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Farid Ghaffari Moghaddam, Abbas Akbarpour* and Afshin Firouzi

Providing a framework for optimizing a mixing design of reactive powder concrete (RPC)

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Abstract: Suitable distribution of particles and the presence of hydration lead to the improved compressive performance and optimum (even reduced) cost in the production of reactive powder concrete (RPC). This study was conducted to obtain a better understanding of RPC and analyze the behavior of modified RPC (MRPC) using the properties of surface resistivity, water penetration, compressive strength, and modulus of elasticity, apart from the cost. The present study was carried out to investigate how to optimize the size and diversity of the aggregate in order to increase the applications and reduce the costs. The options were selected from among the 12 alternatives classified during the construction stages. According to the six weighting parameters used for comparing with the sample, the derived framework can be described as a mixing design for RPC. Five weighting criteria were considered with values of one of the five criteria missing, and in one case, all criteria were taken with equal weights. For the final analysis, the Expert Choice software was used to create a framework for the optimal mix design of RPC and MRPC. The MRPC mixing designs showed good results, with very slight differences compared to RPC. In many cases, MRPC can be used instead of RPC.

Keywords: water penetration, electrical resistivity, modulus of elasticity, pulse velocity, nondestructive testing, construction management, sustainable development and optimal mix design

1 Introduction

A system is a collection whose components interact with each other and are interconnected in different ways. The components perform a common function with respect to an input to produce an output. The components and systems are developed under certain limiting factors in the surrounding area. Considering this theory, concrete comprises a living system with a series of three general subsystems, namely, aggregate, cement paste (cement, water and air bubbles, as well as chemical additives), and interfacial transition zone; in the total larger systems, all of these create a synergy (Ahmadvand et al. 2006).

Indeed, the relationship between the individual components in a system is more important than the system components themselves. In this study, we try a new approach by utilizing two opposite concepts with a systematic view and focus on the aggregate–cement paste connecting area, on which the superplasticizer exerts its effect. This approach introduces the field of new materials in construction in the form of concrete science (Moghaddam 2008).

It is a complex system that can be used to understand the functional properties of concrete. A relevant testing tool, called the rheometer, is used in laboratories to investigate the functional properties of concrete. The two major rheological properties of concrete are as follows:

- Yield stress: it measures the amount of energy required to provide flow concrete, as the concrete should flow under its own weight (gravity movement); so the yield stress should be very low.
- Paste viscosity: it measures the internal friction resistance against the concrete flow. Concrete should have high viscosity in the suspended aggregate particles and, in the homogeneous method, it should be without segregation, excessive water bleeding, air loss, and separation in paste (Moghaddam 2014; American Concrete Institute [ACI] 238.1R 2008).

Reactive powder concrete (RPC) is a relatively new type of ultrahigh-performance concrete developed by Richard and Cheyrezy in the early 1990s. RPC is composed of Portland cement and ultrafine powders, such as crushed quartz and silica fume. Compared to ordinary cement-based materials, the primary improvements of

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***Corresponding author: Abbas Akbarpour,** Department of Civil Engineering, South Tehran Branch, Islamic Azad University, Tehran, Iran. E-mail: a_akbarpour@azad.ac.ir
Farid Ghaffari Moghaddam and Afshin Firouzi, Department of Civil Engineering, Architecture and Art, Science and Research Branch, Islamic Azad University , Tehran, Iran

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RPC are related to particle size homogeneity, porosity, and microstructure. A highly dense matrix is achieved by optimizing the granular packing of these powders. RPC is achieved by a microstructural engineering approach, which includes eliminating coarse aggregates, reducing the water–cementitious material ratio (w/cm), lowering the CaO/SiO_2 ratio by introducing silica components, and incorporating steel microfibers.

