International Journal of
Concrete Technology

ISSN: 2456-8317
Volume 7, Issue 2, 2021
DOI (Journal): 10.37628/IJCT

http://civil.journalspub.info/index.php?journal=IJCT&page=index

Research IJCT

# An Investigation on Aggregate Distribution in Concrete

Hasan Dilbas[1,]*

**_Abstract_**

*Falling behavior is generally studied by mathematicians. The first study is conducted by Comte de Buffon with name "Falling needles experiment" and is widely known. Buffon researched the falling needle behavior finding the fall of needles in relation with Pi. However, although aggregates are fallen to the mould in cement paste, falling behaviour of concrete is rarely studied considering the statistical parameters of the fall. Accordingly, an experimental study is conducted to research the falling behavior of the aggregate and its distribution in cementitious composite "concrete". A conventional concrete design according to TS 802 is considered, and many cylindrical concrete specimens are produced in the laboratory. Then, a method is improved to determine the aggregate location on a surface of sliced concrete face and coordinates of the maximum size aggregates are determined. As a result, the falling behavior of the aggregates in concrete is found in relation with Pi as similar as falling needles. Pi is calculated as "3.139534884…" with a very small error while Pi is "3.141592654…". In addition, it is found that mould edges cause a wall effect decreasing aggregate concentration near the edges. When gone from the edge to "a region" of concrete -it is named as concrete core in this paper-, the aggregate concentration increases.*

**Keywords:** Falling behavior, distribution of aggregate, concrete core, wall effect

## INTRODUCTION

Proper settle of concrete into a mould is a crucial task in civil engineering and this task should be seriously considered in all concrete structures by controllers. Concrete placing process is interested by chemical producers, and many types of plasticizers are evolved to ease the placement of concrete. Also, the problem of settling of fresh concrete has been solved. Although falling and settling behavior of concrete into the mould studied by many researchers, the falling behavior of aggregate in fresh concrete is rarely examined. In the literature, the falling behavior of materials is generally studied by mathematicians and the first study is conducted by Comte de Buffon and Buffon drop needles discovering the falling needle behavior which is controlled by Pi [1]. Although Buffon describes the falling behavior of needles to find Pi precisely, the study is related with only needles. In addition, in the past, Pi takes interest itself and many research are conducted to determine precisely and properly the digits of Pi with many methods [1–9] and Buffon's experiment is one of them. When a deep look is concentrated on the related literature, the first theoretical calculations of Pi was conducted by Archimedes (287-212 BC) and Pi was calculated between 223/71 and 22/7 [2]. 400 years later from Archimedes, a significant work was studied by Ptolemy and Pi calculated as 3.1416 [2]. In the past 50 years, new super-computers examined Pi to increasingly higher decimal places and still mathematicians are searching better methods to determine Pi. However, the most notable experiment on Pi was conducted by Comte de Buffon three centuries ago, and the experiments included probability of falling needles [1].

According to his experiments, many parallel lines were drawn on a plane and the distance

*__Author for Correspondence__
Hasan Dilbas

[1]Faculty, Department of Civil Engineering, Van Yuzuncu Yil University, Van, Turkey

Received Date: September 21, 2021
Accepted Date: October 10, 2021
Published Date: November 27, 2021

**Citation:** Hasan Dilbas. An Investigation on Aggregate Distribution in Concrete. International Journal of Concrete Technology. 2021; 7(2): 1–8p.

between the lines were equal to length of the needles used in the experiment. Also, the needles had equal length. Then, the needles were fallen to the lined plane. As a result of this work, the probability of the needles intersected with a line on the plane was found as a ratio of Pi. In this experiment, the needles passed in air through the plane and here, the air is a fluid matter. Hence, the needles were passed in a fluid matter and fell on the plane. When the fresh concrete is considered, aggregates pass in a fluid matter named "fresh cement paste" in the casting process of concrete and both the needles and the aggregates travel in fluids. The travel similarity of the falling needles and the aggregates is conspicuous and gives an opinion whether aggregates behave similar with needles, Pi can be calculated using an enhanced probabilistic method and aggregate distribution can be observed, also how wall effect is observed in concrete and aggregate distribution is affected by wall effect. According to the best knowledge of the author, although analytical determination techniques are worked on concrete, such as computed tomography observations (i.e., [10]) and the distribution of aggregate is generally accepted as random (i.e., [11]), few research is conducted to determine aggregate distribution behavior in concrete.

