Investigation of the role of super plasticizer on compressive strength and durability of concrete and their effect on the cost of concrete and used steel in educational building structures

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Abstract

Using super plasticizers can lead to a higher strength, lower permeability and also higher durability of concrete by reducing the water-cement ratio, but on the other hand, super plasticizers increase the cost of concrete production. The purpose of this study is to investigate the Role of super plasticizer on the compressive strength and durability of concrete and their effect on the cost of concrete and used steel in educational building structures. In order to do this, two series of concrete have been made. In the first series, by lowering the grade of cement and adding Super plasticizers, the water-cement ratio was reduced. In the second series, by keeping the grade of cement constant and adding super plasticizer, water-cement ratio was also reduced. Three types of common cements in Azerbaijan region were used with the corresponding super plasticizer to prepare concrete mixtures. Hardened concrete samples were tested to determine compressive strength, modulus of elasticity, Poisson's ratio, water absorption and durability against consecutive cycles of freezing and melting. A sample reinforced concrete frame from a 3-story educational building was designed with mechanical properties of prepared concretes. The amount of steel used, the displacement of roof story, maximum of story drift and displacement of the middle of beam bays were then calculated and compared. The results indicate that using super plasticizers in addition to increasing durability and decreasing permeability, by increasing mechanical properties of hardened concrete, reduces the used reinforcement and the structure deformation in reinforced concrete educational buildings.

Keywords: Concrete Compressive Strength, Concrete Durability, Super Plasticizer, Cost Reducing, Educational Building

Introduction

Considering different usages of concrete in building industry and the need for concrete with specific characteristics such as high strength, high durability and low permeability, investigating the usage of concrete admixtures that promote the above-mentioned characteristics with economy is necessary. Super plasticizer is one of the common chemical admixtures that by decreasing the viscosity of concrete, reduces the water-cement ratio that is an effective agent on mechanical properties of concrete. The advantages of chemistry seines and the growing needs of the building industry to new chemical admixtures has led to the development of industries producing chemical admixtures of concrete. So far, this industry of super plasticizer has gone through three different generations .[1,2]

The first generation: the super plasticizer based on Melamine
The second generation: the super plasticizer based on Lignosulfonates
The third generation: the super plasticizer based on Naphthalene
The fourth generation: the super plasticizer based on Polycarboxylate

In this article, in order to investigate the role of super plasticizer based on Polycarboxylate on compressive strength, durability of concrete and its effect on the cost of concrete and the used reinforcement of educational building structures has been examined.

Experimental

In this research, two types of concrete mixes were provided with three types of common cement used in Azerbaijan region with compatible super plasticizers to investigate the effect of the super plasticizers. In the first type of mix, by reducing the cement grade in comparison with the mix control and adding the super plasticizer and in the second series by keeping the cement grade constant and adding super plasticizer, the water-cement ratio was reduced. The hardened concrete samples were then tested for compressive strength, modulus of elasticity, Poisson ratio, water absorption and durability subjected to consecutive cycles of melting and freezing. In the next step, by using the mechanical properties of the concrete samples, a reinforced concrete frame of an three-story educational building was designed, and then for the mentioned frame reinforcements, horizontal displacement of the roof, maximum story drift and the middle displacement of bay beams were calculated and compared.

Used materials for concrete mix:

Course aggregate:

Course aggregate complied with ASTM-C33 with maximum 19mm diameter, 2.65 density, 1628 kg/m^3 specific gravity and 0.95% water absorption.[3]

Fine aggregate:

Fine aggregate complied with ASTM-C33 with 3.27 fineness modulus , 2.60 density and 1.21% water absorption.[3]

Cement:
Three common cement in Azerbaijan region was used:
a. Type II Portland cement of Sofian
b. Type II Portland cement of Khoy.
c. Pozzolanic portland cement of Sofian.
Used water:
The water of Tabriz city has been provided for this mix.
Super plasticizer:
Super plasticizer was used on the basis of Polycarboxylate according to ASTM-C494 standard.[4]

Mortar samples were made from the mentioned types of cement and four types of super plasticizers available in market. Fluidity and compressive strength of the mortars with identical mix designs were compared. According to the results, the super plasticizer based on Polycarboxylate that is more compatible with chosen cement was used.