RPC extensively uses both the pozzolanic properties of highly refined silica fume and optimization of the Portland cement chemistry to produce the highest-strength hydrates. It represents a new class of Portland cement-based material with compressive strengths as large as 200 MPa (29,000 pounds per square inch [psi]). The material exhibits high ductility, with values of energy absorption approaching those that are reserved only for metals.

The RPC concept is based on the principle that a material with a minimum number of defects, such as micro-cracks and voids, will be able to achieve a greater load-carrying capacity and greater durability (Aydın and Baradan 2013).

Finally, the purpose of this investigation is to apply refinements in RPC by introducing graded aggregate into it (3–8 mm) so as to make this RPC more economical and feasible without much reduction in its mechanical properties. This modification makes the traditional RPC an innovative modified RPC (MRPC) (Sujatha and Basanthi 2014).

The main focus of this research is finding whether by increasing the size and type of the aggregates of MRPC, the test results will be similar to those of RPC; moreover, considering the lower cost of MRPC production and its ease of use in projects, this study also aims to determine whether MRPC can replace RPC.

This study identifies the framework to select the type of concrete mix design for RPC and MRPC according to the desired conditions and priorities set forth by the criteria.

2 Research significance

In this study, a new type of ultrahigh-performance concrete, RPC was produced using fine aggregate. This modification converts the traditional RPC into an innovative MRPC. The present study aims to investigate how to optimize the size and diversity of the aggregate in order to increase the applications and reduce the costs. Increasing the aggregate size with small changes in the results may show the possibility of increasing the aggregate size and reducing the cost of concrete. In fact, the purpose of the research is to be able to determine the optimal mixing design according to the priority of each test or cost or the whole criteria.

The possibility of (i) using well-sized aggregates; (ii) using the effect of these changes on compressive strength, the modulus of elasticity, and water penetration; and (iii) studying the cost of the concrete provides a good framework to determine how to use this type of concrete. It is believed that this study will open a new era in using MRPC in RPC applications.

3 Experimental procedure

3.1 Materials and mixture proportion

A total of 77 concrete mixtures (30 mixtures were selected based on the results of the ready mix concrete test) were used throughout this investigation. These concrete mixtures were made in the “Concrete Research and Education Center (ConREC)” affiliated with the ACI (Iran Chapter). According to the American Society for Testing and Materials (ASTM) C150, type II and V Portland cements were used for all of the concrete mixtures. A commercial silica fume was also used in this study. Brunauer, Emmett and Teller (BET) fineness and specific gravity of silica fume were 23,360 m^2/kg and 2,100 kg/m^3, respectively. The chemical compositions of the colloidal and powdered nanosilica and silica fume are presented in Table 1. Commercial quartz sand, in three different size fractions (75 μm to 6 mm, 0–1 mm, and 0–75 μm), as well as natural sand and gravel in four different size proportions (0–75 μm, 0–5 mm, 5–9.5 mm, and 9.5–19 mm) were used as the aggregate. The gravel

Tab. 1: Properties of colloidal nanosilica, powdered nanosilica and silica fume.

	SiO_2, %	Size, nm	Specific surface area, m^2/g	Salt content (%)	Type	Density, kg/m^3 (lb/yd^3)
Colloidal nanosilica	99.9	35	400	24	Combiner	1.05 (1.77)
Powdered nanosilica	99	20–30	160–200	100	Powder	0.150–0.220 (0.253–0.37)
Silica fume	90	229	20.7	100	Powder	2.1 (3.54)

Tab. 2: Chemical compositions (%) of quartz sand and silica fume.

	SiO_2	Al_2O_3	Fe_2O_3	CaO	Na_2O	K_2O
Quartz sand	96–98.8	0.151–1.65	0.2–0.7	0.2–0.5	0.03–0.08	0.03–0.1
Silica fume	90	1.3	1.1	1.7	0.5	0.3

was added by replacing quartz sand in self-compacting concrete (SCC) and traditional concretes. The chemical characteristics of quartz sand and silica fume are shown in Table 2.