To fill the gap in the literature, this comprehensive experimental research is conducted to determine aggregate locations (or coordinates) and falling behavior in concrete using colorful aggregate. A conventional concrete design is employed. In the casting step, vibration, hand ramming, shaking etc. are not employed and aggregate fall is aimed without any external effect. Black marble aggregates are used as maximum size aggregate to observe aggregate locations/aggregate falling behavior/aggregate distribution in this study. In total, 30 aggregate location matrixes are obtained for 30 specimens produced under standard laboratory conditions and the statistical evaluations are conducted on the matrixes.

## METHOD

In this study, CEM I 42.5 R Portland cement is used (TS EN 197-1 [12]). The chemical and the physical properties of cement is presented in Table 1. Basalt based fine and coarse aggregates with 22.4 mm maximum size and siliceous based sand with 4 mm maximum size are utilized. The properties of aggregates are demonstrated in the Table 2.

**Table 1.** The chemical and physical properties of CEM I 42.5R cement.

| Contents | Cement |
|---|---|
| $SiO_2$ | 21.0 |
| CaO | 63.5 |
| $SO_3$ | 2.4 |
| $Al_2O_3$ (%) | 5.8 |
| $Fe_2O_3$ (%) | 3.3 |
| MgO (%) | 0.8 |
| Density (gr/cm$^3$) | 3.16 |
| Chlorine ratio (%) | – |
| Specific surface area (m$^2$/kg) | 3540 |
| Loss on ignition (%) | 1.25 |

**Table 2.** The properties of aggregates.

| Type | Density (gr/cm$^3$) | Water absorption (%) | Initial moisture content (%) | Fineness modulus | Los Angeles abrasion (%) |
|---|---|---|---|---|---|
| Sand | 2.55 | 1.2 | 1.05 | 2.12 | – |
| Fine | 2.75 | 0.8 | 0.67 | 5.57 | – |
| Coarse | 2.72 | 0.6 | 0.53 | 6.41 | 22.32 |
| Black marble | 2.61 | 0.8 | 0.47 | – | 31.20 |

 

The particle size distribution of aggregates is performed in accordance with the requirements of TS 706 EN 12620 [13]. The slump class is chosen as S3 (TS EN 206-1 [14]). The slump class of all mixtures is tuned constant as class S3. The absolute volume method is employed to design the mix proportions of the concrete mixtures. The size distribution of aggregates is presented in Figure 1.

