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Investigation of the chemical reactivity of concrete in some large dams of Iran

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Abstract

The chemical reactivity of concrete is one of the most important factors in long term damage and destruction of concrete structures. In this study, the chemical reactivity of some large concrete structures in the south of Iran has been investigated. For this purpose, the concrete sections of six large dams have been studied during field visits and taking more than 16 concrete samples and sediment of concrete surface. The investigated structures include Dez, Balaroud, Godarlandar (Masjed-Soleyman), Gotvand Uleya, Karkheh, and Jarreh (Ramhormoz) dams. Using field investigations, determination of Damage Rating Index (DRI), and chemical composition of the surface sediments and leachate of the concrete, the chemical reactivity of the concrete and its degradation have been investigated. The method of DRI is the petrographic method to quantify the state of damage of concrete by the alkali-aggregate reaction. The results of DRI and field studies show that except for the Dez dam, all concrete structures under study have an alkali-aggregate reaction, but it is not yet developed enough to cause serious damage to its concrete. The results of the XRD whit emphasis field evidence indicate the presence of external sulfate attacks in the studied parts of Jarreh and Balaroud dams.

Keywords: *Concrete, Aggregate chemical reactivity, Dam, Damage rating index*

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Extended Abstract:

1. Introduction

Chemical reactions in concrete are the main causes of the destruction and deterioration of concrete structures in the last two decades (Sims and Poole, 2017). Chemical reactions such as alkaline-silica reactions have been widely reported as one of the main causes of the destruction of large concrete structures in recent years (Sims and Poole 2017, Berra et al. 2018). Chemical reactions between aggregates and concrete components may be increasing the cavities, joints, and cracks in the concrete. Thereby reducing the strength and durability and increasing the permeability of the concrete. As a result, the strength and durability of concrete may be less than the designer intended, causing damage and destruction of the structure (Blight and Alexander, 2011).

The chemical reactivity of concrete aggregates includes a set of reactions that determine the strength of aggregates against chlorides, sulfates, and acids (Blight and Alexander, 2011). In general, the most important chemical reactivity of concrete includes the two main groups; alkali-aggregate reactions (Alkali-Aggregate Reaction = AAR) and sulfate attacks. The AAR includes alkali-silicate reaction (ASR) and alkali-carbonate reaction (ACR). The sulfate attack includes external attack and internal attack of sulfates. Table 1 shows the types of chemical reactions, cause, and time of appearance (Van Dam et al. 2002).

There are several methods for investigating the chemical reactivity of concrete aggregates. These methods and tests include petrographic examination of aggregates (ASTM C295), accelerated chemical methods (ASTM C289), mortar prism test (ASTM C227), and long-term testing on concrete aggregates (ASTM C1293). However, all of these tests are performed on a limited number of aggregates before the fabrication of the concrete structure. Pre-construction laboratory experiments, both short-term and long-term, cannot be indicative of many environmental conditions and concrete structures (Drolet et al. 2017). Despite all the controls and tests that have been put in to prevent destructive chemical reactions in concrete, there are various reports of the occurrence of destructive chemical reactions in concrete. After the construction of the structure and in the long term, the chemical reactivity of the structures is studied and controlled by some other methods. One of these methods can be considered as sampling concrete samples at different depths of a structure and performing some experiments such as the unconfined compressive strength of concrete (Swamy and Al-Asali, 1988). In this method, by reducing the strength of concrete, the rate of reactivity and degradation of concrete is determined (Blight and Alexander, 2011). Another of these methods is the use of geophysical methods to study joints and cracks and concrete destruction. In addition to cost and time-consuming, this method does not have good results in determining the cause of destruction and requires additional studies (Ohtsu and Watanabe, 2001). Rivard and Saint-Pierre (2009) stated that non-destructive methods of electrical resistance and dynamic modulus are not suitable for investigating the rate of concrete degradation and determining of type of chemical reactions. Therefore, it is not consistent with field results of concrete degradation and laboratory results. Examination of leachate and sediment of concrete surfaces by chemical analysis or X-ray diffraction has been used for this purpose for a long time and also this method is recommended in new standards such as ASTM C856 (2020).

2. Materials and methods

In this study, using the field investigated, sampling and determining the Damage Rating Index (DRI), and investigating the chemical composition of concrete surface sediments and leachate, the rate of chemical reactivity and the resulting concrete degradation have been investigated in the concrete of large dams in the south of Iran. Also, field studies of the appearance of concrete and geological studies of the site and dam reservoirs have been performed. The dams studied in this research include Dez, Balaroud, Godarlandar (Masjed Soleiman), Upper Gotvand, Karkheh and Jareh-Ramhormoz Dam. It should be noted that these studies are dependent on concrete dams and in earthen dams such as Masjed Soleiman Dam (Godarlander) related to its concrete structures such as spillways, outlets, and access galleries.