For all normal concretes, coarse aggregates were crushed into calcareous stone with a maximum size of 19 mm (0.748 in.), and fine aggregates were natural sand. The coarse aggregates had a specific gravity and water absorption of 2,550 kg/m^3 (4,298 lb/yd^3) and 1.10%, respectively, while the fine aggregate had a water absorption of 2.25% and a specific gravity of 2,585 kg/m^3 (4,357 lb/yd^3).

For a polycarboxylate-based high-range water-reducing admixture (HRWRA) complying with ASTM C494-08 Type F, the specific gravity and solid content of the HRWRA were 1,050 kg/m^3 (1,770 lb/yd^3) and 40%, respectively.

Potable water was used for casting all concrete specimens. The mixture proportions for concrete specimens are summarized in Table 3.

3.2 Testing procedure and specimen preparation

In this study, the compressive strength and electrical resistivity of RPC, MRPC, and SCC with different proportions of aggregates and varying sizes were compared. Workability of fresh RPC and MRPC mixtures was evaluated using flow table tests (ASTM C230) to attain the same workability level corresponding to a plastic fluid consistency of 205–216 mm. The strengths were tested according to ASTM C39/C39M (2015) after usage at 3, 7, 28, and 90 days by curing according to ASTM C33 and accelerated curing of 24 hours at 80°C (176°F).

Specimen cubes of sizes 150 × 150 × 150 mm (5.9 × 5.9 × 5.9 in.) were used for the chosen mix design.

The depth of water penetration in the concrete under a pressure of 0.75 MPa (10.87 psi) was determined at 3 days, according to British Standard European Norm (BS EN) 12390-8 with some modifications. The reason for a 3-day test was attributable to the pressure of the equipment, thus making it difficult to achieve water penetration if the concrete was cured for a longer period. For each concrete mixture, three cubic 28-day specimens were used for this test. The specimens were roughened on the circumference surface immediately after remolding.

An electrical resistivity meter was utilized to measure the surface resistivity (SR) of the specimens. This nondestructive laboratory test method measures the electrical resistivity of water-saturated concrete and provides an indication of its permeability. The test result is a function of the electrical resistance of the specimen. Saturated cubes 150 × 150 × 150 mm (5.9 × 5.9 × 5.9 in.) were used at each test age. The electrical resistivity test for concretes was conducted by the four-point Wenner array probe technique. The probe array spacing used was 40 mm (1.57 in.) The resistivity measurements were done at four quaternary longitudinal locations of the specimen (Florida Method [FM] 5-578 2004). On 28-day cubic samples, a nondestructive test was carried out to determine the transfer time of the ultrasonic pulse by the direct method by a pulse velocity test device. The frequency (54 KHz) was sent from the device, and the duration of the pulse transfer in microseconds (μs) and with an accuracy of 0.1 μs was displayed on the device's digital screen. In the ASTM C597 standard, a formula that uses the pulse velocity, Poisson's ratio, and concrete unit weight to obtain the modulus of the dynamic elasticity of the concrete is presented. The results obtained from the pulse velocity test, as well as the compressive strength of the cubic samples at 28 days and other test results are presented in Table 4.

4 Discussion of results

The Expert Choice software was used to implement the analytical hierarchy process technique. The mentioned software has various capabilities, including the possibility of designing the hierarchical chart (Hierarchy), decision-making, design of questions, setting the preferences, final weight calculation, and the ability to analyze the sensitivity to variation in problem parameters. The development of suitable diagrams for providing the

Tab. 3: Mixture proportions of concrete.