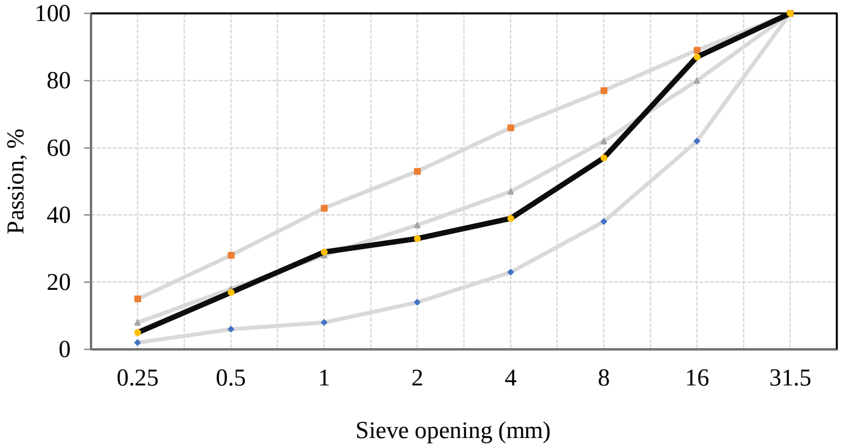


**Figure 1.** Aggregate size distribution of mix.

The water/binder ratio (w/b) is a constant (w/b=0.62), and the quantity of the cement is constant as 300 kg/$m^3$ in the mixtures. All experiments are conducted in the laboratory and the fresh concrete is casted in moulds without vibration, hand ramming, shaking etc. and fresh concrete is fallen from a height of 50 cm to the mould. After 24 hours, the hardened concrete specimens with 150Φ300 mm are demolded and are cured for 28 days at 20±2°C.

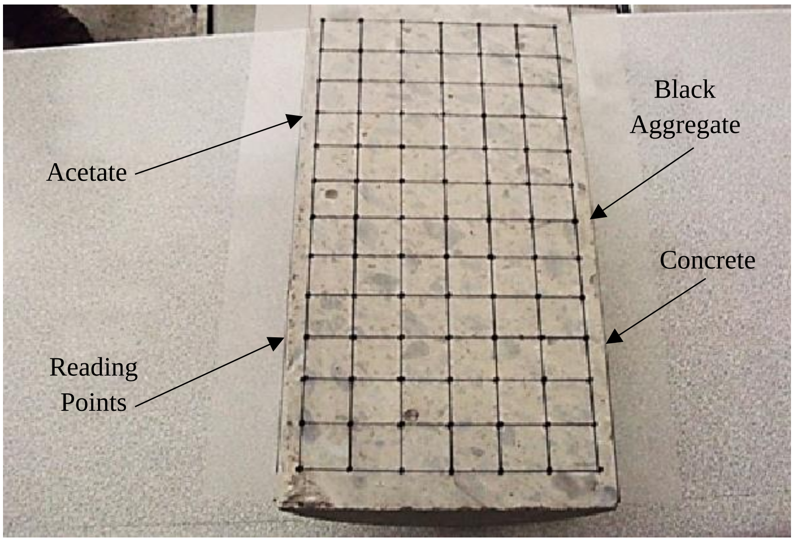


**Figure 2.** A scene of determination of aggregate location.

In the concrete mixtures, the maximum aggregate size is 22.5 mm and transparent acetates are lined vertically and horizontally with an equal distance as 22.5 mm. 13 horizontal and 7 vertical lines with 91 reading points are obtained on the acetate (Figure 2). The specimens are longitudinally cut through centers. Depending on the macroscale observation, voids in the concrete are seen. Because no vibration or shaking or hand ramming processes is employed in the experiment. However, according to macroscale observation, the void rate on the face of the concrete is low. In addition, the most of voids are seen near the mould edge. The void content, pore size, etc. are not studied in this paper and are thought as a subject of future studies.

 

Then, a method is proposed and used in this paper whether the black aggregates are at the reading points. In this method, 0 and 1 are used to fill 13x7 sized matrixes for 30 concrete specimens considering the black aggregates. 0 means that no black aggregate is there at the reading point and 1 means that a black aggregate is there at the reading point. Eventually, 30 matrixes included reading points are obtained for 30 specimens. Then, the simple probability is applied on the matrixes and the results are given in Table 3.