More than 50 locations of concrete sections of dams have been surveyed during field visits and 16 concrete samples were taken. Fifteen selected samples of concrete surface sediment were analyzed by X-ray diffraction studies. Sampling was performed according to the ASTM C856 (2020). The samples were examined for mineralogical and crystallographic content by the XRD method and the device available in the Central Laboratory of the University of Isfahan.

The appearance of concrete in the mentioned structures was investigated. The DRI was determined by the method proposed by Rivard and Ballivy (2005) and the definitions of ASTM C856. Their method is based on the method of Grattan-Bellew (1995). This method has been used in various years such as Grattan-Bellew and Mitchell (2006), Grattan-Bellow (2011), Grattan-Bellew (2012), and Sanchez et al. (2020). In each structure in two to five locations, the DRI was determined.

The DRI is a semi-quantitative petrographic method for assessing the condition of concrete due to alkaline reactions of aggregates. In this method, the concrete surface is divided into parts of 1 cm by 1 cm, and in each part, the presence of specified petrographic features is investigated (Figure 1). To calculate the DRI, the number of units that had a petrographic feature must be multiplied by the weight factor of that complication. These steps are performed for all identified features. At the end of the total score or DRI index is the sum of each weight factor (Rivard and Ballivy, 2005). Of course, this number must be adjusted for the standard cross-section by an area of 100 cm^2. Table (1) presents the petrographic characteristics along with its weight factor proposed by Grattan-Bellow (2011). Based on Sanchez et al. (2014), the area required to determine the DRI is two samples that have an area of 100 cm^2 or 200*100 cm. Sanchez et al. (2015) studied the DRI on an area of 100 cm^2 (10*10). In this research, the DRI in each situation in an area between 100 to 300 square centimeters has been investigated and its values have been adjusted for an area of 100 square centimeters.

3. Results and discussion

The results of the DRI are presented in Figure (1). The range of DRI is between 9 and 48.5. The lowest of DRI is related to sample K5 with a value of 9, which is related to the spillway's concrete of the Karkheh dam. The highest of DRI is related to J2 with the value of 48.5, which is related to the concrete of the left access gallery of the Jarreh dam.

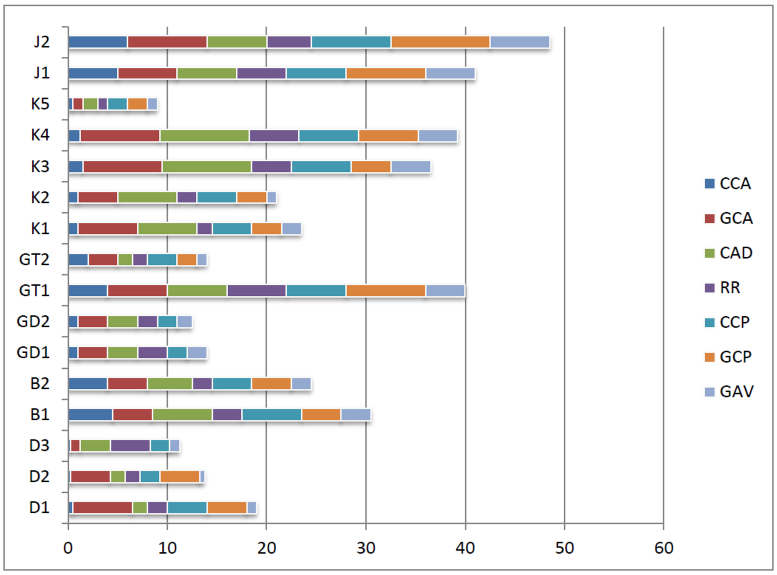

Figure 1- The DRI of samples

According to Grattan-Bellew's (1995) classification, DRI values above 50 indicate concrete damage due to alkaline reactions of ASR aggregates, values between 20 and 50 indicate that alkaline reactions of concrete aggregates indicate It is underway but no serious damage has been done to the concrete structure yet. Values less than 20 do not necessarily mean the effect of alkaline reactions on the concert because some of the properties that DRI incorporates may be present in any concrete (Grattan-Bellew, 1995). According to Grattan-Bellew's (1995) classification, the dams are classified in Table (2). The results show that except for Balaroud and Dez dams, AAR processes are underway in other dams but have not yet caused serious damage to concrete (20<DRI<50). Due to the lifetime of concrete structures in Dez Dam (about 57 years old) that exceed the maximum time of occurrence of alkaline reactions of aggregates and values of DRI, alkaline reactions of aggregates can't find out in these structures. In the case of the concrete structures of the Balaroud Dam, this assurance has not yet been established. Due to the short life of concrete structures in this dam and the time required for the appearance of chemical reactions of aggregates (see Table 1), it is still possible to perform alkaline reactions of aggregates.

