



Ahlul Bayt International
University

Concepts and Functions in The Building Engineering

Journal homepage: <https://www.ijsceng.com>



Study of the Permeability of Roller-Compacted Concrete in Transportation Projects

Esmail Fallah Lajimi

 DOI: [10.22034/ijsceng.2025.176321](https://doi.org/10.22034/ijsceng.2025.176321)

Master's Student in Transportation Engineering Islamic Azad University, Malard Branch, ,
Malard, Iran.

* **Corresponding author:** [es.fallah@ iau.ac.ir](mailto:es.fallah@iau.ac.ir)

ARTICLE INFO

Article history:

Received: 27 December 2024

Revised: 06 February 2025

Accepted: 17 March 2025

Keywords:

Roller-compacted concrete,
permeability, cement content.

ABSTRACT

Roller-compacted concrete (RCC) is defined as a dry concrete with zero slump. In recent years, the use of RCC in the construction of dams and road pavements has gained widespread acceptance. This trend is attributed to both technical and economic justifications, leading to its global adoption. However, concerns regarding fluid seepage in roller-compacted concrete dams have always been a critical consideration for designers. Therefore, measuring the permeability of concrete in dams is essential to determine the extent of fluid seepage and to provide a criterion for evaluating the durability of the concrete.

The main objective of this research is to investigate the effects of various parameters on the permeability of roller-compacted concrete, including mix design, age of the mixtures, cement content, amount of cementitious materials, water-to-cement ratio, percentage replacement of pozzolan (clash), maximum aggregate size, and the amount of silica fume.

E-ISSN: 000-000

© 2024 The Authors. Concepts and Functions in the Building Engineering by Ahlul Bayt International University.

How to cite this article:

E. Fallah Lajimi (2024). Study of the Permeability of Roller-Compacted Concrete in Transportation Projects, 1(3), 29-37. <https://doi.org/10.22034/ijsceng.2024.176321>

Introduction

Roller-compacted concrete (RCC) is a relatively modern method for constructing massive concrete structures such as storage and diversion dams. The concept behind its production is based on using very low-workability dry concrete that can be compacted by vibratory rollers. (Ehsani Zanuz et al., 2009)

According to the American Concrete Institute (ACI), roller-compacted concrete is defined as concrete that, in its fresh and unhardened state, has zero slump and can withstand the load of a vibratory roller during the compaction process. The advantages of this type of concrete include reduced cement consumption and consequently lower heat of hydration, the use of relatively coarse aggregates in the concrete matrix, the possibility of constructing spillways and auxiliary structures integrally with the dam body, and notably, its economic benefits and high construction speed. (Foroughi Asl et al., 2009)

Danestan believes that permeability is a function of the amount of cementitious material used in the mix. However, Schrader stated that the permeability of roller-compacted concrete does not change significantly with variations in cement content. He argues that with proper design of low-cement mixes, permeability comparable to that of conventional concrete can be achieved. According to a theory by Bantia and Pagon, the permeability of RCC depends on the amount of entrapped air and the porosity of the cement matrix. Therefore, the method of mixing and placing the concrete, as well as the degree of final compaction, affect the permeability. (Shokrchi Zadeh et al., 2011)

2. Materials Used

For the preparation of coarse aggregates, three size ranges of aggregates were used: 37.5–19 mm, 19–12.5 mm, and 12.5–4.75 mm. (Ehsani Zanuz et al., 2009)

The cement used in this experiment was Type 2 cement from Hormozgan, and the aggregates were river-sourced materials. The particle size distribution curve of the aggregates also complies with the US Army standards. (Shokrchi Zadeh et al., 2011)

3. General Testing Procedure

After preparing several cylindrical molds and sieves of different sizes, various tests specific to each parameter were conducted, resulting in the following analytical findings:

3-1 Effect of Cement Content

From a concrete perspective, increasing the cement content while maintaining the water-to-cement ratio improves the mechanical and physical properties of the mix. Therefore, it is expected that increasing the amount of cementitious material will lead to higher mechanical strengths, density, and modulus of elasticity, along with reduced porosity and permeability.

On the other hand, the soil mechanics perspective on roller-compacted concrete emphasizes the water content and optimal moisture level, such that increasing water beyond the optimum moisture reduces mechanical strengths and increases permeability, even if the water-to-cement ratio and cement content are maintained.