**Table 3.** Probability matrix.

| | | Vertical lines of acetate | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Horizontal lines of acetate | 1 | 0.18519 | 0.25926 | 0.25926 | 0.29630 | 0.18519 | 0.18519 | 0.25926 |
| | 2 | 0.25926 | 0.37037 | 0.14815 | 0.33333 | 0.22222 | 0.33333 | 0.18519 |
| | 3 | 0.25926 | 0.22222 | 0.29630 | 0.37037 | 0.25926 | 0.40741 | 0.18519 |
| | 4 | 0.22222 | 0.25926 | 0.25926 | 0.40741 | 0.25926 | 0.40741 | 0.11111 |
| | 5 | 0.18519 | 0.44444 | 0.29630 | 0.44444 | 0.29630 | 0.33333 | 0.18519 |
| | 6 | 0.22222 | 0.33333 | 0.40741 | 0.18519 | 0.33333 | 0.29630 | 0.29630 |
| | 7 | 0.25926 | 0.33333 | 0.37037 | 0.33333 | 0.33333 | 0.40741 | 0.22222 |
| | 8 | 0.29630 | 0.22222 | 0.62963 | 0.22222 | 0.29630 | 0.33333 | 0.18519 |
| | 9 | 0.18519 | 0.25926 | 0.29630 | 0.44444 | 0.44444 | 0.37037 | 0.14815 |
| | 10 | 0.29630 | 0.22222 | 0.40741 | 0.33333 | 0.40741 | 0.22222 | 0.18519 |
| | 11 | 0.29630 | 0.40741 | 0.14815 | 0.14815 | 0.25926 | 0.33333 | 0.18519 |
| | 12 | 0.18519 | 0.22222 | 0.14815 | 0.37037 | 0.40741 | 0.25926 | 0.14815 |
| | 13 | 0.22222 | 0.29630 | 0.37037 | 0.22222 | 0.18519 | 0.33333 | 0.14815 |

## RESULTS

In this paper, the probability matrix includes the simple possibility, and 30 matrixes are obtained for 30 specimens. Hence, the black aggregates presence probability at the reading points is found.

It is seen on Table 1 that the average value of probability matrix elements is 0.281644. If the average value is inverted as 1/0.281644, the results is found as 3.550578035 and the result is close to Pi (3.141592654…) with a relative error as 0.13018409. It can be noted that this approach is used by Comte de Buffon to find Pi [1] and hence the similar method is used in this paper. It can be stated that the probability can be related with Pi and the wall effect can be dominant near the mould edges and aggregate presence probability is found low near the edges (Table 1). The isolation of the specimens from external effects (i.e., friction effect between mould edges and fluid cement paste or aggregates) is aimed in this paper. The probability matrix elements are reduced from 13x7 to 11x5 eliminating the first and the last rows and columns due to the wall effect (Table 4). After the matrix size reduction process, the average value of new matrix elements is calculated as 0.318519. If the average value (0.318519) is inverted as 1/0.318519, the result is found as 3.139534884. The result is very interesting and is close to Pi with a relative error as 0.000655. The findings presents that the aggregate distribution in the concrete doesn’t behave randomly although it is stated by researchers that the distribution of aggregate particles in concrete is essentially random [11, 15]. And the aggregates settle in the mould following a rule which is in relation with Pi.

In addition, the wall effect of the mould edges influences the distribution of the aggregates in concrete. The first and last rows and columns of the probability matrix which are related with near the edges of the mould has lower values than others and the values usually increase from the edges to the center of the concrete (Table 3 and Figures 3, 4). It means that the aggregates compose a core formation around the center of the concrete and can be defined as “concrete core” in this paper. The increase of aggregate presence probability (or aggregate concentration) around the center of the concrete may make concrete core more rigid than boundary regions. Because it is well-known that aggregates are the components which increase the resistance of concrete against applied forces and when the aggregate concentration increases in concrete, the strength (i.e., compressive strength) increases [11, 16].

