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# THE CONTROL OF SHRINKAGE CRACKING IN THE GELEVARD CONCRETE FACE ROCKFILL DAM

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**Abstract**.*The aim of this study is to investigate experimentally the different parameters that influence concrete's early age and long term shrinkage.*

*The experimental program is founded on the factorial design of experiments with four main parameters: cement properties, maximum size aggregate, natural pozzolans as cement replacement, chemical superplasticizer.*

*The laboratory and field tests results indicate that the cement properties can significantly reduce concrete's early age shrinkage. Also, water-to-cement ratio near 0.4 with cement content less than 280 kg per m3 together with MSA 38 mm leads to decrease shrinkage. Additionally, superplasticizers with the same chemical base from different factories have various effects on shrinkage.*

## 1 INTRODUCTION

The Gelevard dam is one of the CFRD which is under located in north of Iran. The height of dam is 110 m above river level and its crest length and width are 270 m and 10 m, respectively. The upstream slopes ratio is 1.45H: 1V. The thickness of concrete salb is 0.4m near the parapet wall and 0.65m near the perimeter joint.

The main problem of CFRDs in Iran (SiahBishe, Nesa and Bijar dams) is cracking of the face slabs, which causes leakage leading to further damage to the rock fill body and loss of water.

The cracks of faceplate involve structural cracks and non-structural cracks. Structural cracks result from external force, and other cracks is non-structural cracks. The reason for non-structural cracks consist incorrect construction, chemical reaction of concrete materials, drying shrinkage and thermal stress. Cracks from drying shrinkage and thermal shrinkage of concrete are the most common cracks of faceplate. According to statistics, 80% of faceplate cracks is non-structural cracks, and non-structural cracks become main research object[1].

Shrinkage has been divided into two phases; the early age shrinkage, which occurs in the first 24 hours and the long term shrinkage, which occurs after 24 hours [2]. This division was put toward to distinguish between the driving mechanisms for each phase[2]. There are many types of shrinkage that affect concrete, namely autogenous shrinkage, drying shrinkage, chemical shrinkage, carbonation shrinkage, thermal shrinkage, and plastic shrinkage[3].

Autogenous Shrinkage, which has a strong dependence on *w/c*, is found to increase drastically once the *w/c* value goes below 0.4 [4].

For a concrete mixture with water-to-cement ratio greater than 0.42, the shrinkage at early age is mainly due to the chemical hydration reactions, while the long term shrinkage is attributed to water exchange and evaporation. Early age shrinkage strain is important because it occurs at a time when concrete is developing stiffness at a faster rate than its strength. Paulini indicated that C3A content in cement is the greatest cause of chemical shrinkage in concrete [5].

Chemical reactions induce water movements within the concrete elements leading to chemical and autogenous shrinkage; however water movement outside the concrete elements, which are water losses, causes drying shrinkage [6].

The factors that affect the drying shrinkage are divided into two categories: external and internal. The external factor is the curing method[7]. The internal factors include the cement composition such as the proportion of C3A and S03, the aggregate properties and proportions in the mix design, and water content or w/c ratio [8].

The rate of shrinkage carbonation is slow and its effect is limited to the upper layers of concrete, except for thin elements. Its magnitude is usually negligible in comparison to the other types of shrinkage [9].The major factors that affect the carbonation shrinkage are permeability of concrete, moisture content, relative humidity, high w/c of the mixture, and rate of carbon dioxide in the air[9].

Thermal shrinkage is a concern with the concrete at early age when the tensile strength is low and in massive concrete structure where the heat of hydration produced is very high.

The factors that lead to the rapid evaporation of water from the concrete surface are the main controlling factors of plastic shrinkage. These factors are high wind speed, low relative humidity, and high ambient or concrete temperature [6].

The ability to determine mix design of concrete with significantly lower shrinkage which is satisfied construction specification of Gelevard dam such as workability on relatively steep slope is, therefore, of great practical importance.

According to technical specification of Gelevard dam, the compressive strength of concrete at age of 42 days should be greater than 250 kg/cm2 with about 5% air content in concrete. To minimize the potential risk of autogenous and carbonation shrinkage, water-to-cement ratio was considered 0.4. In this project thermal shrinkage risk is probably very low, Because concrete temperature is controlled within 22 °C and duble layer reinforcement of total 0.4% and 0.35% in vertical and horizontal direction is used in concrete face. Also, By selecting cement containing the least amount of C3A, chemical shrinkage risk is minimized. So the main research point in this project is reducing plastic and drying shrinkage of concrete.

