# The relationship between roller compacted concrete durability and air void parameters using X-ray computed tomography

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## ABSTRACT

**The aim of this study was to investigate the relationship between the durability parameters of roller compacted concrete Pavement (RCCP) exposed to freeze - thaw conditions and the characteristics of the air void obtained by X - ray computed tomography (CT). For this purpose, eight RCCP designs with four water to cement ratios of 0.35, 0.4, 0.45 and 0.5 were prepared using two compaction methods including vibrating table and vibrating hammer. Properties such as air void content, mass changes, ultrasonic pulse velocity, and relative dynamic modulus were investigated. In addition, CT scan and image processing technique were used to estimate the air void content in designed RCCPs. In order to identify the air void, volumetric - based global thresholding algorithm method was used. The results showed that with the increase of water to cement ratio, the percentage of air void increases until the optimal value is reached and then decreases. The difference between the results of durability indicators in the two compaction methods increased with the decrease of water to cement ratio. RCCPs made with a water to cement ratio of 0.35 in the vibrating hammer method and water to cement ratios of 0.35 and 0.4 in the vibrating table method suffered the most damage after freeze - thaw cycles. The increase in capillary pores has a negative effect on the structure of roller compacted concrete and the presence of fine pores has a positive effect on freeze-thaw durability. In both compaction methods, the optimal amount of water to cement ratio was 0.45 showing appropriate durability indicators.**

## KEYWORDS

**Roller compacted concrete, Air void, Digital image processing, CT scan, durability.**

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## 1. Introduction

Road pavements are structures that are constantly exposed to environmental factors. Therefore, it is very important to pay attention to the durability parameters for the long - term performance of these structures. Environmental factors directly affect the durability of road pavements. Various factors such as the effect of moisture, freeze - thaw (F - T), sulfates and salts, etc., which is one of the important factors, the effect of the use of salts in the discussion of winter storage. Therefore, studying its effects on concrete pavements is very important. So, the intensity and speed of damage in freezing conditions and in the presence of chemicals is approximately 10 times of normal freezing [1-2]. Sufficient air void must be created to protect the concrete from damage caused by Antifreeze salt. Due to the inherent difference in the production and application of rolled compacted concrete pavement (RCCP) compared to conventional concretes, achieving a suitable air void matrix is a major challenge. While like other types of concrete, there is a significant relationship between the characteristics of the air void in RCCP and its behavioral and functional characteristics, especially in the discussion of durability. According to several studies, concrete with suitable air void properties has a successful performance in case of severe freezing and thawing. A suitable air void system can help reduce the hydraulic pressures generated by F - T cycles [3].

There are several methods for determining the content of air voids in fresh and hardened concrete samples. Compression, volume and weight methods can be used to determine the amount of fresh concrete void [4-6]. However, these three methods do not provide information on the size and distribution of empty space. Vacuum assessment methods in hardened concrete, microscopic detection method are used to measure dimensions, percentage of voids, etc. [7]. Other methods such as mercury intrusion porosimetry (MIP) and scanning electron microscopy (SEM) are also available to study the microstructural properties of hardened concrete [8-9]. These methods also face problems. For example, in the MIP method, the use of inks increases the size of small to large pores, and the SEM method provides only two - dimensional information [10]. The method that has received more attention in recent years to obtain the parameters of concrete air void and how it is distributed is the X - ray computed tomography (CT) method based on digital image processing techniques. The use of CT in civil engineering materials research has been increased in recent years [11-14].

In this paper, CT method and image processing techniques are used to calculate the air void parameters in RCCP and based on this information, their durability parameters during F - T cycles in the presence of frost solution are investigated.

## 2. Methodology

In this study, RCCP samples were made by two methods of vibrating hammer compaction according to the standard method ASTM C1435 [15] and vibrating table according to the standard method ASTM C1176 [16] in 4 water to cement ratios of 0.35, 0.4, 0.45 and 0.5 were prepared. The CT scan method, using MATLAB software and image processing technique called volumetric - based global thresholding algorithm, was used to determine the desired threshold value to determine the amount of RCCP air void and then the results with the laboratory method [17] were compared.

In addition to the content, number and equivalent diameter of the air void were determined as a parameter to evaluate the size of the air void using the CT scan method. F - T test according to the standard method ASTM C666 [18] and in the presence of NaCl water and salt solution with a concentration of 3% on RCCP samples and the relationship between empty space parameters and durability indicators such as ultrasonic pulse velocity (UPV). The mass changes ($W_{change}$) and the relative dynamic modulus of elasticity ($P_n$) were investigated.

## 3. Results and discussion

According to the research performed in this study, samples with water to cement ratio of 0.45 and 0.35 have the lowest and highest content of empty air space, respectively. Also, the vibration hammer compaction method creates less space in RCCP samples due to the high amount of compression energy compared to the vibration table. The standard deviation of the results obtained from CT and laboratory is less than 0.5% which shows the high correlation between the results obtained from both methods.

Based on CT results, by reducing the content of air void and increasing the water to cement ratio to 0.45, fewer capillary pores are created in the RCCP structure. In addition, with decreasing water to cement ratio, the number of air void decreased and with changing the compaction method from vibrating hammer to vibrating table, the number of air void increased. The dryness of RCCP samples due to the low water to cement ratio creates a larger air void. However, by increasing the ratio of water to cement after the optimal value of 0.45, the equivalent diameter increases.

The results of regression analysis between UPV, $P_n$ and $W_{change}$ with air void parameters showed that there was a good correlation between these indicators with the content and size of air void but due to the difference in the size of air void in the different RCCPs samples have low correlation with the number of air voids.

## 4. Conclusions

1. Based on the obtained results, the volumetric-based global thresholding algorithm is a suitable method for examining RCCP air void parameters. Due to the uniform intensity of X - rays in an image, the intensity of light received by the sensor indicates the degree of permeability or impermeability of the components of the sample. Therefore, by determining the global threshold value, air voids with the highest permeability can be distinguished from other components. Comparison of the results obtained by the CT method and laboratory air void shows that the CT method can estimate the air void of RCCP samples accurately.
2. Based on CT results, the ratio of water to cement is an important parameter in the content of air voids obtained in RCCP.
3. According to the obtained results, the selection of the optimal ratio of water to cement has beneficial effects on the parameters of air void and durability and in the amount of water to cement 0.45, due to the optimal content of air voids, reduction of capillary pores and small equivalently diameter, the UPV, $P_n$ and $W_{change}$ indices are at their most appropriate values. Also, the vibrating hammer method resulted in higher durability compared to the vibrating table method due to its higher compaction strength.
4. High correlation between durability indices with air void parameters showed that by determining the content and size of air void in RCCP samples, the durability of these samples against F - T cycles can be predicted. However, the number of air void is not a good measure of durability.

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