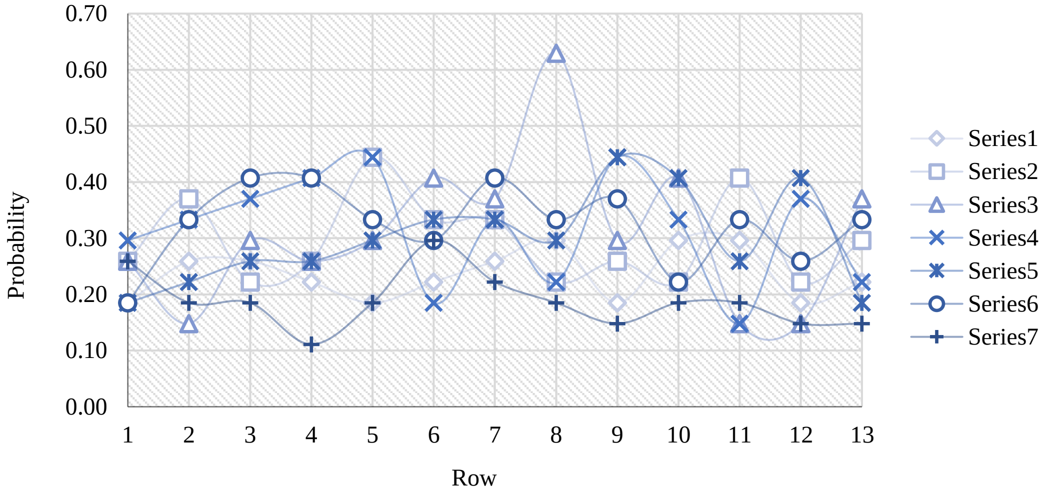


**Figure 3.** Aggregate distribution probability on concrete face.

**Table 4.** Probability matrix of concrete core region.

| | | Vertical lines of acetate | | | | |
|---|---|---|---|---|---|---|
| | | 2 | 3 | 4 | 5 | 6 |
| Horizontal lines of acetate | 2 | 0.37037 | 0.14815 | 0.33333 | 0.22222 | 0.33333 |
| | 3 | 0.22222 | 0.29630 | 0.37037 | 0.25926 | 0.40741 |
| | 4 | 0.25926 | 0.25926 | 0.40741 | 0.25926 | 0.40741 |
| | 5 | 0.44444 | 0.29630 | 0.44444 | 0.29630 | 0.33333 |
| | 6 | 0.33333 | 0.40741 | 0.18519 | 0.33333 | 0.29630 |
| | 7 | 0.33333 | 0.37037 | 0.33333 | 0.33333 | 0.40741 |
| | 8 | 0.22222 | 0.62963 | 0.22222 | 0.29630 | 0.33333 |
| | 9 | 0.25926 | 0.29630 | 0.44444 | 0.44444 | 0.37037 |
| | 10 | 0.22222 | 0.40741 | 0.33333 | 0.40741 | 0.22222 |
| | 11 | 0.40741 | 0.14815 | 0.14815 | 0.25926 | 0.33333 |
| | 12 | 0.22222 | 0.14815 | 0.37037 | 0.40741 | 0.25926 |