## 2 MATERIALS

### 2.1 Cements

Portland cement (ASTM C 150-Type II) obtained from Khazar, Faraz Firozkouh, Neka, Abyek, Firozkouh and Tehran and pozzolan tehran cement manufacture that are near the project location were used in study.

## 2.2 Aggregates

Maximum size aggregate (MSA) including 38 and 25 mm was used. Grading curve of natural river sand (0-5mm) is given in Figure 1. Fineness modulus of sand is between 2.6 – 2.9 and specific gravity and absorption percent are 2.63 and 2.08%. Aggregate with MSA=38mm includes natural river sand (0-5mm), fine gravel (5-19mm) and coarse gravel (19-38mm). Grading curves of them are given in Figure 2. In fine gravel, elongation, flakiness and Los Angeles abrasion percent are 10.3%, 28.9%, 20.9% respectively.

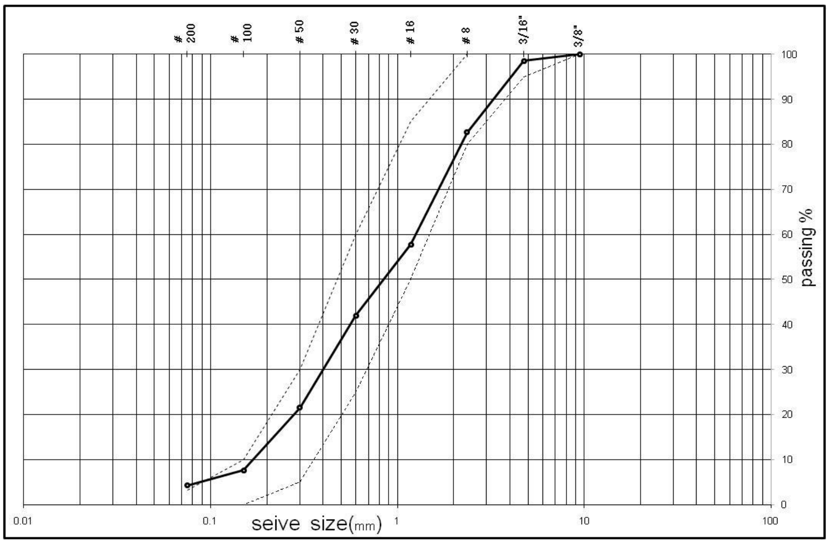


Figure 1: Grading curve of natural river sand (0-5mm)