As shown in Figure 1, the permeability coefficient does not increase continuously with increasing cement content; the best result is observed at a cement content of 110 kg/m³. The explanation is that in this series of tests, the cement content was increased while maintaining the water-to-cement ratio, so at 110 kg/m³, the water content reached its optimum point. This leads to increased density

at this point, consequently reducing porosity and ultimately decreasing the permeability coefficient, as illustrated in Figure 2. (Shokrchi Zadeh et al., 2011)

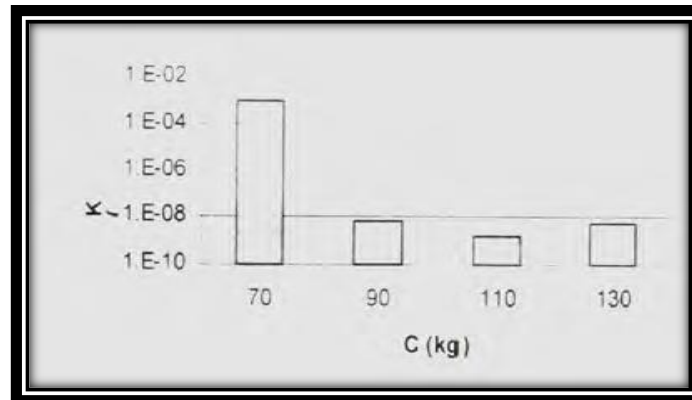


Figure 1. Effect of Cement Content on Permeability Coefficient (Shokrchi Zadeh et al., 2011)

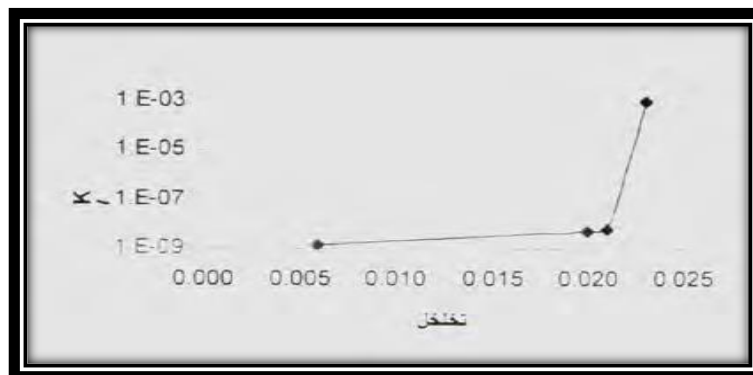


Figure 2. Direct Relationship Between Porosity and Permeability (Shokrchi Zadeh et al., 2011)

3-2 Effect of Maximum Aggregate Size

After examining the effect of maximum aggregate size on the permeability of samples at fixed ages of 3, 7, and 28 days with various water-to-cement ratios, the results for the 3- and 28-day ages are presented in Figures 3 and 4, respectively. (Foroughi Asl et al., 2009)

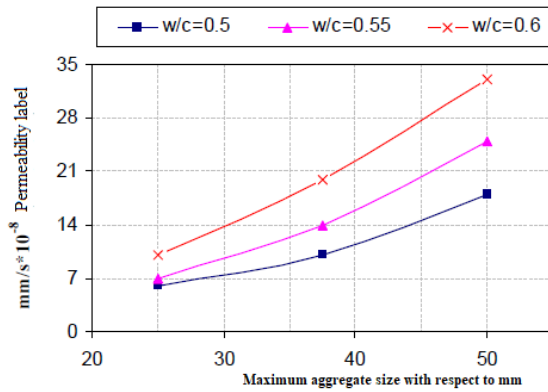


Figure 4. Effect of Maximum Aggregate Size on 28-Day Permeability (Foroughi Asl et al., 2009)

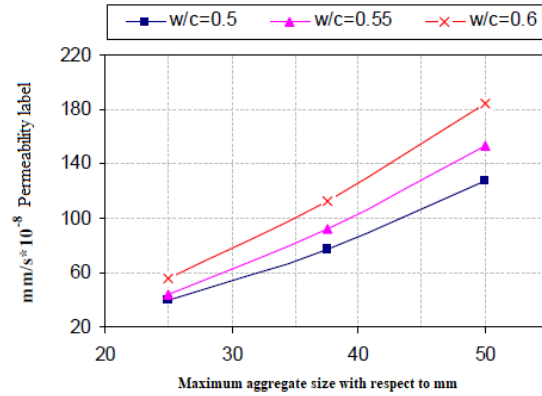


Figure 3. Effect of Maximum Aggregate Size on 3-Day Permeability (Foroughi Asl et al., 2009)

