

## **PROPERTIES AND PERFORMANCE OF ROLLER COMPACTED CONCRETE PAVEMENT AND ITS ECONOMIC EVALUATION**

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### **ABSTRACT**

One of the most important parts of road is the pavement of it. The aim of the pavement is providing a flat and smooth surface with sufficient safety for the vehicles traffic. The pavement should have properties which moreover bearing vehicles weight can resist climatic and physical factors in all climate conditions. Road pavement in terms of cost of construction, maintenance, traffic quality, cost of vehicle depreciation and cost of accidents has a significant role. Durability and quality of the pavement, causes dynamism in a road network. Generally, there are two types of road pavement including asphalt and roller compacted concrete. Decision making about selecting type of pavement in a particular project requires the existence of necessary information and tools in order to perform a systematic comparison between the two types of pavement. Therefore, determining the comparative evaluation criteria for different types of pavement is necessary and accuracy in this case lead to dynamism in the road construction industry. Roller compacted concrete is a concrete pavement which is distributed with asphalt pavers or soil distribution machinery and by using the roller is stabilized. Due to the low consumption of cement, low shrinkage, high strength, fast implementation and other advantages, this type of pavement have been used and studied more since 1980. In this study the properties and performance of concrete pavements are evaluated.

**Keywords:** *RCC, Economic Evaluation, Strength, Pavement*

### **INTRODUCTION**

Most of the of the natural fields in untouched condition can not able to bear applied loads of vehicles wheels such as heavy trucks and airplanes and the use of natural field for bearing these loads is impossible .Hence, in order to bear heavy loads, the intensity of induced stresses should be reduced up to bed strength. Therefore, by laying resistant layer on the bed, which is known as the pavement, we will achieve to this demand. Properties of this layer should be such that moreover sufficient thickness in order to reduce applied stresses and transfer them to natural bed, have enough strength against climatic and physical factors. Vertical compressive stress from loading on bed by increasing the modulus of layers and thickness of the pavement is decreased, which is due to increase in load bearing effective area. The intensity of these stresses under the applied load area is maximum.

Pavements subjected to heavy traffic should have a high strength. So in order to this purpose in construction and implementation of these pavements, taro cement materials with respect to relevant standards are used. Pavements because of loading are deformed and thus the tensile and compressive stresses are resulted in them. If the resulting tensile stresses in each layer of the pavement layers is more than the tensile strength of the material of that layer, it will cause the failure and cracking in that layer.

#### ***Roller Compacted Concrete Pavement (RCCP)***

Roller compacted concrete is a concrete pavement which is distributed with asphalt pavers or soil distribution machinery and by using the roller is stabilized. Due to the low consumption of cement, low shrinkage, high strength, fast performance and other advantages, this type of pavement have been used and studied more since 1980. However, because of the following problems, development of this type of pavement in large-scale and in high-grade roads, is restricted:

1. Pave and smooth out this type of pavement is very difficult.
2. Obtain the appropriate surface roughness for required friction in braking is very difficult.
3. Being ensured of the uniformity and qualitative stability of pavement is difficult.

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In order to solve the above problems, in some cases, also an asphalt concrete pavement is used. Spain and some other European countries have good experiences of asphalt concrete pavements. Asphalt concrete pavement is an applicable option for solving the problems, but it may be due to additional needed materials and vehicles lead to increase in the cost as well as problems of reflective cracking and adhesive intermediate layer (Akbarnejad *et al.*, 2008).

RCCs are mixture of graded aggregates, Portland cement and a little water. Mixture is in form of a homogeneous mass that its slump is equal to zero and because of difficulty to achieve smooth and comfort surface for driving, these materials are not appropriate for high-speed roads. This type of pavement for roads by traffic of heavy vehicles with low speed that are used for transportation and also factory yards, airplane categorizing area, heavy vehicles parking lots, the commercial roads and terminals lot is appropriate. Also for new roads, parking's, bus stations, construction shoulder of roads with heavy traffic and creep bands and hangars is appropriate (Akbarnejad *et al.*, 2008).

The advantages of using them in urban areas is for filling underground service channels including telephone and electricity cables, sewerage and drainage pipes.

In this type of pavement aggregate to cement ratio (1: 6) and the water to cement ratio 0.14–0.35 and the slump value is zero. In RCCPs by reducing the filler percentage in the aggregate grading, ground compaction before implementation and implementation road shoulder pavement with the fresh RCC and initial compaction by roller without vibration and final compaction by a heavy vibratory roller, proper results are obtained.