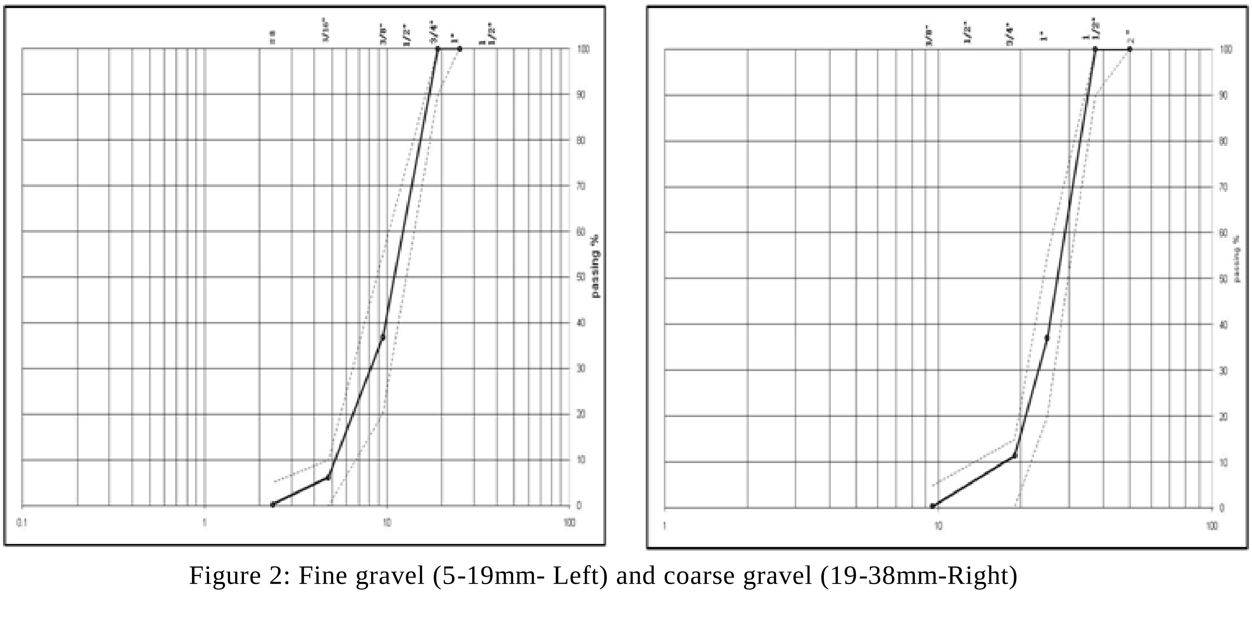

Figure 2: Fine gravel (5-19mm- Left) and coarse gravel (19-38mm-Right)

Likewise, for coarse gravel these amount are 15.7%, 21.8%and 17.8% respectively. Furthermore, the specific gravity and absorption percent in fine gravel are 2.63, 1.7% and in coarse gravel are 2.63 and 1.6% respectively. Also, Aggregate with MSA=25mm includes natural river sand (0-5mm), fine gravel (5-12.5mm) and coarse gravel (12.5-

25mm). Grading curves of them are given in Figure 3. In fine gravel, elongation, flakiness

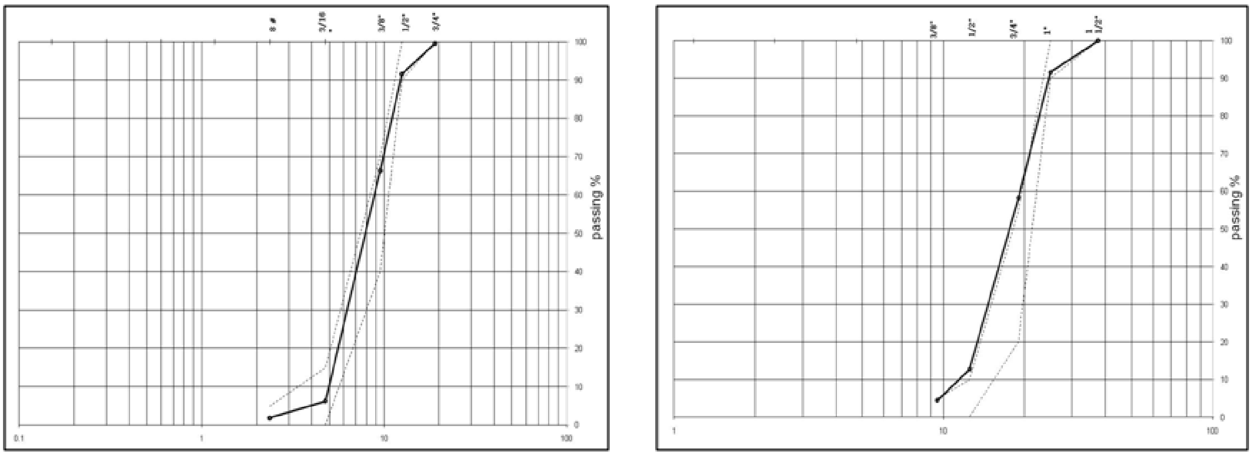


Figure 3: Fine gravel (5-12.5mm- Left) and coarse gravel (12.5-25mm-Right)

and Los Angeles abrasion percent are 16.4%, 20.5%, 19% respectively. Likewise, for coarse gravel these amount are 10.4%, 22.7% and 18% respectively. Moreover, the specific gravity and absorption percent in fine gravel are 2.65, 1.4% and in coarse gravel are 2.64 and 1.3% respectively.

Furthermore, Aggregates petrography, chemical analysis and long and short-term results (alkali aggregate reaction tests) indicate that there is not alkali reaction potential in aggregates.

### 2.3 Admixtures

In this study, we used S1 and S2 polycarboxylate-based superplasticizer because the water- cement ratio is very low. Also,for increasing concrete resistance to the action of freezing and thawing, air-entraining admixture (AS1 and AS2) were used.