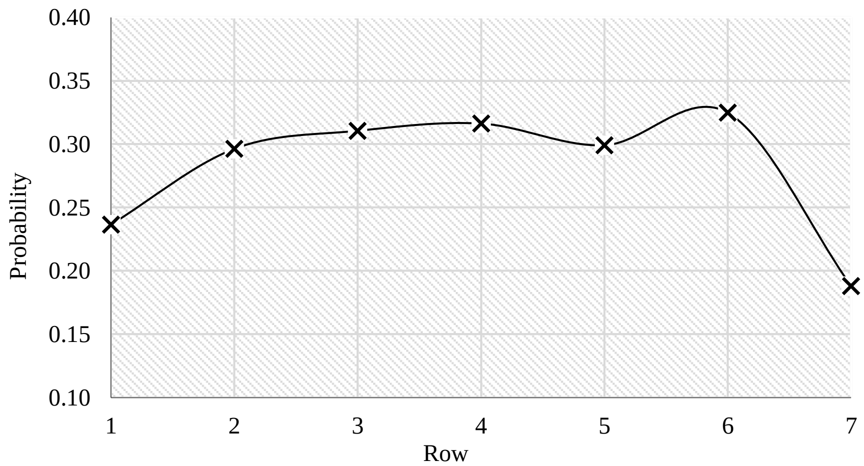


**Figure 4.** Average aggregate distribution probability on face of concrete at each row.

The random distribution of aggregates is also theoretically examined by Zheng et al. [11] and their theoretical examination of 2-dimensional and 3-dimensional aggregate distribution shows that a core formation is formed in central region of concrete. In their research, the aggregate concentration in the section/volume is analytically examined and an equation which is related with maximum aggregate size and aggregate volume fraction is derived (Eq. 1) (Figure 5).

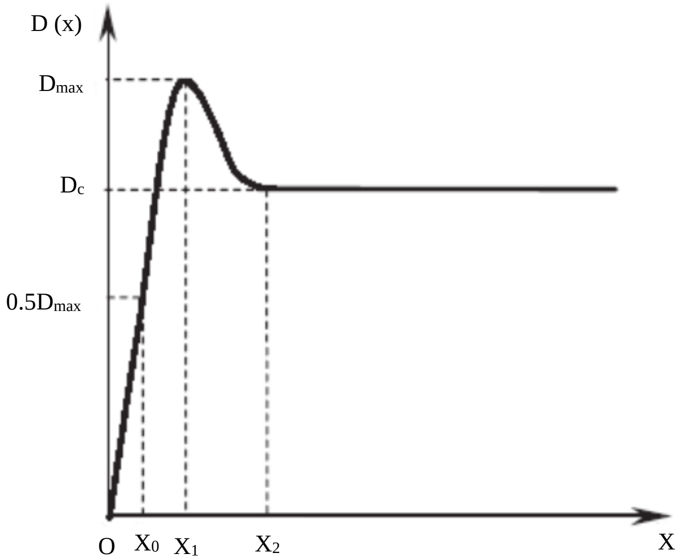


**Figure 5.** Schematic of aggregate density function [11].

In Figure 5, the relation between the variables are defined for 3-dimensional aggregate distribution as [11] (Eq.1):

$$x_0/d_m=0.270-0.299V \quad (1a)$$

$$x_1/d_m=0.653-0.725V \quad (1b)$$

$$x_2/d_m=2.174-3.356V \quad (1c)$$

$$D_c/V=1.088-0.118V \quad (1d)$$

$$D_{am}/V=1.001+0.332V \quad (1e)$$

Here, D is aggregate density values, $D_c$ aggregate density in central region, $x_0$, $x_1$ and $x_2$ are the distance from mould edge, $d_m$ maximum aggregate size.

In this research, black aggregates has %30 volume fraction in the concrete and according to (Eq.1d) aggregate concentration in central region (it is named as core in this paper) is found as 0.31578. If the result is reversed as 1/0.31578, it is found as 3.16676 and is close to Pi with a relative error as 0.008011. Also, in Figure 5, the beginning point of the core location ($x_2$) is found as 26.2 mm according to (Eq.1c) and experimentally it is found as 32.5 mm according to Figure 4.

Thus, the analytical results support the experimental findings of the current paper, and the concrete core formation has a uniform aggregate concentration (Figures 4, 5) rather than the regions near the edges.

**CONCLUSION**

In this research, a conventional concrete aggregate distribution is examined, and 30 concrete specimens are considered to define the distribution of the aggregates in the concrete in 2D. Also, a comprehensive and simple method is proposed and used to define the aggregate locations in the concrete. Based on the test results, the following conclusions are drawn:

- The falling behavior of the aggregates in concrete is found in relation with Pi (3.141592654…) and Pi is calculated as 3.139534884 with a minor relative error considering the aggregate distribution results.
- The mould edges affect the aggregate distribution in concrete and when gone to the concrete core, the aggregate presence probability (or aggregate concentration) increases. Also, concrete core has approximately the same aggregate concentration at each point.
- The analytical results obtained from the literature support the experimental findings of this study and it can be concluded that aggregate distribution function can be generated using Pi as a constant.

