than 1 cm (Fig. 3). Recently, to prevent reflective cracking, seams has been applied every 2.5 to 4 m [7].

Transverse joints are very dependent on weather conditions and the strength of the RCCP. The joints that are created at the end of the day (the longitudinal and transverse joints), are necessary to be cut as close as possible to the vertical angle. Otherwise, by increasing in temperature, the ending parts of edges will overlap [16].

Fig. 3 Transvers joint

VIII. Advantages of the RCC Pavements Compared to Asphalt

RCCP in the low and medium traffic is ideal. The maintenance cost of RCCP is less than asphalt. The useful life of RCCP is more than asphalt (40 to 50 years compared with 15 to 20 years). RCCP provides greater visibility at night and it can increase the road safety. The RCCP thickness is less than the asphalt thickness and it is preferred in some areas where there are restrictions on the thickness and materials usage decrease. Due to savings in the use of materials, destruction of natural resources in RCCP will be less. In steep and mountainous areas with a large number of heavy vehicles that do not meet the asphalt pavement requirements, RCCP can be considered as a good option. In high temperature environments, the performance of RCCP is better.

IX. Disadvantages of the RCC Pavements Compared to Asphalt

The initial construction cost of RCCP is more than asphalt pavement. The RCCP repair is more difficult. Using of expansion joints in the RCCP cause weakness points and has a key factor in the resonance crashes and destruction. Therefore, there is a problem in the maintenance and repair of expansion joints in the RCCP.

X. Flexural Strength

As mentioned earlier, flexural strength of concrete is an important parameter in designing of pavement. But preparing the bending samples in the labs or cutting the prismatic samples from in-situ concrete is a difficult parameter. It is worth to mention that, the compressive strength parameters such as W/C ratio and the degree of condensation have an effective influence on the bending strength. Due to lack of appropriate moisture or density, bending strength will be lost [17].

XI. Compressive Strength

Due to the importance of thermal issues in the RCC dam, try to minimize the amount of requirement cement. Therefore, the compressive strength of the RCC pavement considerably is more than an RCC dam. Because of the low thickness of the concrete in the RCC pavement, it can waste the heat of hydration easily; accordingly, the amount of cement is not very important. Therefore, the amount of cementation material on the RCC pavement is significantly more than the usual amount of cement in the RCC dam [20]. The compressive strength of some projects in America is presented in Table I.

TABLE I
Compressive Strength from Some Project of RCCP in US

Project	Age of concrete (Month)	Layer thickness (mm)	Design Compressive strength (MPa)	Compressive strength of cores (MPa)
A	9	178	31	48.5
B	19	165	34.5	32.7
C	19	216	34.5	26.5
D	18	216	25.3	48.5
E	12	254	13.8	24
F	28	178	31	31
G	32	216	34.5	41

XII. Brazilian Tensile Strength

Brazilian tensile strength is determined by testing on the cylindrical samples made of concrete or using the core samples taken from the RCC pavement concrete. The tensile strength of some projects executed in America is presented in Table II. The results illustrate the similarity in the relationship between Brazilian tensile strength and flexural strength of RCC pavement concrete with ordinary concrete.

TABLE II
Flexural and Brazilian Tensile Strength in Some USA's Projects

Project	Age of concrete (Day)	Flexural strength (MPa)	Brazilian tensile strength (MPa)
Stewart	90	7.2	---
Hood	7	4.7	---
	28	5.9	---
Harvey	7	---	2.4
	28	5.6	2.9
Campbell	7	4.6	2.8
	28	----	---
Aberdeen	7	4	2.7
	28	4.5	3.2

XIII. Fatigue

Fatigue cracking is one of the reasons for the deterioration of RCC pavement. This type of cracking represents the beginning of failure in the structures of RCC pavements that alter the shape of the stress and caused the changes in the construction of pavement layers [18]. Fatigue failure occurred in two stages based on the following:

- The first step is to create a hairline crack between the cement paste and aggregate.
- And secondly hairline cracks are formed and grow. As a result, the material weaknesses will gradually appear and the applied repetitive load lead to destroy.

Wide research on fatigue behavior on the RCC pavement has been shown that RCC pavement fatigue behavior is similar to concrete pavement. It can be expected that for the same amount of cement, RCC pavement have a greater resistance to fatigue because the water-cement ratio in these mixtures is considerably less. This research has also shown that aggregates have relatively important role on fatigue behavior. The aggregate with more durability and toughness have more fatigue resist.

XIV. CONCLUSION

For low-speed traffic, RCCP can be the best choice and usually considerable financial savings, especially when special equipment needed for the manufacturing process are not available. Also, on freeways and highways is an economical choice. It is expected that with new developments in the pavement machines for RCCP to reach high-density compression, reducing the number of roller passes and improvement of driving characteristics lead to more widespread use of RCCP.

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