## 3 RESULTS

### 3.1 Evaluation of physical, chemical and mechanical properties of cements

Physical and meshanical properties and chemical composition of cements are given in Table 1. As can be seen in the Table1, Khazar and Faraz Firozkouh cements compressive strength is less than the permissible limit provided in the standard ASTM. Hence, in the following study, Neka, Tehran, Abyek, Firozkouh and Pozzolan Tehran cements were selected. Since chemical shrinkage depends on the amount of C3A and drying shrinkage depends on the amount of SO3 and C3A, it seems that tehran cement has better condition than the others.

| Tests | Khazar | Faraz Firozkouh | Neka | Abyek | Firozkouh | Tehran | Pozzolan Tehran |
|---|---|---|---|---|---|---|---|
| Physical tests<br>Fineness Blaine, m2/kg | 3650 | 3487 | 3190 | 3200 | 3460 | 3220 | 3900 |
| Compressive strength | | | | | | | |
| 3 days, MPa | 14.8 | 11.8 | 14 | 17.2 | 22.8 | 19.4 | 18.3 |
| 7 days, MPa | 18.2 | 14.3 | 22.1 | 27.8 | 24.8 | 27.5 | 24.4 |
| 28 days, MPa | 26.7 | 24.5 | 33.5 | 35.2 | 31.4 | 35.7 | 33 |
| Initial Setting, min | 150 | 139 | 135 | 145 | 154 | 115 | 190 |
| Final Setting,min | 240 | 185 | 225 | 250 | 261 | 185 | 215 |
| Chemical analysis,% | | | | | | | |
| SiO2 | 20.32 | 21.42 | 21.3 | 20.3 | 20 | 21.4 | 20.3 |
| Al2O3 | 3.48 | 4.92 | 4.8 | 5.4 | 4.9 | 4.4 | 6.5 |
| Fe2O3 | 4.72 | 3.6 | 3.4 | 3.94 | 3.44 | 3.54 | 2.74 |
| CaO | 59.8 | 62.86 | 63 | 61.9 | 61.4 | 63.1 | 48.1 |
| MgO | 4.3 | 1.8 | 1.4 | 3 | 2.2 | 3.6 | 2.9 |
| SO3 | 3.53 | 2.1 | 2.27 | 1.97 | 2.69 | 2.01 | 2.45 |
| Na2O | 0.37 | 0.29 | 0.73 | 0.2 | 0.42 | 0.11 | 0.39 |
| K2O | 0.88 | 0.73 | 0.22 | 0.68 | 0.7 | 0.74 | 0.84 |
| Loss on ignition | 1.48 | 2.45 | 2 | 2.3 | 3.9 | 0.9 | 5.4 |
| C3S | 49 | 49 | 51 | 50 | 52 | 59 | |
| C2S | 21 | 25 | 23 | 20 | 18 | 17 | |
| C3A | 1 | 7 | 7 | 8 | 7 | 5 | |
| C4AF | 14 | 11 | 10 | 12 | 10 | 11 | |

Table 1: Physical properties and chemical analysis of cements

| Mix Designs | Slump (cm) | | Air Content | Crack width Average | Crack length |
|---|---|---|---|---|---|
| Cements | 10 min | 20 min | % | mm | mm |
| Neka | 21 | 16 | 0.9 | 0.76 | 300 |
| Abyek | 17 | 13 | 0.8 | 0.27 | 300 |
| Firozkouh | 21 | 16 | 0.8 | 0.78 | 300 |
| Tehran | 22 | 18 | 0.8 | 0.1 | 20 |
| Pozzolan Tehran | 15 | 11 | 0.9 | 0.11 | 120 |

Table2: The properties of fresh concrete and the average width and length of cracks

### 3.2 Comparison of the potential shrinkage of cements

For investigation of potential shrinkage of cements and comparison of them, the concrete samples were made according to ASTM C1579 standard with a similar mix design without any additives for creating same chemical condition.

All mix designs includes 320 kg per $m^3$ cement, 0.65 w/c ratio, 45% natural sand, 30% fine gravel (5-12.5mm), 25% coarse gravel (12.5-25mm). The properties of fresh concrete and the average width and length of cracks under ASTM C1579 standard are given in Table 2. According to Table 2, the minimum and maximum shrinkage potential are related to Tehran cement and Firozkouh cement, respectively. So in the following study, Tehran, Abyek, Neka and Pozzolan Tehran cements were selected.

Images of samples made with different cements are given in Figure 4.