As observed in the above figures, permeability increases with an increase in the maximum aggregate size. This phenomenon can be attributed to the formation of microcracks in the concrete transition zone as the maximum aggregate size increases. Additionally, for a given aggregate size, permeability of the samples increases with an increase in the water-to-cement ratio. This is due to the creation of more pores and higher porosity in concrete samples as the water-to-cement ratio rises. (Foroughi Asl et al., 2009)

Investigation of Mixture Properties with Varying Cement Content

The statistical averages of the obtained results are presented in Table 1, and their comparison is shown in Figures 5 and 6. As seen in Figure 5, increasing the cement content in the mixtures, similar to conventional concrete, leads to improved mechanical properties and reduced permeability. Figure 6 also indicates a decrease in permeability of the mixtures corresponding to an increase in compressive strength. (Ehsani Zanuz et al., 2009)

Table 1. Statistical Averages of Results Obtained with Varying Cement Content (Ibid., 2009)

Design Code	Cementitious Materials(kg/m ³)	Density(kg/m ³)	Vebe Time (sec)	Permeability Coefficient(cm/s)	Technological Strength(kg/cm ²)
A0	200	2510	13	1/19×10 ⁻⁹	152
A1	180	2502	15	1/68×10 ⁻⁹	144
A2	160	2506	15	1/46×10 ⁻⁹	103
A3	140	2468	16	1/50×10 ⁻⁹	90
A4	120	2496	18	1/55×10 ⁻⁹	72

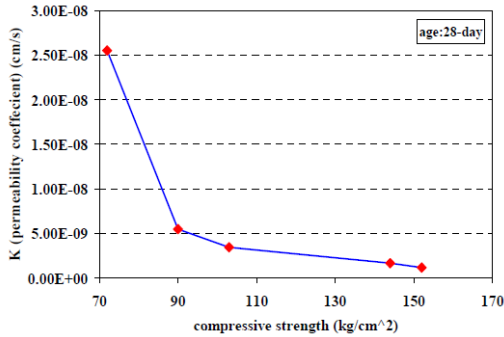


Figure 6. Variations of Permeability Coefficient versus Compressive Strength (with Variable Cement Content)

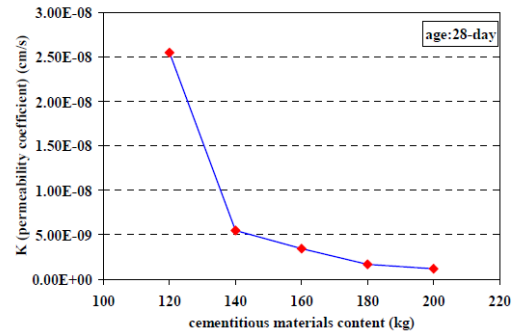


Figure 5. Changes in the Average Permeability Coefficient with Varying Cement Content

Investigation of Mixture Properties with Varying Water-to-Cement Ratio

The statistical averages of the obtained results are presented in Table 2, and their comparison is shown in Figures 7 and 8. Figure 7 illustrates a descending-then-ascending trend in the permeability of the mixtures as the water-to-cement ratio increases. As observed, the minimum permeability value occurs at a water-to-cement ratio of 0.5, after which permeability increases with further increases in the water-to-cement ratio.

At low water-to-cement ratios, the compactability of the mixture practically decreases, leading to incomplete compaction of the roller-compacted concrete. This results in reduced mechanical properties and increased permeability of the RCC. It is worth noting that at a ratio of 0.5, the phenomenon of aggregate segregation is clearly visible, which can cause critical and detrimental conditions in field applications. Therefore, using higher water-to-cement ratios to prevent segregation appears necessary.