To estimate the cost of these types of concrete, the price of used materials has been asked from the market and can be seen in table (1).

Table1: Cost of material for concrete (Tomans/kg)

Super-plasticizer	Sofian Pozzolanic Portland Cement	Khoy Type II Portland Cement	Sofian Type II Portland Cement	Aggregate	Material Type
4000	106	112	108	5	Cost, Tomans/kg

The mix design was gained from ACI-211-01 Code.[5] For each cement type, three designs has been considered.

a. **Design 1 or Control:** Concrete without super plasticizer and the minimum slump of 10cm
b. **Design 2 :**Concrete with super plasticizer, lower content of cement and lower water-cement ratio in comparison to the first design and with the minimum slump of 10 cm
c. **Design 3:**Concret with super plasticizer, identical content of cement and lower water-cement ratio in comparison with design 1 and with the slump of 10 cm
From each mix design, 11 samples were made as below:

Six 10×10×10 cubic samples for compressive strength test, two10×10×10 cubic samples for water absorption, two10×10×10 cubic samples for melting and freezing test and one 15×30 cylinder sample for calculating the modulus of elasticity and Poisson ratio by Extensometer system. The weight reduction percent of the samples considered for melting and freezing consecutive cycles were cut through with 4 cm thickness and after 30 cycles of melting and freezing have been compared. Each cycle of melting and freezing includes 12 hours of (-16°) (freezing) and 12 hours of (+20°) (melting)[6]. All the samples were kept in the templates for 24 hours after being made and laid in 20° water for 2 hours before test in order to undergo the curing process (Moist Curing time of concrete with type II Portland cement is 28 days and for the concrete with Portland pozzolanic cement is 42 days).

Figure1: Extensometer system

Figure2: Cut sample

The mix design of concrete was showed in table 2

Table 2: mix design of concrete

Fresh Concrete Density ,kg/m^3	Super-plasticizer ,kg	Fine Aggregate ,kg	Coarse Aggregate ,kg	Water ,kg	Cement ,kg	Cement Type	Mix No.
2383	-	922	940	194	327	Sofian Type II Portland	Mix1 SPII1
2440	5.1	1114	912	126	283	Sofian Type II Portland	Mix2 SPII2
2414	5.95	1080	880	118	330	Sofian Type II Portland	Mix3 SPII3
2397	-	889	962	181	365	Khoy Type II Portland	Mix4 KPII1
2455	5.35	1097	922	123	307	Khoy Type II Portland	Mix5 KPII2
2485	6.8	1072	900	130	376	Khoy Type II Portland	Mix6 KPII3
2373	-	848	928	202	395	Sofian Pozzolanic Portland	Mix7 SPP1
2455	5.65	1058	908	140	343	Sofian Pozzolanic Portland	Mix8 SPP2

2455	6.94	919	980	131	408	Sofian Pozzolanic Portland	Mix9 SPP3

In order to study the effect of provided concrete on used reinforcements, horizontal displacement of the roof, maximum story drift and middle displacement of bay beams, a frame of a three story educational building using designs 1,2,3 and three types of cement (totally 9 types of concrete) has been designed. The plan for this building is shown in figure 3, the region seismicity is very high and the soil type is 3.The structural system is moment frame with intermediate ductility, the height of stories is 3.4 m and the structure plan is symmetric. For the designed frame used reinforcements, horizontal displacement of the roof, maximum story drift and middle displacement of bay beams were calculated and compared.[7,8,9]

