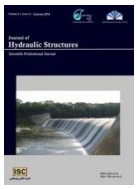
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Investigating the Effect of Loading Rate on the Behavior of Plastic Concrete Samples Consisting of Different Types of Fiber: A Case Study of Nargesi Embankment Dam

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Abstract

One of the important issues in the construction of dams is plastic concrete cut-off walls. Careful study of the behavior of the used plastic concrete and the factors affecting it are essential concerning the failure in understanding its proper behavior that may cause irreparable damages. In line with determining the correct behavior of plastic concrete, investigating the effect of loading rate on the behavior of this concrete is considered as one of the factors affecting the stress-strain curve. In this research, in addition to studying fiber effects on the plastic concrete behavior, concrete samples were made with no fibers rather than polypropylene fibers, hooked and corrugated metal fibers with 0.19 % vol. that were under pressure load for 28 days at loading rates of 0.4, 0.6, 0.8, 1.0, 1.2 and 1.4 mm / min. The results indicated that an increase in the loading rate from 0.4 to 1.4 mm / min increased the compressive strength up to 18.8, 17.3, 11.1 and 23.2 percent, respectively; Besides, it increased the elasticity modulus of samples made of plastic concrete, with no fibers rather than polypropylene fibers, hooked and corrugated metal fibers up to 29.1, 31.8, 7.9 and 25.6 percentage. In addition, by adding fibers to plastic concrete samples, the stress-strain behavior of samples was improved by increasing the surface under the stress-strain curve and strain hardening.

Keywords: Loading rate, plastic concrete, polypropylene fibers, hooked metal fibers, corrugated metal fibers.

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1. Introduction

Plastic concrete includes aggregate, cement, water, and clay mixtures with a high ratio of water to cement to produce flexible substances. The factor that causes manifestation of different features from ordinary concrete in plastic concrete is the presence of Bentonite in this concrete [1]. During concreting, bentonite slurry keeps gravel, sand, and cement suspended in plastic concrete, which reduces the permeability during the setting concrete time. According to the ICOLD suggestions, a bentonite slurry is used to enhance the ductility of concrete [2]. The concrete mixing plan of plastics should have a permeability coefficient within the range of approximately 10^-7 to 10^-9 m / s and slump in the range of 15 to 22 cm. In general, bentonite is used in civil engineering for sealing purposes [3-11].

Plastic concrete is a kind of concrete with a slight resistance and high plasticity. This feature has distinguished this concrete from the other concretes [12]. In response to sealing problems, engineers have used plastic concretes in cutoff walls that have behavior similar to the surrounding soil [13].

In 1964, the first studies were done on concrete stress-strain relations during periodic loading, both qualitatively and quantitatively. Experiments were done on cylindrical samples with a compressive strength of about 29 to 22 Mega Pascal [14]. Moreover, in 1969, a research was carried out more precisely on loading in compressive range and based on its results more precise definition of the sustainability limit was provided [15].

Ruby et al. [16] conducted experiments on fiber concrete combining steel and polypropylene fibers. In these experiments, the compressive strength, tensile strength, and bending strength of the fiber concrete were investigated. The results showed that the combination of 0.25% polypropylene fibers and 0.75% steel fibers yields the best resistance results. In fact, this combination had created the highest compressive, tensile, and bending strength. On the other hand, the uses of steel fibers undoubtedly lead to a more resistant and thinner behavior in materials, which has already been identified. In fact, this research specifically focused on the combination of these two fibers and showed exactly which combination of these fibers produced the highest resistance.

Studies on the use of polypropylene fibers in conventional and self-compacting concrete had shown that these fibers had no significant effect on the compressive strength and modulus of elasticity of light concrete, but improved the tensile strength and modulus of concrete rupture [17-19]. And also, a sharp decline has been reported in the efficiency of the new self-compacting concrete due to the addition of these fibers to concretes made of lightweight aggregates [17-20].

The effect of loading rate on concrete properties has been the main concern of relatively extensive researches over the past decades. A quick overview of researches that studied the effects of loading rate on compressive strength and concrete's modulus of elasticity are presented here.

Ramezanianpour [21] listed his results as follows. One of the factors affecting the stress-strain curve of concrete is loading rate. Strains caused by the creep under long-term load changed the stress-strain curve. The maximum compressive stress was reduced by slowing down the loading, but the strain, such as maximum stress, increased, and the final strain of concrete failure increased. In other words, by reducing the loading rate, the compressive concrete became softer. Since, the loading rate was obtained through the approximate role of time variations, it could have effects on the compressive strength of concrete, and its probable cause was the creep phenomenon.

Mostofinejad [2] investigated the loading rate concrete samples and concluded that the reason for compressive strength increase at higher loading rate in ordinary concrete scan be searched in

the creep phenomenon.

Amourzai and Dabbagh [22] studied fibrous steel-equipped lightweight concrete behavior under periodic compressive loading and showed that combining two types of steel fibers in the form of 30% corrugated fibers and 70% smooth fibers with hooked ends would make the optimal composition. Compared to the sample with no fibers, by increasing the amount of steel fiber, the tensile strength of splitting, flexural strength, and compressive energy absorption was increased considerably. Nevertheless, there was not any significant improvement in compressive strength and modulus of elasticity. Also, the effective parameters on stress-strain curve under different patterns of periodic loading in pressure including common point, difficulty in reloading, the strain of plastic and reloading on the strain curve were examined.

Fathi and Dabbagh [23] investigated self-compacting concrete behavior under periodic compressive loading and they concluded that in self-compacting concrete uniform loading by increasing loading rate, the compressive strength decreased and then increased. In periodical loadings by increasing loading times, persistent strain in concretes increased and in compressive strength reduced. During periodical loading before arriving at maximum tension, the gradient of loading branch in each cycle increases and after maximum stress peak, it decreased. By increasing the compressive strength of the self-compacting concrete, the amount of changes due to periodical compressive loading prior to maximum stress was lowered, and then the intensity of changes exceeded the routine range. If a periodical loading was applied at various rates on concrete samples self-compacting, with increasing rate, the possibility of proper opening and closure of the cracks was not given to the concrete and the rate of hysteresis loops volume was lowered relative to the periodical loading at lower rates.