Figure 8 also shows that permeability decreases in parallel with an increase in compressive strength. (Ehsani Zanuz et al., 2009)

Table 2. Statistical Averages of Results Obtained with Varying Water-to-Cement Ratios (Ibid., 2009)

Design Code	Cementitious Materials(kg/m ³)	Density(kg/m ³)	Vebe Time (sec)	Permeability Coefficient(cm/s)	Technological Strength(kg/cm ²)
B0	0/4	2460	---	$3/27 \times 10^{-9}$	135
B1	0/5	2505	100<	$3/14 \times 10^{-10}$	173
B2	0/6	2510	13	$1/19 \times 10^{-9}$	152
B3	0/7	2518	9	$2/36 \times 10^{-9}$	143
B4	0/8	2450	6>	$4/72 \times 10^{-9}$	107

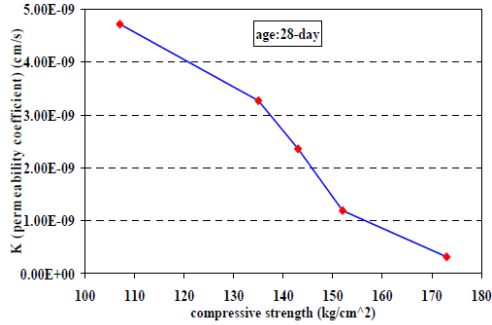


Figure 8. Variations of Permeability Coefficient versus Compressive Strength (with Variable Water-to-Cement Ratio)

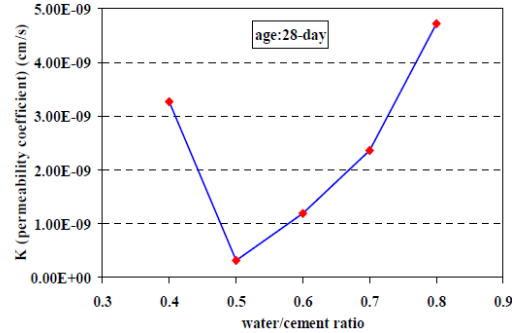


Figure 7. Changes in the Average Permeability Coefficient with Varying Water-to-Cement Ratio

3-5 Investigation of Mixture Properties with Varying Percentage of Pozzolan (Clash) Replacement

In this series of mixtures, the effect of varying the percentage of pozzolan (clash) replacement for cement on the properties of the mixtures, particularly their permeability, was investigated. The statistical averages of the obtained results are presented in Table 3, and their comparison is shown in Figures 9 and 10. It is noteworthy that the samples were tested at the age of 56 days.

As observed in Figure 9, at the tested age, increasing the percentage of pozzolan replacement leads to an increase in the permeability of the samples. However, this increase becomes significantly more pronounced after a 30% replacement level. Figure 10 also indicates a decrease in permeability of the mixtures in parallel with an increase in compressive strength. (Ehsani Zanuz et al., 2009)

Table 3. Statistical Averages of Results Obtained with Varying Percentage of Pozzolan (Clash) Replacement (Ibid., 2009)

Design Code	Cementitious Materials(kg/m ³)	Density(kg/m ³)	Vebe Time (sec)	Permeability Coefficient(cm/s)	Technological Strength(kg/cm ²)
C0	0	2513	18	$1/12 \times 10^{-11}$	217
C1	0/1	2489	18	$2/28 \times 10^{-11}$	198
C2	0/2	2506	15	$3/75 \times 10^{-11}$	176
C3	0/3	2510	13	$3/93 \times 10^{-11}$	172
C4	0/4	2496	13	$3/27 \times 10^{-10}$	152
C5	0/5	2503	13	$1/29 \times 10^{-9}$	132

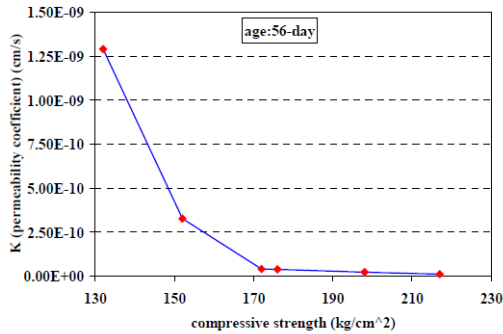


Figure 10. Changes in the Average Compressive Strength

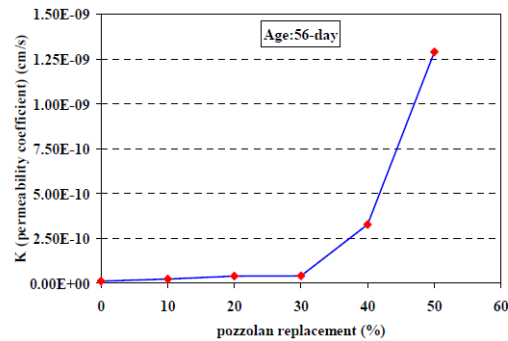


Figure 9. Changes in the Average Percentage of Pozzolan (Clash) Replacement

3-6 Investigation of Mixture Properties with Increasing Age

The statistical averages of the obtained results are presented in Table 4, and their comparison is shown in Figures 11 and 12. Figure 11 illustrates the permeability of the mixtures as their age increases, showing that most of the reduction occurs between 3 and 7 days. Figure 12 also indicates a decrease in permeability of the mixtures in parallel with an increase in compressive strength. (Ehsani Zanuz et al., 2009)