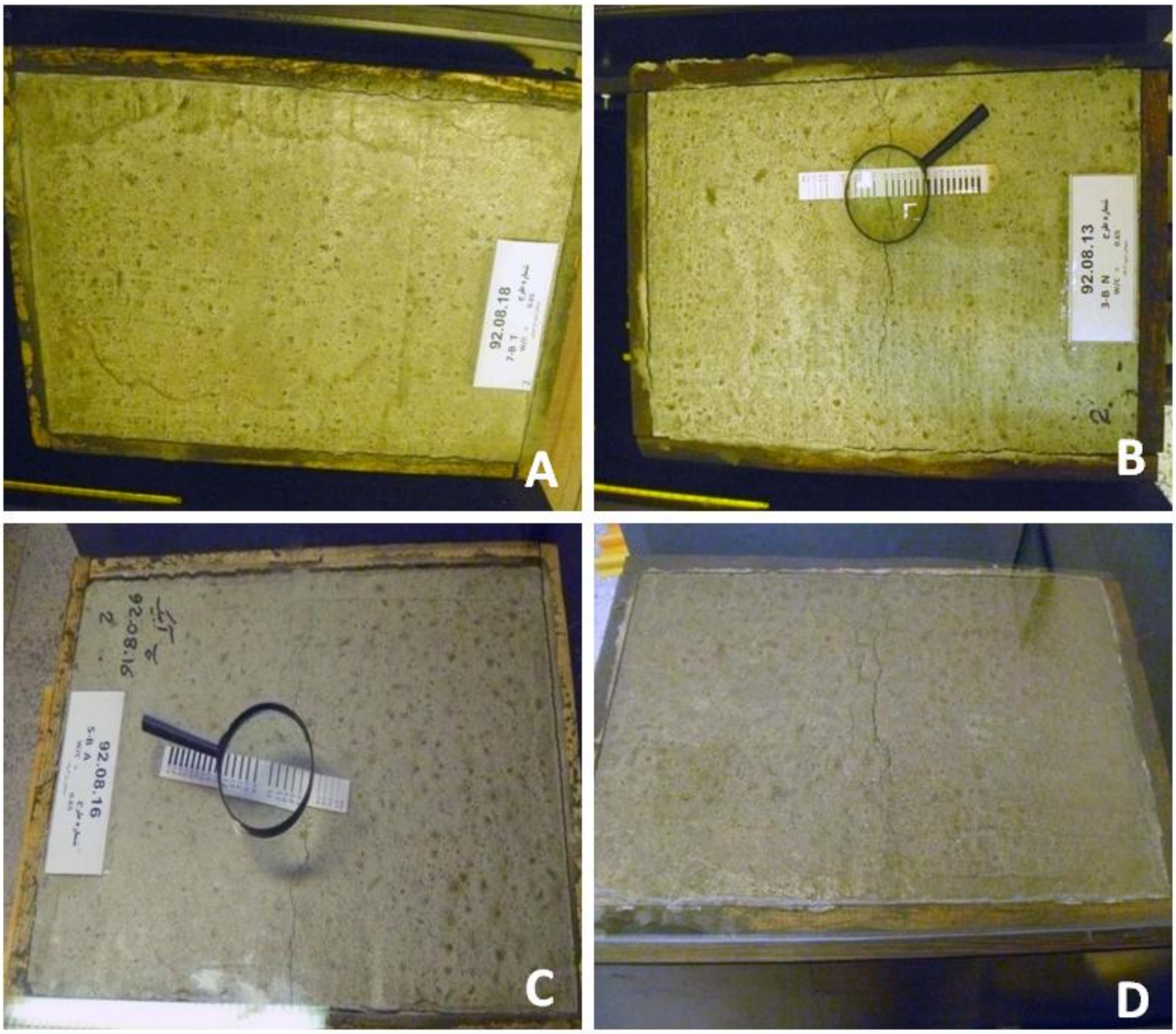


Figure 4: Samples made with different cements. (A): Tehran cement, (B): Neka Cement, (C): Abyek cement, (D): Firozkouh cement

According to Table 1 and 2, It seems that cement with minimum C3A shows low plastic shrinkage. Also, Comparison the length and width crack of Tehran cement and Pozzolan

Tehran cement shows that pozzolan can increase plastic shrinkage.