### **Properties and Performance of Roller Compacted Concrete**

Roller compacted concrete as used for road pavement (RCCP), in the fresh condition is different from conventional concrete and that is more rigid and its efficiency is less more. In hardened form, roller compacted concrete pavement from many aspects is similar to the conventional concrete and main effective parameters on the properties of conventional concretes such as water to cement ratio ( $w / c$ ) and density, have a similar impact on the properties of roller compacted concrete pavement. Also it should be considered that because of low efficiency of these concretes, methods for providing specimens in order to investigate their properties, is different from conventional concrete. Roller compacted concrete specimens through special methods such as compaction with special wind hammer and or vibratory methods under (excess) load or through implementation of trial cross and cutting required samples and or coring are provided.

### **Performance**

Roller compacted concrete (RCC) in fresh condition should be able to bear the weight of roller, so it is very stiff and dry concrete which its water content is much less than other concretes. Therefore, common methods in order to determine plasticity and efficiency such as slump test are not applicable. The method that is developed for measuring the performance of roller compacted concrete is plasticity determining method by modified VB-test. In this test standard VB-equipment with one weight is used. This weight depending on different references is various and between 13.3 to 22.71 is considered.

### **Water Bleeding**

Problem of water bleeding possibility in conventional concrete and pavements of conventional concrete is one of the cases that should be considered and controlled. In roller compacted concrete because of low content of mixture water the bleeding phenomenon does not occur, so the problems caused by creating weak layer on concrete surface due to bleeding in these concretes are not problematic and can be considered as advantages of this type concretes.

### **Compressive Strength**

The considered compressive strength for roller compacted concrete to pavement construction significantly is more than the considered strengths for roller compacted concrete that is used in dam construction. In roller compacted concretes of dam construction due to importance of thermal issues, trying limit the amount of cement to minimum required amount. Also, with respect to no need for high strength in mass concretes of dam construction, water to cement ratio in these concretes generally is high and it often is determined between 0.5 to 1.

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### **Drying Shrinkage**

Drying Shrinkage is one of the characteristics of cement based materials, including different concrete types and for conventional concretes the final drying shrinkage generally are in the range of  $200 \times 10^{-6}$  to  $1200 \times 10^{-6}$ . Because of the considerable shrinkage in concrete pavements in order to prevent accidental cracking caused by that, joints with intervals of 4 to 6.8 meters, about 24 hours after the implementation of concrete pavement will be created. In roller compacted concrete pavement that its use mainly is mainly for pavement in order to heavy loads crossing and as a result cutting the edge of joints lead to problems about crushing the edge of joints and often avoid cutting the edge of joints and it is allowed that cracks are generated accidentally. The intervals between cracks are considerable and about 10 to 25 meters and for some thicker pavements, longer intervals are reported. Due to the increasing the use of roller compacted concrete pavement on the roads, it is important to predict the cracks intervals that this issue is related to the shrinkage characteristics of these concretes. Laboratory investigation on the number of roller compacted concrete pavement specimens were done and average of long-term shrinkage of these mixtures is about  $370 \times 10^{-6}$  that this amount is somewhat lower than the value of this parameter for conventional concretes (Akbarnejad, 2007).

### **Comparison of Roller Compacted Concrete Pavement with Asphalt Concrete Pavement**

#### **A- Technical Comparison**

One of the main problems that road engineer must decide about it, is selecting the type of pavement for investigated road among concrete and asphalt pavements and for this issue various parameters should be examined. One of the effective parameters for selecting the pavement type, is the amount of traffic or the number of passing vehicles. The asphalt pavements due to viscoelastic properties under heavy applied loads have weak performance and performance and after a loading time and repeated load, this weakness is exacerbated. Hence, nowadays in the areas with high passing traffic rate, concrete pavements specially roller compacted concrete pavements are used (Heidari and Tavazoe, 2013).

#### **B- Implementation Comparison**

Roller compacted concrete pavements implementation machines, actually is the required machines for asphalt pavement, and only in the method of implementation are slightly different. In order to distribute the roller compacted concrete pavement, only with applying small changes common pavers for road construction can be used. On the other hand, generally pavers are equipped with vibrating screeds that somewhat caused the initial compression of the concrete.