Table 4. Statistical Averages of Results Obtained at Different Ages (Ibid., 2009)

Design Code	Cementitious Materials(kg/m3)	Density(kg/m ³)	Vebe Time (sec)	Permeability Coefficient(cm/s)	Technological Strength(kg/cm ²)
D0	3	2510	13	$6/77 \times 10^{-7}$	74
D1	7	2510	13	$2/43 \times 10^{-8}$	82
D2	14	2510	13	$1/55 \times 10^{-8}$	109
D3	28	2510	13	$1/19 \times 10^{-9}$	152
D4	56	2510	13	$3/93 \times 10^{-11}$	172

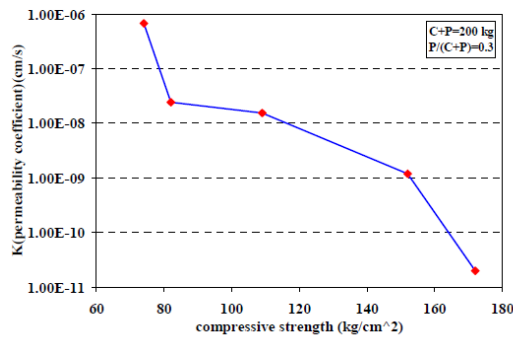


Figure 12. Variations of Permeability Coefficient versus Compressive Strength at Different Ages

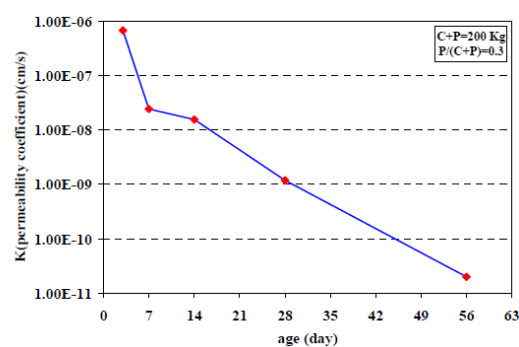


Figure 11. Changes in the Average Permeability Coefficient at Different Ages

3-7 Effect of Silica Fume Content on Compressive Strength and Permeability

As shown in Figure 13, with an increase in silica fume content, the compressive strength of the samples increases while their permeability decreases; in other words, higher compressive strength corresponds to lower permeability. This trend continues as long as the silica fume content does not exceed 25% by weight (as a cement replacement) in the

mixture. However, once the silica fume content surpasses 25%, the compressive strength suddenly decreases, and consequently, the permeability increases. (Hosseini et al., 2004)