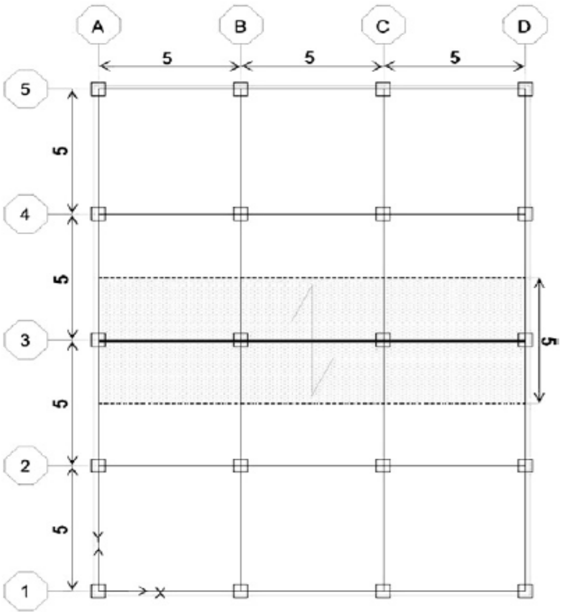

Figure 3: selected plane

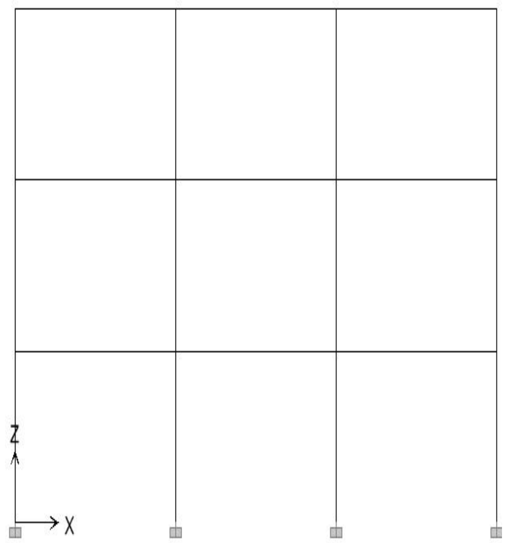

Figure 4: selected frame

Results and Discussion

Shear modulus of concrete equal: $G = \frac{E}{2(1+\upsilon)}$ Where G is the shear modulus of concrete that augments with increasing in modulus of elasticity and decreasing in Poisson ratio.

Mechanical properties of concrete such as compressive strength, modulus of elasticity, shear modulus and Poisson ratio of concrete samples are shown in table 3.

Table 3: properties of prepared concrete

Slump ,cm	Shear Modulus, kg/cm^2	Poisson Ratio	Young Modulus, kg/cm^2	W/C	Compressive Strength, kg/cm^2	Mix No.
10	109097	0.25	272743	0.60	286	Mix1 SPII1
15	142449	0.20	341878	0.45	452	Mix2 SPII2
15	158346	0.17	370530	0.35	525	Mix3 SPII3
10	115418	0.24	286237	0.50	315	Mix4 KPII1
14	132378	0.21	320355	0.40	412	Mix5 KPII2
17	164504	0.16	381650	0.35	560	Mix6 KPII3
12	103193	0.26	260048	0.51	270	Mix7 SPP1
15	144828	0.22	353381	0.40	490	Mix8 SPP2
17	162923	0.17	381240	0.32	570	Mix9 SPP3

Water absorption percent and weight reduction percent of hardened concrete under 30 consecutive cycles of melting and freezing are shown in table 4 and figure 5

Table 4: weight reduction percent after 30 consecutive cycles of melting and freezing

Mix9 SPP3	Mix8 SPP2	Mix7 SPP1	Mix6 KPII3	Mix5 KPII2	Mix4 KPII1	Mix3 SPII3	Mix2 SPII2	Mix1 SPII1	Mix No.
0.09	0.61	Cracked	0.45	0.87	Crushed	1.26	Crushed	Crushed	Weight Loss (%)