### 3.3 Concrete face mix designs

Concrete mix designs with MSA 38 and 25 mm were made. To determine the best combination of aggregate, the concrete specimens were made with different ratios of aggregate composition. Finally, the best combination of aggregate grading with MSA 38 mm includes 40% natural sand, 32% fine gravel and 28% coarse gravel. Likewise, in MSA 25 mm includes 45% natural sand, 30% fine gravel and 25% coarse gravel.

As mentioned above, the compressive strength of concrete at age of 42 days should be greater than 250 kg/cm2 with about 5% air content in concrete. Hence, in mix designs, cement contents were considered 280 and 320 $Kg/m^3$ for MSA 38 mm and 25 mm, respectively.

All mix designs with results are given in Table 3.

| Mix NO. | MSA (mm) | Cement | Cement Content (Kg/m3) | Super plasticizer | Air-entraining agent | Slump 5 min (cm) | Slump 20 min (cm) | Air 20 min (%) | Compressive St. (Kg/Cm2) 11 days | 42 days |
|---|---|---|---|---|---|---|---|---|---|---|
| T1 | 25 | Neka | 320 | S1 (0.8%) | AS1 (0.014%) | 13 | 6 | 4 | 371 | 410 |
| T2 | 25 | Neka | 320 | S2 (0.87%) | AS2 (0.04%) | 7 | 5 | 4.1 | 364 | 429 |
| T3 | 25 | Abyek | 320 | S1 (0.7%) | AS1 (0.011%) | 15 | 6 | 4.8 | 254 | 359 |
| T4 | 25 | Abyek | 320 | S2 (0.82%) | AS2 (0.037%) | 14 | 6 | 3.9 | 298 | 403 |
| T5 | 25 | Tehran | 320 | S1 (0.7%) | AS1 (0.015%) | 16 | 10 | 4.5 | 310 | 395 |
| T6 | 25 | Tehran | 320 | S2 (0.85%) | AS2 (0.027%) | 14 | 8 | 4.1 | 342 | 415 |
| T7 | 25 | Pozzolan Tehran | 320 | S1 (0.1%) | AS1 (0.02%) | 20 | 5 | 3.5 | 260 | 353 |
| T8 | 25 | Pozzolan Tehran | 320 | S2 (1.25%) | AS2 (0.0.02%) | 16 | 3 | 3 | 228 | 310 |
| T9 | 38 | Tehran | 280 | S1 (0.8%) | AS1 (0.02%) | 14 | 8 | 4.1 | 225 | 345 |
| T10 | 38 | Tehran | 280 | S2 (0.8%) | AS2 (0.02%) | 13 | 7 | 5 | 303 | 350 |

Table 3: Concrete face mix designs

According to the Table 3, All of the concrete mix design are acceptable in terms of compressive strength, but in terms of workability and slump loss, mix designs with pozzolan tehran cement are not acceptable. So, pozzolan tehran cement mix designs (T7 and T8) were removed at this stage of studies.

### 3.4 Comparison of plastic shrinkage in different mix designs

T1, T2, T3, T4, T5, T6, T9, T10 mix designs samples were made based on ASTM C1579 standard in order to compare plastic shrinkage. The results of average crack width are given in Table4.

| Mix NO. | T1 | T2 | T3 | T4 | T5 | T6 | T9 | T10 |
|---|---|---|---|---|---|---|---|---|
| Crack width average (mm) | 0.2 | 0.33 | 0.1 | 0.25 | No Crack | No Crack | No Crack | No Crack |

Table 4: Crack width average

It can be seen from Table 4, there are not any cracks in mix design containing Tehran cement. So, in the following study, T5, T6, T9 and T10 mix design were selected.

### 3.5 Comparison of drying shrinkage in different mix designs

Samples were made with T5, T6, T9 and T10 mix design in accordance to ASTM C157 standard for measuring length changes of concrete at the age of 90 days.
Results of this test are given in Table 5.

| Mix NO. | T5 | T6 | T9 | T10 |
|---|---|---|---|---|
| Máximum Shrinkage (%) | -0.029 | -0.037 | -0.024 | -0.029 |
| Máximum Permability (mm) | 36.5 | 26.5 | 36.5 | 39 |

Table 5: Máximum Shrinkage and Permability

ASTM C157 test is just to compare different mix designs and there are no criteria about shrinkage amount permitted limits, so the results show the shrinkage of MSA 38 mm mix design is a few lower than the shrinkage of MSA 25 mm.
Also, depth of water penetration results in hardened concrete at the age of 28 days evaluated according to EN 12390:part8 standard in T5, T6, T9 and T10 mix designs. Results of this test are given in Table 5.
In this test, depth of water penetration was used as an index for concrete quality evaluation and samples with penetration depth less than 50 mm and 30 mm consider impenetrable and impenetrable under destructive conditions, respectively. Therefore, Table 5 illustrate that all of concrete mix designs are impenetrable. Moreover, superplasticizers with the same chemical base from different factories have various effects on shrinkage.