A laboratory program and the structure review of this were elaborated first, it was attempted to investigate the mixing design and specifications of the plastic concrete cut-off wall of Nargesi dam. Then, in line with the effect of different types of fibers on this concrete, it has been tried to make mixing designs with the same conditions by adding various types of fibers. It will be ultimately designed to measure the impact of loading rate on the behavior of this concrete, made concrete samples were influenced by different loading rates.

2. Nargesi embankment dam site

The catchment of the Nargesi dam is located in the Fars Province, Southwest of Shiraz, Iran. The catchment is located in the geographic latitude of 29 ° 12' to 29 ° 37' and the geographic longitude 00 ° 52' to 52 ° 18'.

2.1 Geometric Properties of Nargesi Dam:

- Type of dam: embankment with clay core
- The height of the riverbed: 77.5 meters
- Level of the riverbed at the dam site: 905 meters above sea level
- Minimum water level: 938 meters above sea level
- Optimal Normal Level: 978 meters
- Total volume of the dam body: 6.5 million cubic meters
- Total reservoir capacity: 113 million cubic meters
- Dead volume of the reservoir: 15 million cubic meters
- Useful reservoir capacity: 98 million cubic meters
- Length of the lake: 5300 meters
- Average lake width: 900 meters

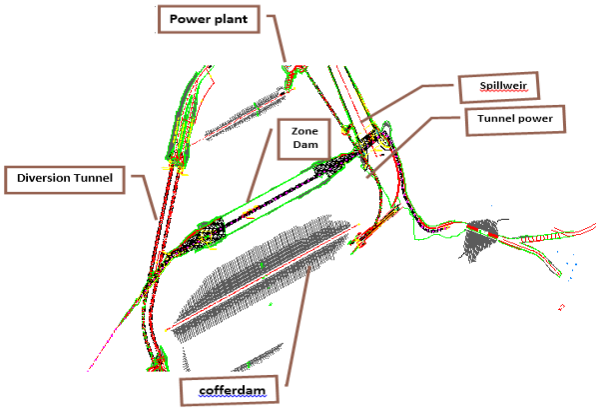


Figure 1. Location plan of the Nargesi Dam

2.2 Mixing plan

The mixing plan and specifications of the plastic concrete of the Nargesi dam cut-off wall are shown in Tables 1 and 2, which are in accordance with the target technical specifications of the design. The required compressive strength was considered for a 7-day age range of approximately 0.8 to 1.5 MPa and for the age of 28 days was 1.5 to 2.5 MPa and the Young modulus for 28 days was between 200 and 400 MPa. In Figures 2(a), 2(b) and 2(c), respectively, the shape of corrugated metal fibers, hooked metal fibers and polypropylene fibers used in this study are shown.

Table 1. The distribution of the amount of materials used to make 1 cubic meter of plastic concrete.

Consumed materials	(kg)
cement	130
bentonite	40
water	382
sand	705
Pea gravel	520
Almond gravel	259

Table 2. The distribution of approved mixing plan of the cut-off wall in Nargesi dam.

Cement (Kg) weight	Bentonite weight(kg)	Water to bentonite proportion(W/B)	slump(cm)	28 days(kg/cm^2)	
				Compressive (kg/cm^2) strength	Elasticity (kg/cm^2) modulus
130	40	9.55	20.5	13.8	2750



(a) Corrugated metal fibers.



(b) Hooked metal fibers



(c) Polypropylene fibers

Figure 2. Types of fibers

3. Results

After reviewing the mixing plan and the plastic concrete results of Nargesi dam, for further verification, samples were constructed and studied exactly under the same conditions as the basic mix design. The process was further evaluated by adding fibers to the original design. Then, to test the loading rate, the samples were tested by the compressive strength test based on the various loading rates. The results of the tests are shown in Tables 3 to 8.

Table 3. The distribution of basic mixing plan of the plastic concrete

Cement weight (kg)	Bentonite weight(kg)	(W/B)Water to bentonite proportion	slump(cm)
130	40	9.55	20.5

Table 4. Mixing plan with 0.19% vol. fiber per cubic meter.

Fibers' type	Fibers' weight (kg)	Slump (cm)	Cement weight (kg)	Bentonite weight (kg)	Water to bentonite proportion (W/B)
Polypropylene fibers	1.7	18	130	40	9.55
Hooked metal fibers	14.66	20	130	40	9.55
Corrugated metal fibers	14.66	19.80	130	40	9.55

Table 5. Plan without fiber.

Loading rate (mm/min)	28-days stress (kg/cm^2)	28-days module (kg/cm^2)	Maximum loading time (s)
0.4	7.82	1742.8	187.5
0.6	8.02	1785.3	125
0.8	8.52	1878.6	101.25
1	8.92	2074.9	96

1.2	9.18	2156.9	47.5
1.4	9.29	2250.8	36.4

Table 6. Plan with Polypropylene fibers.

Loading rate (mm/min)	28-days stress (kg/cm^2)	28-days module (kg/cm^2)	Maximum loading time (s)
0.4	8.65	1965.4	240
0.6	8.99	2432.352	195
0.8	9.06	2358.421	153.75
1	9.18	2612.331	132
1.2	9.85	2740.743	90
1.4	10.15	2590.933	72.9

Table 7. Plan with hooked metal fibers.

Loading rate (mm/min)	28-days stress (kg/cm^2)	28-days module (kg/cm^2)	Maximum loading time (s)
0.4	10.13	1615.6	210
0.6	10.3	1655.8	140
0.8	10.53	1661.4	105
1	10.8	1685	84
1.2	11.05	1732.4	70
1.4	11.25	1744.4	60

Table 8. Plan with corrugated metal fibers.

Loading rate (mm/min)	28-days stress (kg/cm^2)	28-days module (kg/cm^2)	Maximum loading time (s)
0.4	10.16	1643	210
0.6	10.68	1692.8	140
0.8	11.27	1729	105
1	11.48	1801.7	78
1.2	11.86	1822.2	55
1.4	12.52	2064.1	42.9

The manufacturing process of the plastic concrete in this study is as follows. The bentonite slurry was first made according to portions mentioned in the mixing scheme and turned into gelatin after 24 hours of processing. Then the other concrete-forming materials such as dry sand, gravel and cement were mixed in a betonyer for 5 minutes and then gently bentonite slurry was added. All the concrete ingredients were then mixed in the betonyer for 15 minutes. After sampling for 24 hours, the samples were kept in the mold at the laboratory

temperature (20 ° C) and then the molds were opened and stored in a pond containing water. After 28 days of sampling, the samples were taken out of the pond and the two ends of the specimens were changed to a flat surface before being put under a bentonite cracker jack in order to uniform loading by melted sulfur and then tested. These steps can be seen in the pictures below.