## Further Investigations and Suggestions

This research paper opens a new subject in the literature and adds a new line on the aggregate distribution. New generation admixture which organizes the aggregate distribution in concrete can be produced. Here, the viscosity regulator admixtures are well-known in the literature and in the industry, but further investigation for the flows of the fresh concrete can be done again considering the aggregate distribution in concrete. Aggregate distribution function using Pi as a constant in terms of size, volume, etc. can be derived and examined. In addition, new granular composite models and new particle packing methods can be composed considering falling probability function of particles.

In this paper, a conventional concrete is considered, and other types of concretes can be considered to observe the aggregate distribution in concrete. Also, in the design of concrete elements reinforced by rebars, concrete core phenomenon can be re-considered. Thus, concrete cover can be re-evaluated and selected considering aggregate distribution in a cross-section. Because aggregates form a concrete core, and the core has high aggregate concentration.

## Author Contributions

H.D., Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Resources; Validation; Visualization; Roles/Writing-original draft; Writing-review & editing.

## REFERENCES

1. Badger, L.: Lazzarini’s lucky approximation of Pi. Mathematics Magazine 67, 83-91, 1994.
2. McCreary, J., Allen, M.: Various estimations of π as demonstrations of the monte Carlo method. Department of Mathematics Technical Report No. 2001-4. Tennessee Technological University, Cookeville, TN 38505, 2001.
3. Solomon, H.: Geometric Probability - Buffon Needle Problem, Extensions, and Estimation of Pi, pp. 1-24, SIAM, Philadelphia, 1978.
4. Diaconis, P.: Buffon's Needle Problem with a Long Needle. J. Appl. Prob. 13, 614-618, 1976.
5. Dörrie, H.: 100 Great Problems of Elementary Mathematics: Their History and Solutions-Buffon's Needle Problem. pp. 73-77. New York, Dover 1965.
6. Mantel, L.: An Extension of the Buffon Needle Problem. Ann. Math. Stat. 24, 674-677, 1953.
7. Schuster, E. F.: Buffon's Needle Experiment. Amer. Math. Monthly 81, 26-29, 1974.
8. Kraitchik, M.: Mathematical Recreations-The Needle Problem, New York, W. W. Norton, pp: 132-140, 1942.
9. Wegert, E., Trefethen, L. N.: From the Buffon Needle Problem to the Kreiss Matrix Theorem. Amer. Math. Monthly 101, 132-139, 1994.
10. Abed, M., Nemes, R., Tayeh, B.A.: Properties of self-compacting high-strength concrete containing multiple use of recycled aggregate. J. King Saud Univ.-Eng. Sci. 32, 108-114, 2018.
11. Zheng, J.J., Li, C.Q., Jones, M.R.: Aggregate distribution in concrete with wall effect. Magazine of Concrete Research 55, 257-265, 2003.

12. TS EN 197-1. Cement-Part 1: Composition, specifications and conformity criteria for common cements. Turkish Institute of Standards, Yucetepe, Ankara, Turkey, 2012.
13. TS 706 EN 12620. Aggregates for concrete. Turkish Institute of Standards, Yucetepe, Ankara, Turkey, 2003.
14. TS EN 206-1. Concrete-Part 1: Specification, performance, production and conformity. Turkish Institute of Standards, Yucetepe, Ankara, Turkey, 2002.
15. Erdoğan, T.Y., Beton, METU Press, Ankara, Turkey, 2007.
16. Kocatürk, A.N., Haberveren, S., Altıntepe, A., Bayramov, F., Ağar, A.Ş., Taşdemir, M.A.: Agrega konsantrasyonunun betonun aşınma direncine etkisi. In: 5. Ulusal Beton Kongresi, pp. 535-544, Istanbul, Turkey, 2003.

 