### 3.6 Concrete face cracking evaluation

Up to 31 October 2104, eight starter slabs with T5 mix design, one starter slab with T9 mix design and two main slab with T5 mix design were constructed. Constructed concrete face is shown in Figure 5 and volume of concrete face slabs is given in Figure 6. There are not any cracks in main slabs after four week and starter slabs after 4 month.

Figure 5: Concrete face of Gelevard dam

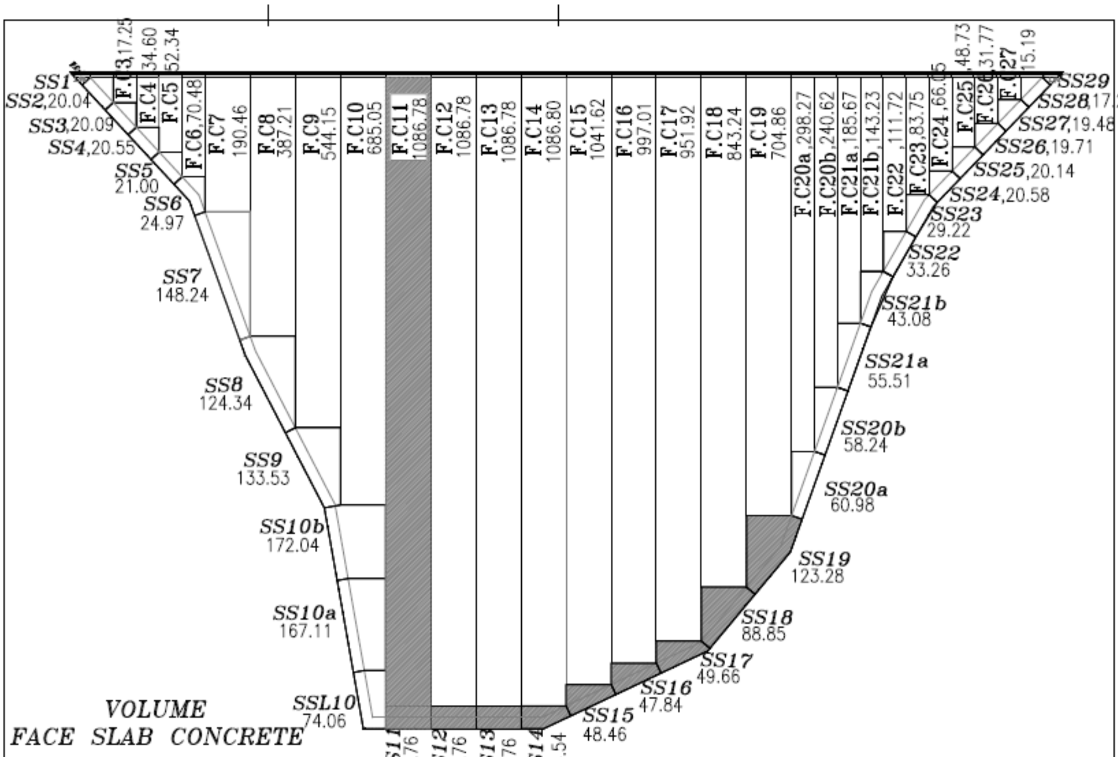


Figure 6: Volume face slab of Gelevard dam

## 4. CONCLUSION

1. Chemical and physical cement test results and comparison of concrete plastic shrinkage results (ASTM C1579), indicates that cement with minimum C3A shows low plastic shrinkage.
2. The results of ASTM C157 test show that the shrinkage of MSA 38 mm mix design is a few lower than the shrinkage of MSA 25 mm, but in order to more convenient concrete performance, mix design with MSA 25 mm was selected.
3. Comparison of Tehran cement and Pozzolan Tehran cement in plastic shrinkage test (ASTM C1579), shows that pozzolan can increase plastic shrinkage probably.
4. superplasticizers with the same chemical base from different factories have various effects on shrinkage.

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