Figure 3. Mixing the aggregates in the mixer



Figure 4. Sampling of plastic concrete

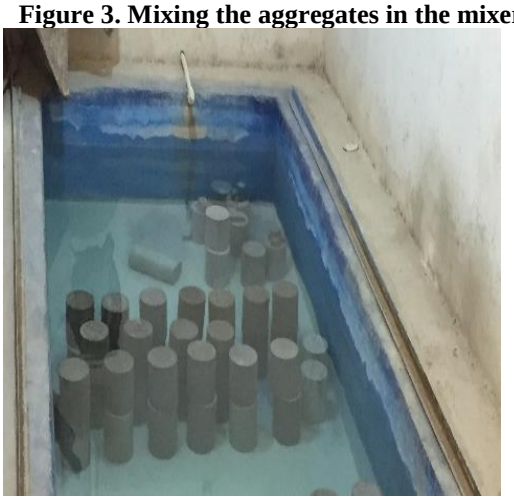


Figure 5. Curing concrete samples



Figure 6. Preparation of two samples using melted sulfur to conduct a test of compressive strength



Figure 7. Concrete sample after compressive strength test



Figure 8. Pressure test device for plastic concrete compressive strength

To determine the modulus of elasticity, "Scant Method" was used as mentioned below. According to the definition of "Scant Modulus", the following formula calculates the slope of the line between the two points corresponded to the stresses of S1 and S2, which is the modulus of elasticity of the concrete, or the stress-strain curve of "Scant Modulus".[1,5]

$E= (S2- S1) / (Ɛ2-0.00005)$

It should be noted that "Stress" is obtained from the ratio of final load to cross-sectional area and "Strain" is obtained from the ratio of the amount of deformation to the effective length of the test.

E = the modulus of elasticity

S2 = the stress corresponded to 40% of the final load

S1 = The stress corresponded to the longitudinal strain Ɛ1 = 0.000050

As stated in this section, the stress-strain curve for all specimens, including specimens without fibers, specimens made with polypropylene fibers, specimens made with hooked metal fibers, and specimens made with corrugated metal fibers at age 28, are drawn for loading rates of 0.4 to 1.4 mm / min, which can be seen in Figures 9 to 12.

In all designs using fibers in their structure, the stress-strain curve of the specimens improved with increasing the area which is under the stress-strain curve and strain softening, which means increased ductility, toughness and absorption. This is more visible in specimens made of polypropylene fibers than other specimens.

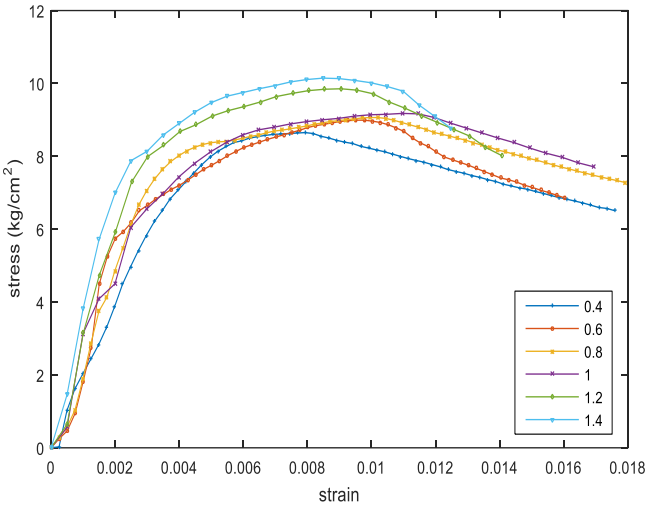


Figure 9. Stress-strain curve of base design (non-fiber)