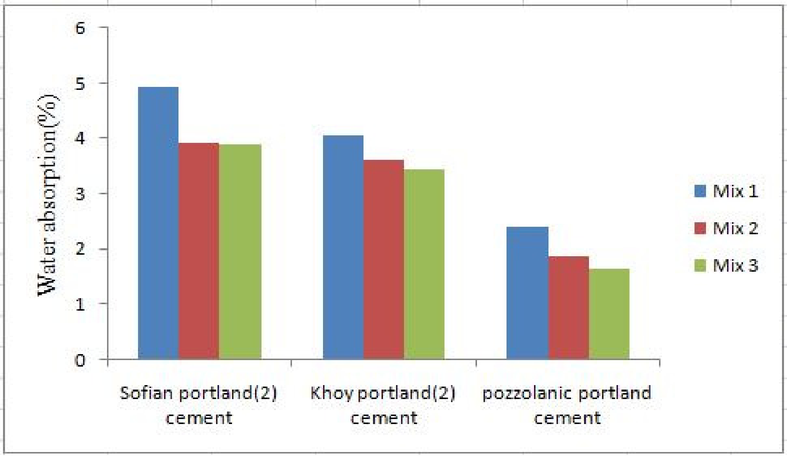

Figure 5: water absorption percent of sample concrete

It can be understood from the consequences of table 4 and figure 5 that:

- Using super plasticizer and low water-cement ratio would reduce water-absorption percent and increase durability against melting and freezing, as concrete samples without super plasticizer would be crushed absolutely after 30 consecutive cycles of melting and freezing. - -
- Concrete with Pozzolanic cement has the least water absorption percent and the most durability against melting and freezing in comparison to other concretes. -
- In mix design 3(added super plasticizer, low water-cement ratio and constant grade of cement) we have the least water absorption and the most durability of concrete. This point show the significant role of super plasticizer in concrete durability.

Cost per unit and cost- strength ratio of prepared concrete respectively were showed in figures 6, 7:

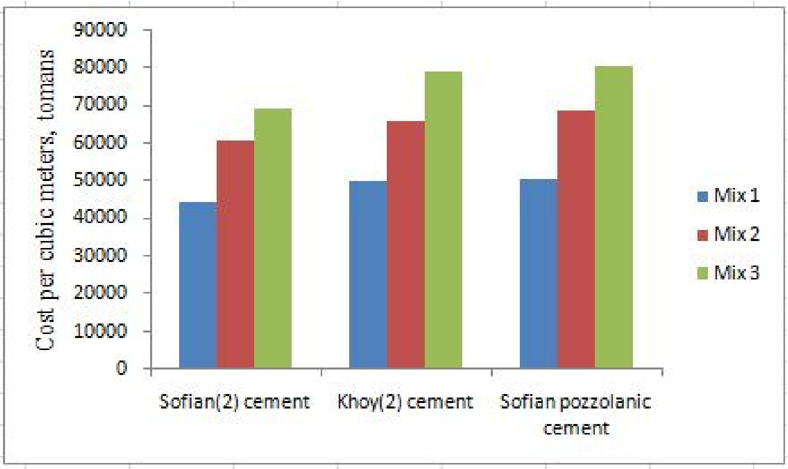

Figure 6: Cost per unit of concrete (tomans)

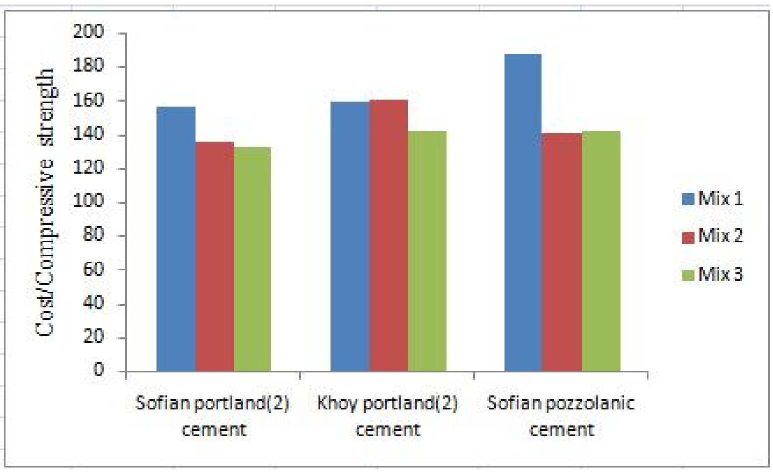

Figure 7: Cost- strength ratio (Tomans/kg/cm^2)