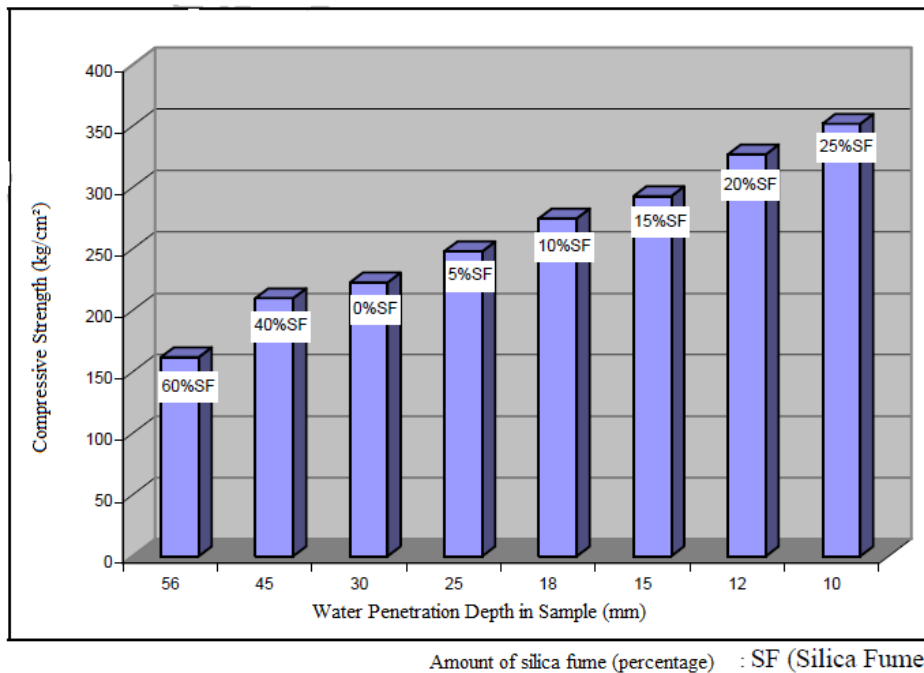


Figure 13 - Permeability-Compressive Strength Relationship (Abolfazl Hassani et al., 2004)

Conclusion

After conducting research and studies, we reached the following conclusions: In large projects such as dam construction, in addition to technical issues, economic aspects are also very important. It appears that the use of efficient management methods would be highly beneficial in the design and execution of a large dam construction project. (Jahanshahi, 2008)

Replacing cement with silica fume in roller-compacted concrete (RCC) mixtures improves beneficial concrete properties such as compressive strength and permeability. For instance, replacing 25% by weight of cement with silica fume in the mixture increases compressive strength by 58% and also reduces permeability by 32%. (Hassani et al., 2004)

As the amount of cementitious materials decreases, the permeability of the mixtures increases. (Ehsani Zonouz et al., 2009)

The permeability value shows a decreasing-increasing trend with respect to the water-to-cementitious materials ratio. The optimal water-to-cementitious materials ratio for which permeability is minimized was found to be 0.5. However, due to the occurrence of segregation at this ratio, a ratio of 0.6 is recommended. (Ehsani Zonouz et al., 2009) At the test age, i.e., 56 days, increasing the percentage of pozzolan replacement for cement in the concrete matrix increases the permeability of the mixtures. However, considering the necessity of using pozzolans for thermal reasons in the matrix of mass roller-compacted concretes, and given the significant increase in permeability after 30% replacement, a 30% replacement is recommended. Of course, considering the long-term

effect of pozzolans, it is advisable to conduct this test at older ages. (Ehsani Zonouz et al., 2009)

As the age of the specimens increases, their permeability decreases, with the largest reduction occurring within the 3 to 7-day period. (Ehsani Zonouz et al., 2009)

Also, reducing the maximum aggregate size decreases the permeability of roller-compacted concrete. This is attributed to the reduction in the area of the transition zone between aggregates and cement paste, and consequently, a reduced risk of micro-cracks occurring in this region. (Foroughi Asl et al., 2009)

The permeability of specimens shows greater sensitivity to the water-to-cement ratio than to aggregate size. Therefore, it is suggested that when constructing a hydraulic structure, to control permeability, first use the minimum possible water-to-cement ratio, and second, use a smaller maximum aggregate size. (Foroughi Asl et al., 2009)

References

Ehsani Zonouz, Ehsan, and Ali Foroughi Asl. 2009. "Permeability of Roller-Compacted Concrete." *International Congress on Civil Engineering*, Eight, pp. 1, 4, 5, 6, 7, 8. Shiraz University.

Hassani, Abolfazl, and Abedin Azadi. 2005. "Study of the Effect of Silica Fume on Permeability and Compressive Strength of Roller-Compacted Concrete Specimens." *Modares Technical and Engineering Journal*, No. 21, pp. 6, 8.

Foroughi Asl, Ali, Beig Mohammadi, Morteza, and Saeed Farzin. 2009. "Effect of Maximum Aggregate Size on Permeability of Roller-Compacted Concrete." *International Congress on Civil Engineering*, Eight, pp. 1, 2, 7, 8. Shiraz University.

Jahanshahi, Neda. 2009. "Investigation of Two Important Factors in the Construction of Roller-Compacted Concrete Dams." *First International Concrete Conference*. p. 7.

Shekarchizadeh, Mohammad; Fagher, Ali; Eftekhari, Mohammad Hossein; and Keyvan Zare Rami. 2011. "Investigation of Roller-Compacted Concrete Permeability and Its Comparison with Other Concrete Properties." *National Congress on Civil Engineering*, Six, pp. 1, 2, 3, 4. Semnan University.