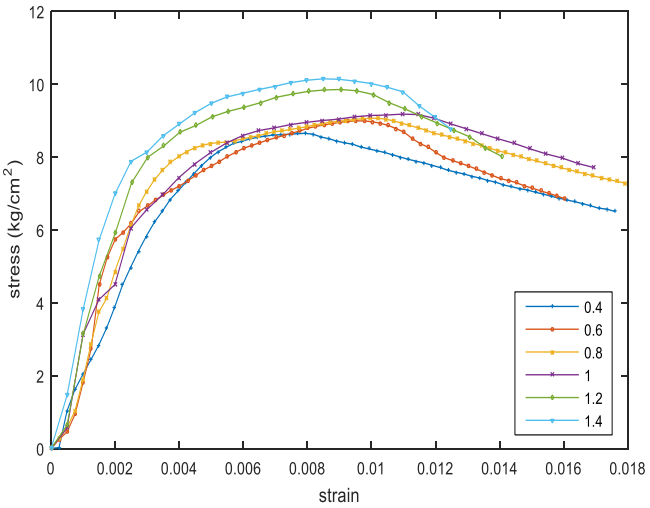


Figure 10. Stress-strain curve of polypropylene fiber design

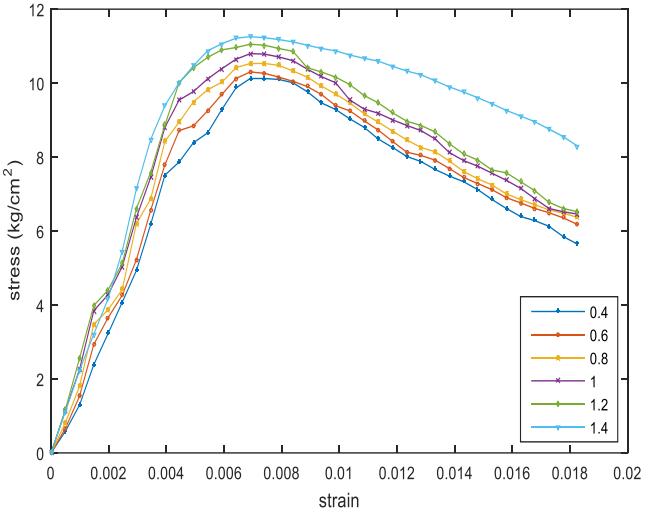


Figure 11. Stress-strain curve of hooked metal fiber design

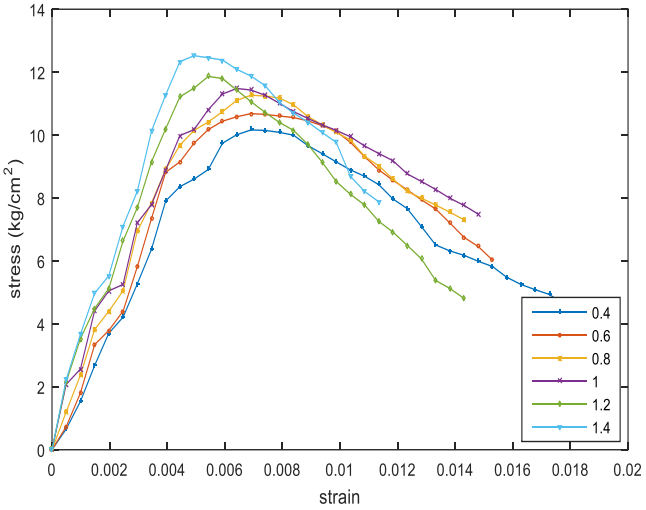


Figure 12. Stress-strain curve of corrugated metal fiber design

After plotting Figures 9 to 12, which illustrated the behavior of concrete samples under different loading rates, in this part we decided to explain this issue clearly by drawing Figures 13 to 18 to highlight the effect of different types of fibers on the behavior of concrete specimens. As shown in these Figures, in all the used designs in the fibers in their structure, the strain-strain graphs of the samples have been improved with increasing the surface under the stress-strain curve and strain hardening, which means increased ductility, resistance to tensile strength and more energy absorption by the samples. This is true for samples made with polypropylene fibers; Yellen was seen more than other samples.

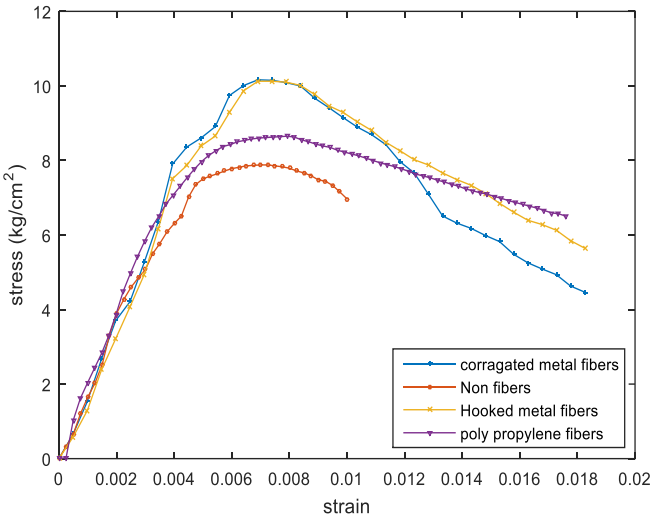


Figure 13. Stress-strain curve for loading rate of 0.4 Millimeter per minute

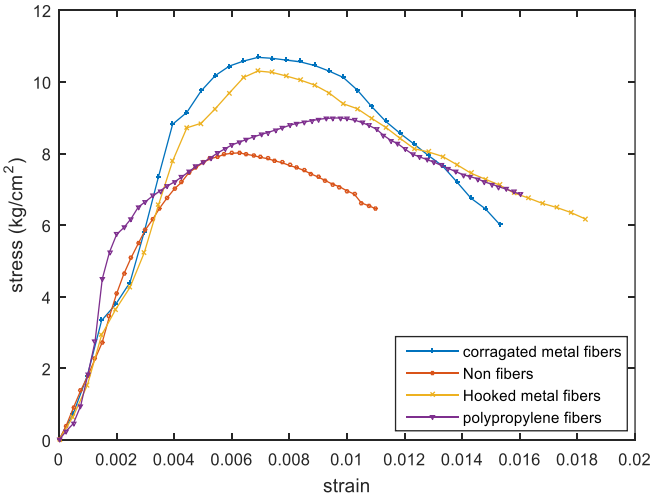


Figure 14. Stress-strain curve for loading rate of 0.6 Millimeter per minute

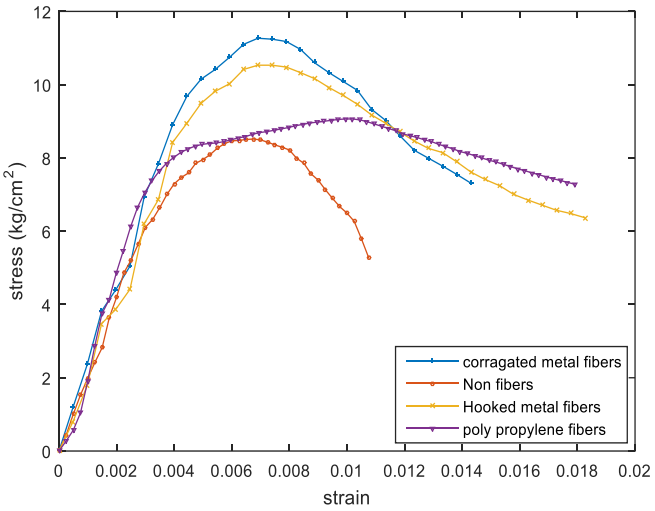


Figure 15. Stress-strain curve for loading rate of 0.8 Millimeter per minute.