It can be understood from the consequences of figures 6 & 7 that:

- Although there is a rise in pure and direct expense of provided concrete using super plasticizer, price-strength ratio decreases. In other word, adding super plasticizer indirectly reduces the costs. - -
- As it can be seen in figures 6 & 7, Portland cement of Sofian has better economical function in comparison to others and using pozzolanic cement would cause more costs, thus it is not desirable to use pozzolanic cement unless in some special cases such as durability and hydration heat problems are noticeable. -

Used reinforcement, center displacement of bay beams, horizontal displacement of roof and the maximum story drifts of the designed frame using studied concretes have been showed in figures 8,9,10 & 11.

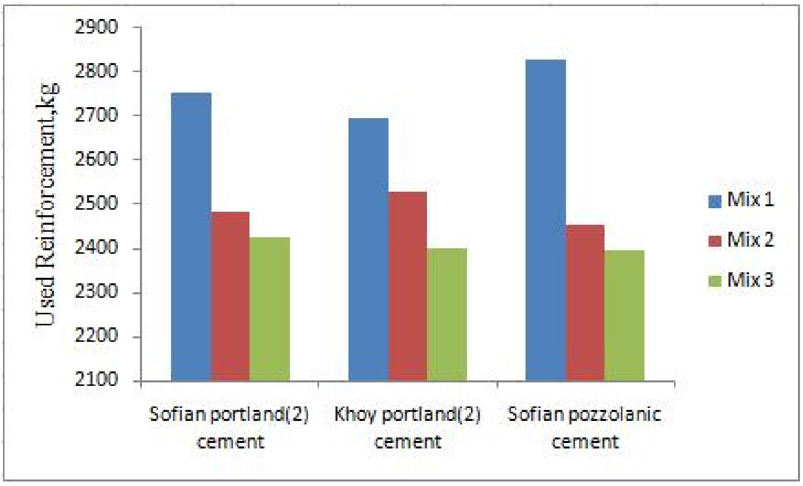

Figure 8: Used reinforcement (kg)

It can be understood from the consequences of figure8 that:

- By increasing the compressive strength and flowingly increasing the modulus of elasticity and shear modulus of concrete the need for reinforcement would be low in the frame. This shortage of strength by reinforcement would be recovered with the increase in concrete compressive strength by adding super plasticizer. -
- In design mix 3 (added super plasticizer, low water-cement ratio and constant grade of cement) there is the least need for reinforcement

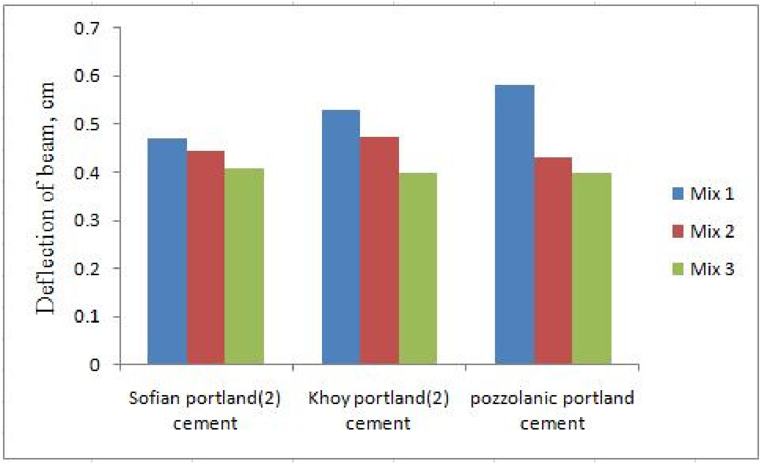

Figure 9: displacement of middle bay beams

It can be understood from the consequences of figures 8 that:

- Increasing the compressive strength and flowingly increasing the elasticity modulus and shear modulus improves beams stiffness and reduces their deformation. -
- In design mix 3 (added super plasticizer, low water-cement ratio and constant grade of cement) there would be more increase in beams stiffness that causes lower deformation under gravity loads.