As a result, according to the DRI values, except for the Dez dam, all the concrete structures are subject to alkaline reactions of aggregates but it is not yet developed enough to cause serious damage to concrete. In this case, the use of diagnosis, control, and treatment planes to inhibition of chemical reactions of aggregates is recommended.

Table 2 - Classification of structures based on DRI values

DRI	Jarreh	Karkheh	Balaroud	Dez	Gotvand Uleya	Godarlandar
Average	44.75	25.85	27.50	14.67	27	13.25
Minimum	41	9	24.5	11.25	14	12.5
Maximum	48.5	36.25	30.5	19	40	14
Class	R	K5=NR Others=R	R	NR	GT1=R GT2=NR	NR

NR = no alkaline reactions of aggregates and DRI<20, R AAR reactions in progress but the structure is not seriously damaged yet 20<DRI<50, RD AAR reactions in progress, and concrete damaged in 50<DRI.

According to the results of XRD analysis, ettringite mineral was observed in the JX2 sample of the Jarreh dam. This mineral represents an external reaction of sulfates attacks. Montmorillonite mineral is present in sample JX1 of Jarreh dam. The presence of cement alkalis causes partial dissolution of montmorillonite and formation of different layers of illite-smectite and zeolite under hyper alkaline conditions (Fernandez et al., 2016). Concrete materials that are exposed to clay environments are exposed to carbonate and sulfate deposition (Jenni et al., 2014). According to the results of the samples studied in Jareh Dam, the presence of zeolite and clay minerals next to each other indicates the occurrence of sulfate attack reactions in the concrete of the samples of this dam. Field studies also indicate that this attack is likely to be an external attack of sulfates. The location of the Gachsaran Formation near the lake of Jareh Dam and the presence of minerals and sulfate compounds such as gypsum in this formation can be the cause of the external attack of sulfates in Jareh Dam. High DRI values, the appearance of the concrete, and the chemical composition of concrete surface and leachate in Jarreh dam; all indicate the unfavorable condition of concrete and the appearance of its destructive effects due to chemical reactions. At the BX2 samples of the Balaroud dam, there is a possibility of sulfate attack reactions due to the presence of natrolite mineralization. Field evidence also confirms the possibility of an external attack of sulfates.

4. Conclusion

In this research, by determining the DRI of concrete samples, field studies, and XRD analysis, the reactivity status of concrete of Dez, Balaroud, Godarlander, Upper Gotvand, Karkheh and Jareh Ramhormoz dams has been investigated.

By timely identification and detection of chemical reactions in concrete, it can be prevented of destruction structures by spending less money and by implementing treatment methods.

The results showed that there is a relationship between the appearance of concrete, DRI, concrete leachate composition, and geological formations at the dam site. The results of the DRI showed that except for Dez Dam, all concrete structures under study have some alkaline reactions of aggregates, but have not yet developed enough to cause serious damage to concrete. DRI is low in the concrete sections of Balaroud Dam, but due to the short life of this structure, it is still possible for alkaline reactions of aggregates to occur. The highest DRI (44.75) is related to Jarreh Dam and the lowest with a value of 13.25 is related to Godarlander Dam, both with a life of 22 years. The average DRI of the Dez dam is 14.67 which indicates the optimal condition of the dam after 57 years of its life and despite the passage of the maximum appearance time of the effects of alkaline silicate reactions. The results of field studies and sediments of concrete surface in some dams such as Jarreh and Balaroud indicate the presence of external attack reactions of sulfates. High DRI values, the presence of natrolite, ettringite, and montmorillonite minerals in the chemical composition of the surface, and the appearance of concrete in the Jarreh dam indicate the unfavorable condition of its concrete and the appearance of degradation. In this regard, it is recommended to conduct more studies and take improvement methods before further development of chemical reactions and serious damage to concrete. This research is one of the first scientific attempts to study the concrete status of large dams in Iran, after 15 to 57 years of their life.

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