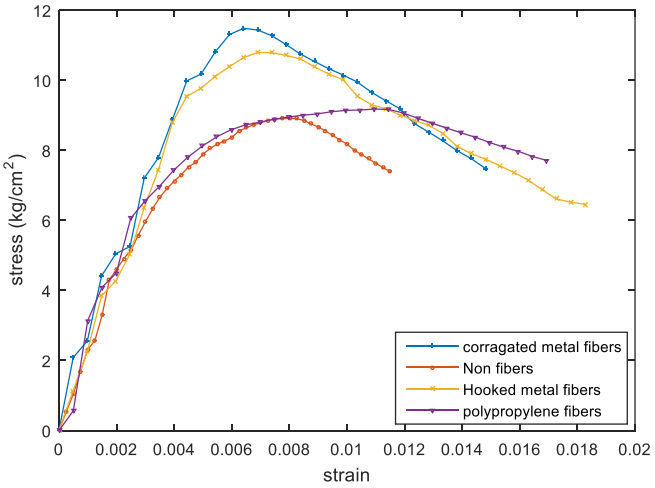


Figure 16. Stress-strain curve for loading rate of 1 Millimeter per minute

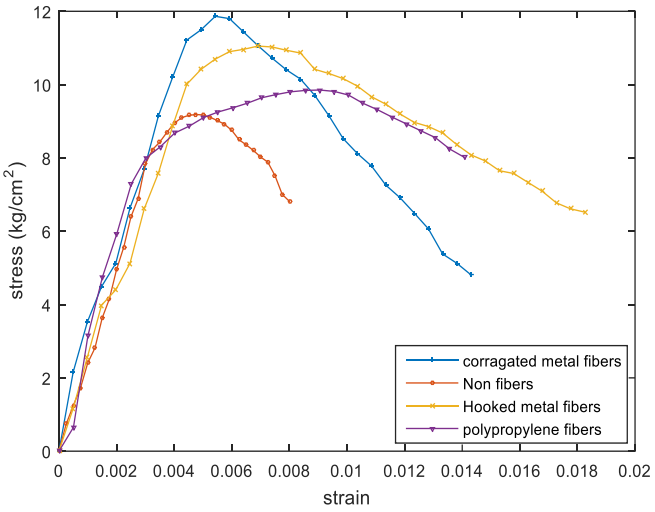


Figure 17. Stress-strain curve for loading rate of 1.2 Millimeter per minute

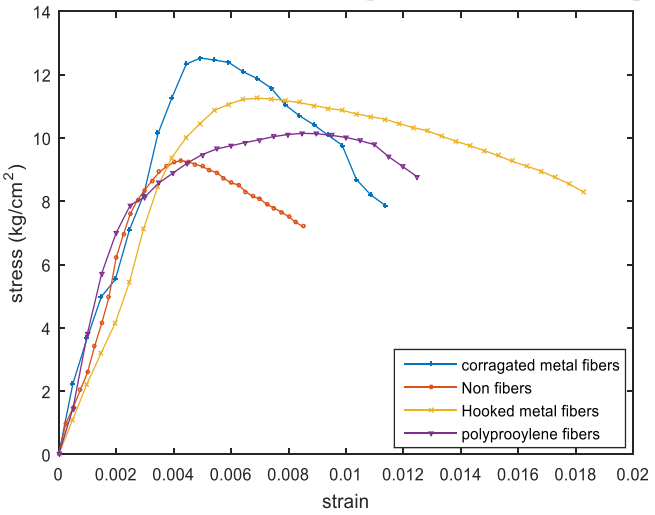


Figure 18. Stress-strain curve for loading rate of 1.4 Millimeter per minute.

Figure 19 showed the effect of loading rate on compressive strength . as shown in these Figures, with increasing the loading rate, compressive strength was boosted and this was true for all the suggestions presented in this study. Figure 20 showed that by increasing the loading rate, the time to reach the maximum load or the time of failure of the samples was reduced and the rate of this decrease was recognizable at different loading rates as well. Finally, it is clear that the impact of the loading rate, as one of the factors influencing the properties of the plastic concrete, was that the Figures showed the importance and impact rate of loading on the properties concrete.