Concrete compaction is doing by the rollers that are used for the compaction of asphalt layers (Gregory and Halsted, 2005).

#### **C- Economic Comparison**

One of the effective parameters in the evaluation of engineering projects is economic parameter. Nowadays many designers and organizations that codify the standards, in order to save energy and cost of service, many designers and organizations develop the regulations, in order to save energy and maintenance costs, and consequently improves the useful life of the pavement, review the existing methods. Also, many organizations in addition to the initial costs, consider the consumer costs including delay caused by traffic in repair or rehabilitation, depreciation of vehicles, etc., as well as design effective cost (Gregory and Halsted, 2005).

### **Analysis of Technical Economical Feasibility of Roller Compacted Concrete Pavements (RCC) in Iran**

Use of concrete pavements is common in other countries, but in our country despite of existence adequate materials, due to the low price of tar, and do not introducing other appropriate alternative options and in some cases, lack of technical- practical knowledge, and some special equipments, implementation and construction of this type of pavements is not taken into consideration. Among these concrete pavements, RCCP (roller compacted concrete pavement) has optimal conditions respect to other concrete pavements.

#### **A- Evaluation Criteria**

Evaluation criteria include:

- Technical and practical criteria
- Economical Criteria

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### B- Technical and Practical Criteria

Technical and practical criteria of RCCP (roller compacted concrete pavement) and also the advantages and disadvantages of other concrete pavements have been studied in the previous sections.

### C- Economical Criteria

One of the effective parameters in the evaluation of engineering projects is economic parameter. Pavement costs can be categorized as follows:

- The cost of construction and implementation
- The cost of repair and maintenance
- The cost of consumers (depreciation of vehicles and tires, spending time for travelling, the spending cost in case of accident occurrence due to imperfect performance of pavement, the cost of fuel consumption and ...)
- The cost of construction

Construction cost includes the cost of planning, design and implementation of the pavement. Hence, in this paper the cost of several concrete and asphalt and RCC pavement specimens are given for comparison. Table 1 shows the cost of materials for various pavements construction.

**Table of materials cost in pavement**

Material type	Material cost	Prime cost of pavement
Portland cement	14-18 (dollars per cubic yard)	28-36 (dollars per cubic yard)
Asphalt	8-10(dollars per ton)	11-15 (dollars per ton)
Crushed stone	3-5 (dollars per ton)	5-8 (dollars per ton)
Grainy basis	2-4 (dollars per ton)	3-6 (dollars per ton)
Borrow material for filling	1-2 (dollars per cubic yard)	2-3 (dollars per cubic yard)

It can be seen that two thirds of the total cost of the pavement, is for materials. It should be considered that that costs mentioned on the table, are for previous years, but rate of the cost that obtained from table is acceptable.

### - The Cost of Maintenance

In order to prevent from premature failure and structural damage of pavement maintenance operations are done that in Iran, considering that there is not any systematic management plan for repair and maintenance of road and on the other hand estimating the repair and maintenance cost of different road types (gravel roads, main road and byway) with various pavement types (asphalt, concrete) requires that having annual periodic data that this data is not available, too. Therefore, in the case of pavement repair and maintenance costs, and the estimations and studies that are carried out in abroad, have been referenced. Items of maintenance can be enumerated as follows (Hassani, 2004).

- Visit the joints and clean them of any foreign object
- Repair the technical structures
- bush digging
- filling longitudinal and transverse cracks by implementation of local coating
- Repair formed rutting in the road
- Repair sand seal
- Supply and repair of lighting along the road, especially in the arcs with low vision and foggy regions
- Replacement and repair of traffic signs along the pavement and pavement markings

Increase and review of safety Proceedings in order to increase security of users in the accident-prone points such as repairing or adding or adding Guard rail, separator concrete blocks of traffic paths or creating traffic islands...

As can be seen, lighting the roads is one of the repair and maintenance cases. One of the differences of concrete pavements with asphalt pavement is their brighter surface that due to increase of reflection on the surface of pavement, the less light for lighting will be needed which lead to cost reduction in this regard.

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From the other cases, implementation of local coating due to deformation (deepen) of pavement is required and in concrete pavements because of surface rigidity this phenomenon does not occur.

In Figure 2, the ratio of the construction, repair and maintenance costs and users cost for a concrete pavement in the UK is shown.