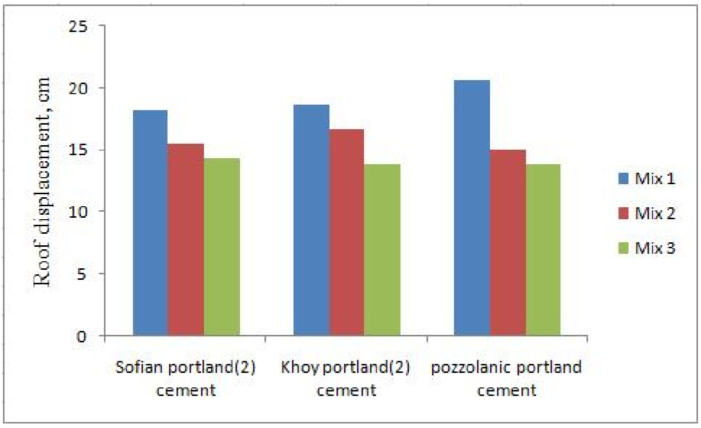

Figure 9: horizontal Roof displacement (cm)

It can be understood from the consequences of figures 10 that:

- Increasing the compressive strength and flowingly increasing the mechanical properties of the concrete, frame stiffness would grow up under lateral loads that cause the lower displacement of the roof. - ---
- High compressive strength in mix design 3 wolud cause lower displacement of the roof.

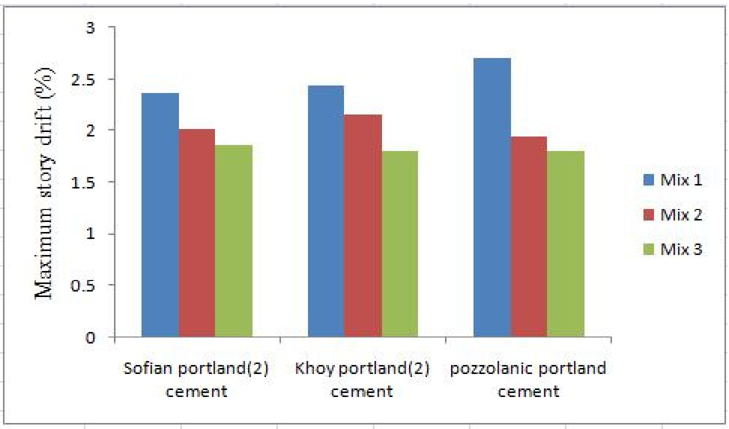

Figure 9: maximum story drift

It can be understood from the consequences of figure 11 that:

- Increasing the compressive strength and flowingly increasing the mechanical properties of the concrete, frame stiffness would grow up under earthquake loads that reduces story drift under earthquake loads. -
- In this case, high compressive strength in mix design 3 would cause more lower in story drift.

Conclusions

In this study, the following conclusions can be drawn:

- Beside the good effect on the workability and slump of fresh concrete, super plasticizers increase compressive strength and modulus of elasticity and decrease Poisson ratio with a low water-cement ratio that would increase the shear modulus of concrete.

- Super plasticizers decrease water absorption and increase durability under consecutive cycles of melting and freezing by lowering water-cement ratio.

- Type II Portland cement and Pozzolanic Portland cement of Sofian subsequently have better function in terms of economical and durability problems.

- Using expensive super plasticizers would directly cause high expenses, but because of their effect on upgrading the compressive strength, cost-strength ratio would be reduced due to using such super plasticizers. This means that super plasticizers indirectly reduce the costs.

- For educational concrete buildings using super plasticizers reduces required reinforcements, horizontal displacement of the roof, maximum story drift and middle displacement of beam bays. So it can be expressed that proper usage of super plasticizers could result in indirect low costs.

- Using super plasticizers and reducing horizontal displacement of roof, story drift and deformation of beam, are factors that increase the safety of structure in case of cracking, effective moment of inertia reduction and $P-\Delta$ effect.

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