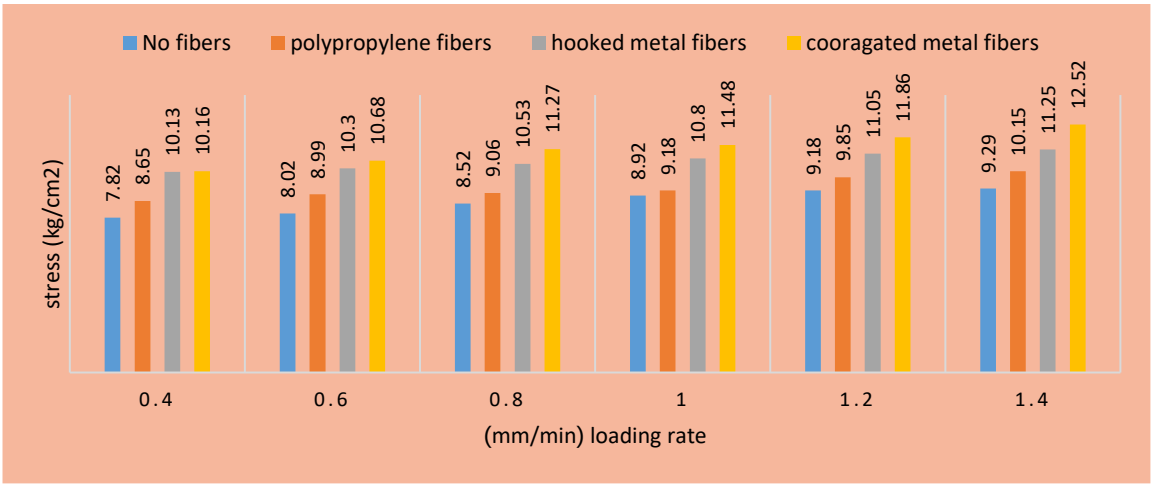


Figure 19. Stress-loading rate bar graph

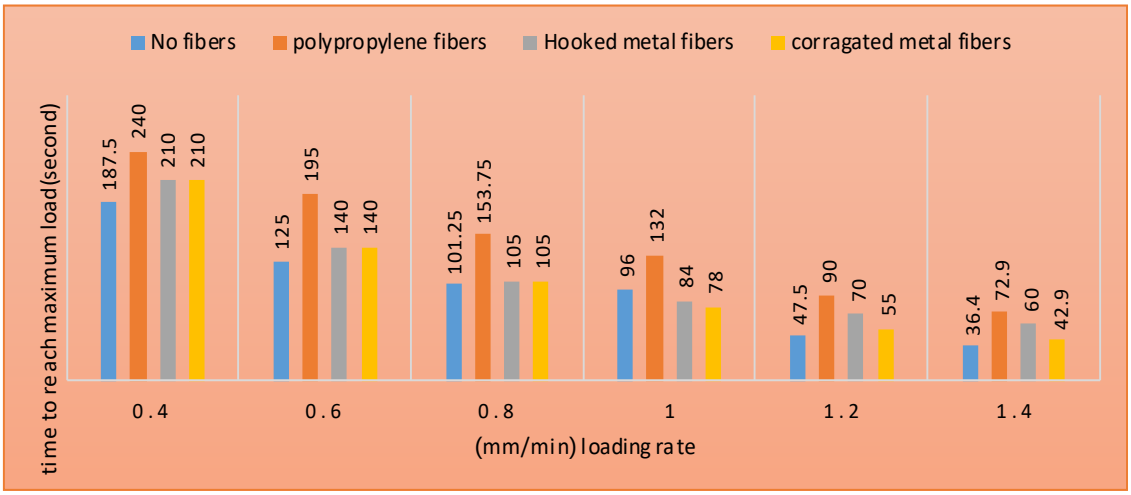
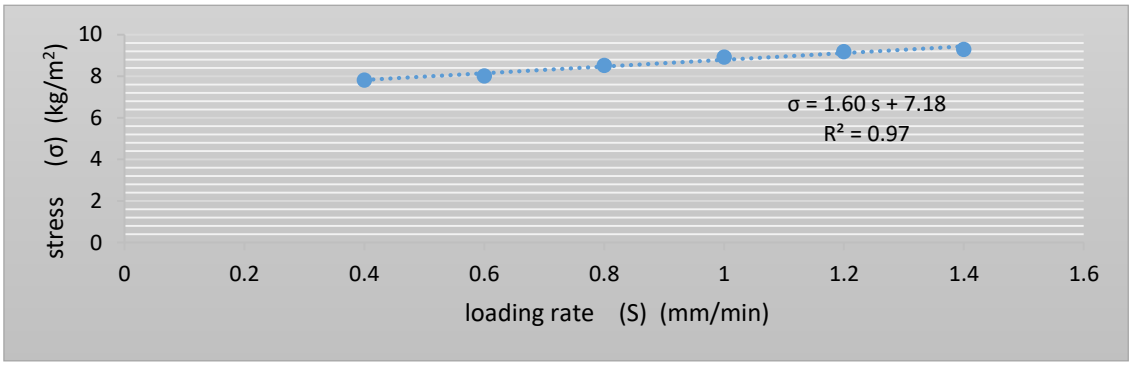


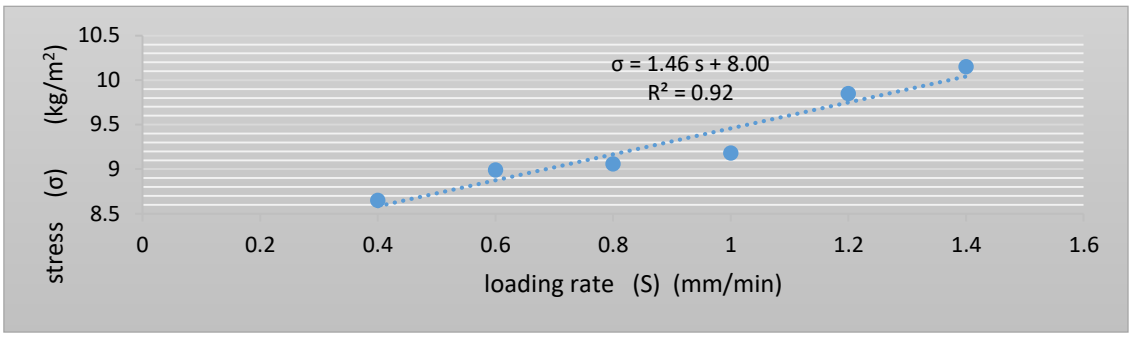
Figure 20. Time to reach maximum load chart - in terms of loading rate

4. Relationship between the loading rate, compressive stress and elastic modulus of different concrete samples:

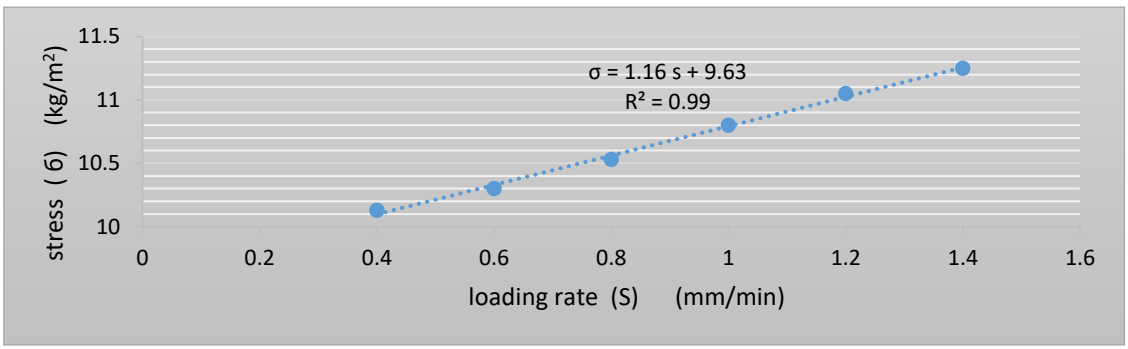
After performing the tests and presenting the results according to Tables 5 to 8, the analysis of the results was carried out according to Figures 21 and 22, which led to the presentation of the relationship between the compressive stress and the loading rate, as well as the modulus of elasticity and loading rate. The obtained values of R2 represented the high accuracy of the obtained relationships (in all the relationships between the compressive stress unit and the modulus of elasticity kg /m2, as well as the loading rate millimeter / minute).



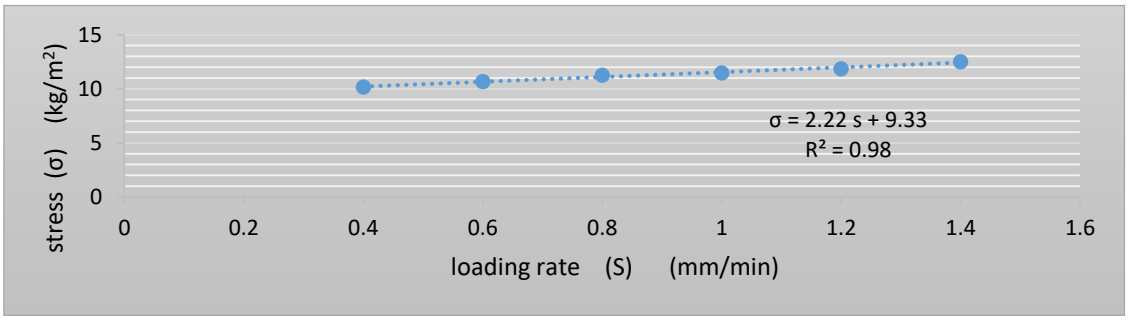
a. Stress-loading rate curve of non-fiber concrete sample