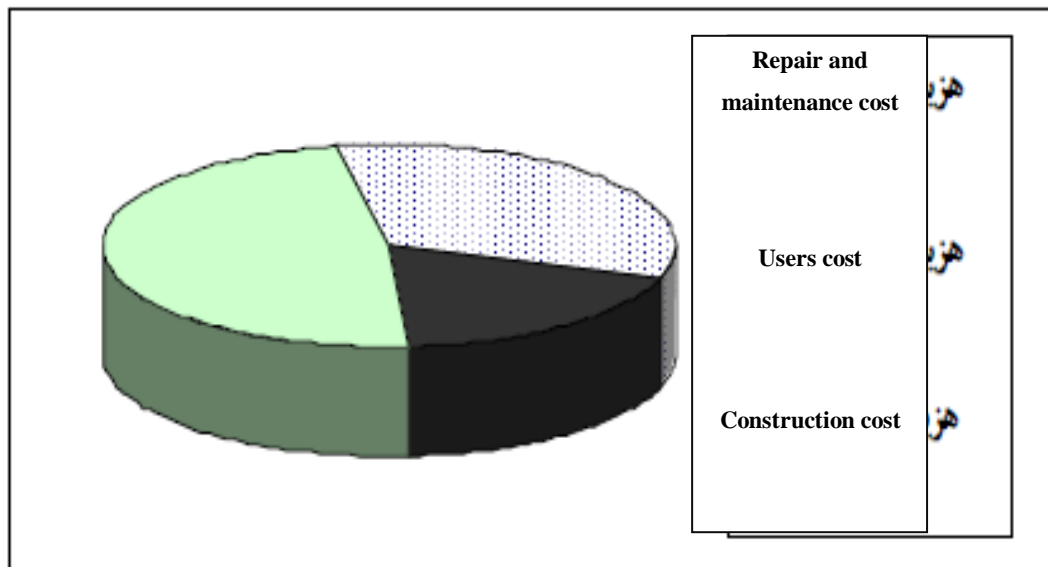


Figure 1: Ratio of cost per concrete pavement life

As can be seen, construction cost, repair and maintenance cost and users cost respectively have the maximum cost of road. It can be seen that the maintenance cost of concrete pavement is approximately half of the construction cost. In several examples that in order to estimate the cost of asphalt pavement maintenance is expressed in the book (that is written by Uderabout pavement), repair and maintenance cost of this type of pavements is estimated equal or more than the construction cost.

### Evaluation of RCCP Performance Problems

#### A-Smoothness of Surface

Roller compacted concrete pavements at present have problems.

Smoothness of produced surface by the existing machines still is not satisfying for high-speed traffic and a lot of noise, will disturb the driver and passengers. At first roller compacted concrete pavement on the road with little traffic, residential streets, parking lots and industrial centres were used and because of that their surface was not finished.

But nowadays due to tendency to use this type of pavements in the roads with faster traffic like main roadways and freeways and highways, more appropriate surface with more quality is needed. In many countries, like Spain and France to solve this problem and achieve the smooth surface, final asphalt surface layer is used. However, during the implementation of asphalt layer on the surface of roller compacted concrete, by use of existing sealing methods, should prevent from the formation of reflective cracks in RCC joints and cracks (Hassani *et al.*, 2008).

Another problem of roller compacted concrete pavement is the lack of sufficient and appropriate density of its layers that can be seen in the pavements with high layer thickness. In appropriate density and lack of cohesion between layers lead to low performance and fundamental damages on the pavement surface. In projects such as Freeway that Smoothness of surface has great importance, the following items in order to achieve smoother surface can be used:

- The maximum aggregate size is limited to 59mm.
- The thickness of layers for density is greater than 188mm.
- Achieve the maximum density with minimum number of roller.



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### ***B-Permeability and Durability***

One of the problems in all types of pavements especially roller compacted concrete pavement, is the permeability of the pavement structure. The most important factor that leads to this problem is the lack of proper implementation and appropriate materials usage. Therefore, the used materials in this type of pavement and implementation method are very important. As a result in case of non-compliance with these items, the quality of the pavement will be reduced drastically and its structure is very vulnerable. On the other hand, the shrinkage narrow cracks, causing transfer lead to damages such as water bleeding on the pavement surface. Of course the roller compacted concrete pavement that is provided and implemented technically, can be considered completely impermeable and impenetrable.