b. Stress-loading rate curve of concrete sample with polypropylene fibers

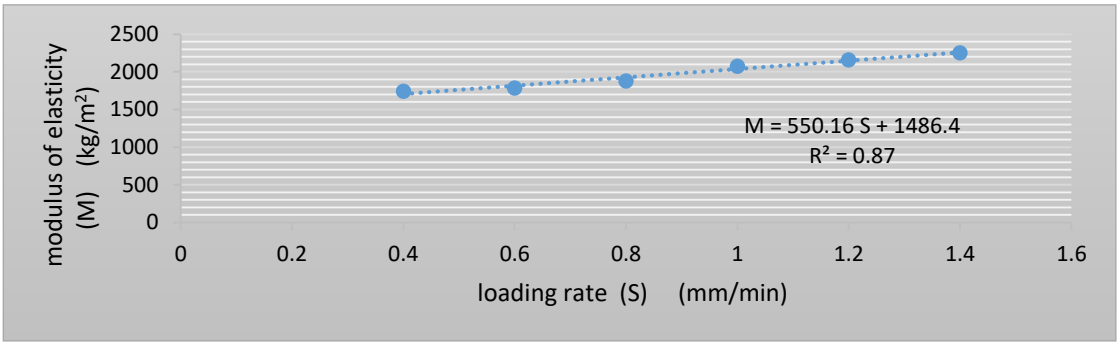


c. Stress-loading rate curve of concrete sample with hooked metal fibers

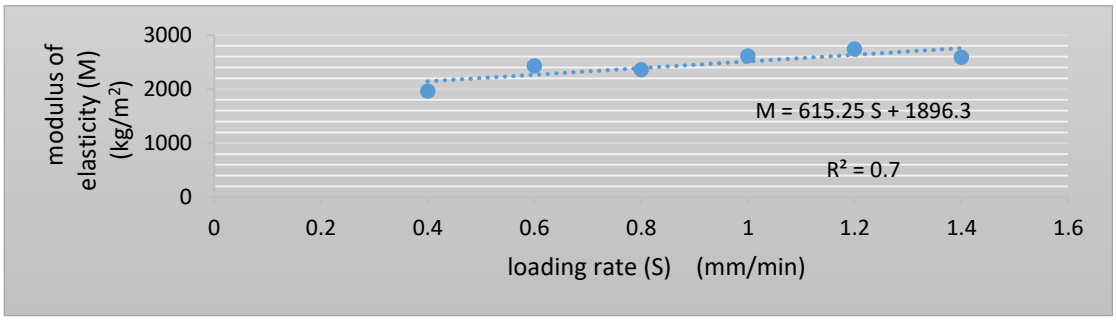


d. Stress-loading rate curve of concrete sample with corrugated metal fibers

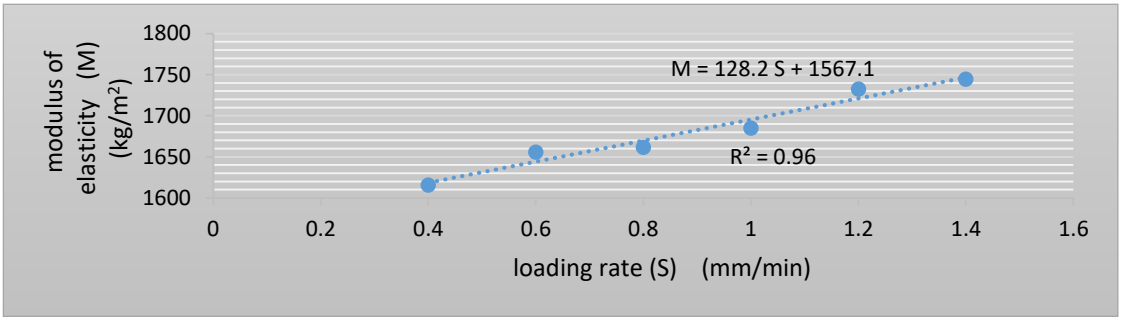
Figure 21. Stress-loading rate curves of concrete samples in different loading rates



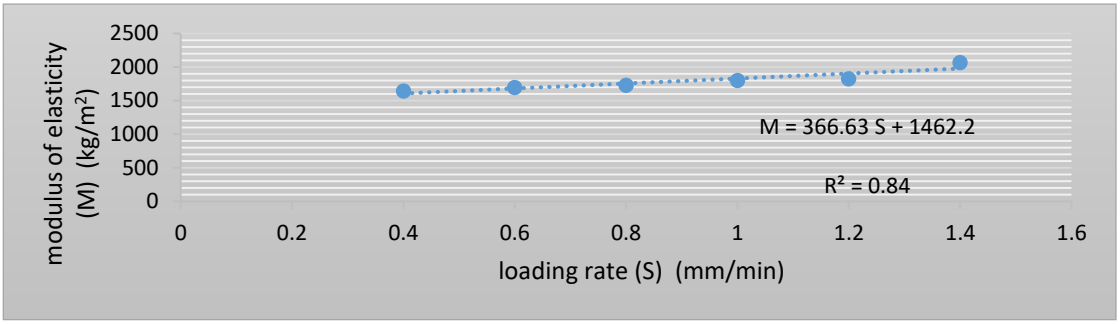
a) Modulus of elasticity - loading rate diagram of non-fibrous concrete samples



b) Modulus of elasticity - loading rate diagram of concrete samples with polypropylene fibers



c) Modulus of elasticity - loading rate diagram of concrete samples with hooked metal fibers



d) Modulus of elasticity - loading rate diagram of concrete samples with corrugated metal fibers

Figure 22. Modulus of elasticity - loading rate diagram of concrete samples indifferent loading rates

5. Discussions

As shown in Figures 9 to 18, there was a direct relationship between the loading rate with increasing compressive strength and modulus of elasticity. Regarding the failure time of the samples it could be said that the faster the loading rate was, the shorter the failure time would be. This trend of increasing strength, modulus of elasticity and reducing the failure time of the samples was more perceptible due to loading rate increase at a loading rate greater than 0.6 Millimeter per minute.

The results of this study indicated that, by adding fiber, strain-stress behavior of the samples has been improved by increasing the surface under the stress-strain curve and strain softening. This means increased plasticity, final strength and energy absorption by the samples. Some of the researches in this area are as follows, all of which confirmed the results of this study:

Zhou and Hao [24] cited that in concrete with low compressive strength, increasing loading speed caused the stress-strain curve of the concrete to have more smooth behavior after the peak of the curve, and the area under the graph increases.

Fathi and Dabbagh [23] stated that the steel fibers had a high elastic modulus and a high breaking strain which was considered to be the most suitable and economical type of fiber due to its good plasticity and tensile strength. This type of fiber with various shapes could be used to improve the behavior of concrete, as well as mixing them with other concrete materials easily.

In another study conforming to the present results, it was stated that by adding steel fibers to concrete, its mechanical properties such as strength, plasticity, durability and performance

under dynamic load and impact improved [25-27].

According to the ACI Committee 544, the steel fibers increased the failure energy under the impact load by approximately 2.5 times for concrete with typical-strength and approximately 3.5 times for high-strength concretes [28].

Bencardino, et al. [29] argued that polypropylene fibers were also the most used synthetic fibers used in concrete due to its cheapness compared to other fibers.

Kim, et al. [30] stated that reducing the cracks and preventing their expansion, fixed chemical, non-magnetism, low weight and reducing permeability in concrete were the benefits of polypropylene fibers. In addition, they were resistant to acids and alkalines, so they would not be destroyed. It is the most effective polypropylene fibers to reduce the damage caused by fire in concrete, which reduces damage even in low consumption percentages.

Sajedi and Lotfavi [31] in a laboratory study of compressive strength of high-strength concrete under various loading rates found that the higher the loading speed, the higher strength the concrete would be. As the loading rate increased, the concrete failure time would be shorter. It was shown that higher concrete strength, led to more accurate estimation of strength and the determination of the relationship between different ages. At a constant loading rate, greater samples strength led to their longer failure time. These findings were applied precisely to the results of the current research.

Saeidijam and Azimi [32] evaluated the strength and permeability parameters of plastic concrete reinforced with polypropylene fibers. The results showed that the presence of polypropylene fibers in plastic concrete with 0.25 to 0.5% volumetric concrete increased compressive and tensile strength and produced the highest strength in presence of 0.5% fiber.

According to the ICOLD [1] guidelines, the lower loading rate led to more creep occurring in the sample and, under a certain level of stress, the more compression strains occurred, less sample failure under less stress was examined.

Rakhshanimehr and Bakhshi [33] investigated the effect of amount of fiber and strength class on the mechanical properties of steel-fibered concrete. They stated that the use of steel fibers had the impact on the strength, the time of the appearance of the first crack and the final strength of the concrete considerably increases.

Patel et al. [34] studied the mechanical properties of propylene fiber-reinforced concrete with a water ratio of 0.5, with fiber 0, 0.5, 1, 1.5, and 2 percent as follows:

Adding polypropylene fibers to the concrete increased the compressive strength of 28 days with a fiber percentage of 1.5 to 16%. In addition, the amount of compressive strength in 1.5% fiber percent was much higher than the resistance of 2% fiber samples and the compressive strength for all samples was increased in comparison with the control sample, which was due to the property of the binding of the fiber. Therefore, the amount of compressive strength increased with increasing fiber percentages.

Undoubtedly, the most important part of a dam structure is its grout curtain. If, for whatever reason, the grout curtain is not properly implemented or its influential factors are not known, the most important expectation of a dam structure, which is the water supply, is not implemented and the total cost to run this important structure would be practically wasted.

One of the parts of the grout curtain is the cut-off plastic concrete wall, which is of

particular sensitivity to other concretes, so it is very important to know the type of concrete and the factors affecting it. One of the factors affecting this type of concrete is the loading rate

As shown in Tables 5 to 8, the increase in loading rate from 0.4 to 1.4 mm / min increased compressive strength by 18.8, 17.3, 11.1 and 23.2%, respectively, and increased 29.1, 31.8, 7.9, and 25.6% modulus of elasticity of the samples made of plastic concretes with no fiber, polypropylene fibers, hooked metal fibers and corrugated metal fibers.

Between compressive stress and loading rate, it is possible to recommend 1 to 4 relationships according to Fig.21 for the base plan (no fibers), the polypropylene fiber plan, the hooked metal fiber plan, and the corrugated metal fiber plan. In those relationships, σ was the compressive stress in kilograms per square centimeter and S was the loading rate in millimeters per minute.

$$\sigma = 1.6\,S + 7.18 \quad (1)$$
$$\sigma = 1.46\,S + 8 \quad (2)$$
$$\sigma = 1.16\,S + 9.63 \quad (3)$$
$$\sigma = 2.22\,S + 9.23 \quad (4)$$

The relationship between the modulus of elasticity and the loading rate can be recommended according to Fig. 22 for the base plan (no fibers), the plan with polypropylene fibers, the plan with hooked metal fibers and the plan with corrugated metal fibers according to relations 5 to 8, where M was the modulus of elasticity in kilograms per square centimeter and S was the loading rate in millimeters per minute.

$$M = 550.16\,S + 1486.4 \quad (5)$$
$$M = 615.25\,S + 1896.3 \quad (6)$$
$$M = 128.2\,S + 1567.1 \quad (7)$$
$$M = 366.63S + 1462.2 \quad (8)$$

6. Conclusios

Undoubtedly, the most important part of a dam structure is its grout curtain. If, for whatever reason, the grout curtain is not properly implemented or its influential factors are not known, the most important expectation of a dam structure, which is the water supply, is not implemented and the total cost to run this important structure has been practically wasted.
One of the parts of the grout curtain is the cut-off plastic concrete wall, which is of particular sensitivity to other concretes, so it is very important to know the type of concrete and the factors affecting it. One of the factors affecting this type of concrete is the loading rate. According to the experiments, the following results obtained:

- As the loading rate increases, the compressive strength increases and the concrete failure time significantly decreases.
- The cause of low strength in concrete samples at low loading rates is the occurrence of fatigue failure phenomena in concrete.
- By adding fibers to plastic concrete samples, the strain-stress behavior of the samples improved with increasing the surface under the stress-strain curve and strain softness.

This means increasing plasticity, final strength and energy absorption by the samples.

- Among the fibers used in this study, the samples made with corrugated metal fibers were the most effective in increasing compressive stress, but the samples made with polypropylene fibers had a more uniform behavior and the surface under its stress-strain curve has a greater increase compared to other concrete samples, which means more plasticity and more final strength than other concrete samples. It is recommended that fibers be used since the plasticity of the cut-off walls be of importance as well as the low price of the polypropylene fibers in order to make them more flexible.

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