Roller compacted concrete pavement against the environmental effects and physical effects and damages to its surface, has shown good strength and durability. In some cases, if the appropriate continuity during construction is not provided, little erosion (less than 6mm) on the surface of the pavement will occur. However, the experiment and tests has shown that the erosion stops after a while and will not increase even under traffic impact (Michael and Ayers, 2012).

### ***Application in the World***

Construction methods of roadways around the world have changed a lot and due to different reaction caused by petroleum in the asphalt during time, the issue of changing the texture of streets and highways and replacing it by roller compacted concrete pavement have been used in developed countries . Examples are as follows:

- Highways, freeways, major roads and by ways as well as port areas and parking lots in many states of US such as Carolina, New Jersey, Oklahoma, Virginia, etc (Morgan, 2011).
- Landscaping of many military and strategic areas of US army.
- Highways and major roads and by ways in several states of Spain including Castile, Andalucía, Barcelona, Basque and...
- Many parking lots in European countries
- Several highway and road way in the countries of East Europe such as Norway, Finland, Sweden and Switzerland, that the winters are very cold and long.
- Several roadway and port areas and parking lots in Japan.
- In several road grade 1 and 2 in India in recent years (Gregory and Halsted, 2009).
- And many other countries.

### ***Application in the Country***

In the country due to abundance of tar and its low prices before increasing prices, concrete pavements are not taken into consideration. But in recent years and increasing the prices due to increase the tar price, trends to concrete pavements especially roller compacted concrete increase. Also several projects in our country are implemented that can be noted as follows:

- Region 22 of Tehran municipality for the first time implemented roller compacted concrete pavement in 2009. This pavement in the 35 meters from the north of Hemmat highway with classification of martial road grade 2 with length of 8 km and a width of 15.7 meters was implemented.
- For the first time in 2012 for streets and Maskan- Mehr housing project of Hashtgerd new town was used.
- Construction and implementation of roller compacted concrete pavement in major road north axis of Mashhad cement factory by Mashhad cement factory in RazaviKhorasan province in the mid 2012's
- In 2012, Niayesh tunnel pavement by offer of project contractor and in order to increase pavement life and its durability by roller compacted concrete pavement was implemented.
- At the end of 2012 for the first time in Esfahan, roller compacted concrete pavement in the entrance of Sofeh manufacturing plant by the Esfahan municipal civil organization was implemented (Heidari and Tavazoe, 2013).

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### **CONCLUSION**

Roller compacted concrete pavement in many countries were used and are being used, but unfortunately in our country because of the low price of tar in the several past years and the lack of technical and practical knowledge and special required equipments, is not considered. From the theoretically and experimentally point of view, it can be concluded that the concrete pavements in any environmental, traffic, dust, etc. conditions, by considering economic factors can be used. Roller compacted concrete pavement as a type of concrete pavement recently has been used widely and in many cases has been accepted and due to environmental compatibility, many of natural wastes in order to increase its strength can be used and on the other hand its damages to the environment is much less than the asphalt pavement. Concrete pavement and subsequently roller compacted concrete pavement due to high rigidity can be used in many environmental conditions and on the other hand, not only the damage of concrete pavement is less than the asphalt pavement, but the life of concrete pavement is several times of the asphalt pavement life. Implementation of roller compacted concrete pavement is similar to the asphalt pavement and only minor changes in the road construction finisher and time and pause of roller passing are needed. By comparison the cost of asphalt pavement and roller compacted concrete pavement, it can be concluded that the cost of roller compacted concrete pavement construction is significantly less than the asphalt pavement construction. Also, in addition to the cost of construction, repair and maintenance costs, which sometimes in long term might be more than the construction cost. Experiments of roller compacted concrete pavement implementation in our country or foreign countries can show that this type of pavement moreover maintenance the quality of implementation, greatly reduces the implementation cost. If the pavement lifecycle cost is considered, however its analysis due to lack of roller compacted concrete pavement and concrete pavement implementation will not be possible but available evidences from world experience show that because of longer life of concrete pavement and lower repair and maintenance cost of it respect to asphalt pavement, total cost of roller compacted concrete pavement in comparison with asphalt pavement cost will be less. So it is recommended that roller compacted concrete pavement is used first in areas with steep slopes and hot weather with a heavy and slow loading that in which asphalt pavement has a problem and is not amenable.

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