No.	Mixtures	Cement content/ type (Kg)	W/CM	PCE (kg/m³)	Silica fume (kg/m³)	Colloidal nanosilica (kg/m³)	Powdered nanosilica (kg/m³)	Quartz (0–75 µm), (kg/m³)	Sand (0–75 µm), kg/m³	Sand (0–5 mm), kg/m³	Gravel (5–9.5 mm), kg/m³	Gravel (9.5–19 mm), kg/m³	Quartz (0–1 mm), kg/m³	Quartz (75 µm to 6 mm), kg/m³
1	S62	900/II	0.28	48.7	225	9	90	1,000*	–	–	–	–	–	–
2	S63	900/II	0.31	48.7	225	9	90	1,000*	–	–	–	–	–	–
3	S64	900/V	0.28	44	180	18	18	–	1,000	–	–	–	–	–
4	S65		0.247	44	180	18	18	–	1,001	–	–	–	–	–
5	S68	900/V	0.27.4	46.5	180	18	18	–	–	1,000	–	–	–	–
6	S70	900/V	0.27.4	50	180	18	18	–	–	1,000**	–	–	–	–
7	S72	900/II	0.25.1	52	180	18	–	–	1,100**	–	–	–	–	–
8	S73	900/II	0.27.2	52	180	18	–	–	1,100**	–	–	–	–	–
9	S76	900/II	0.30.4	56	165	18	–	1,000	–	–	–	–	–	–
10	S77	900/II	0.27.7	56	165	18	–	–	–	–	–	–	1,000	–
11	RP,S1	900/II	0.31	46	165	18	–	139	–	–	–	–	–	861
12	RP,S2	900/II	0.31	46	165	18	–	50	–	–	–	–	–	950
13	RP,S3	900/II	0.31	46	165	18	–	100	–	–	–	–	–	900
14	RP,S4	900/II	0.31	46	165	18	–	0	–	–	–	–	–	1,000
15	RP,O1	900/II	0.31	46	165	18	165	268	567*	–	–	–	–	–
16	RP,O2	900/II	0.31	46	165	18	165	567	268*	–	–	–	–	–
17	RP,O3	900/II	0.31	46	165	18	85	315	600*	–	–	–	–	–
18	RP,O4	900/II	0.31	46	165	18	85	600	315*	–	–	–	–	–
19	RP,M1	900/II	0.25	40	165	18	–	–	–	600	–	–	400	–
20	RP,M2	900/II	0.25	40	165	18	–	–	–	500	–	–	500	–
21	RP,M3	900/II	0.25	40	165	18	–	–	–	400	–	–	600	–
22	RP,M4	900/II	0.25	40	165	18	–	–	–	700	–	–	300	–
23	SCC1	400/II	0.48	12	60	..	120	–	–	820	750	–	–	–
24	SCC2	400/II	0.5	9	60	..	120	–	–	820	750	–	–	–
25	SCC3	400/II	0.45	9	70	..	74	–	–	900	525	225	–	–
26	SCC4	400/II	0.45	9	70	..	74	–	–	800	450	400	–	–
27	SCC5	400/II	0.45	9	70	..	74	–	–	900	225	525	–	–
28	C1	400/II	0.45	1.75	..	..	–	–	–	920	440	460	–	–
29	C2	400/II	0.45	1.75	..	..	–	–	–	900	220	700	–	–
30	C3	400/II	0.45	1.75	..	..	–	–	–	850	470	400	–	–

Notes: * = Ottawa sand; ** = Crystal sand.

Tab.4: Test results for the compressive strength, surface resistivity, water penetration and modulus of elasticity (E_d).

No.	Mixtures	Compressive strength (28 days), MPa		Surface resistivity, kΩ·cm	Water penetration, mm	E_d, GPa
		23°C	80°C			
1	S 62	138.8	–	95	9.5	56.68
2	S63	118.7	–	73	12.1	52.66
3	S64	146.3	–	63.9	12.4	59.32
4	S65	174.5	–	68	12.1	67.82
5	S68	100.6	–	79.1	10.5	49.17
6	S70	118.1	–	89.6	11	53.63
7	S72	120.2	–	107.9	7.5	55.98
8	S73	113.4	–	76.6	10	48.24
9	S76	137	193.5	125	6.1	78.53
10	S77	125.3	187	123	6.6	74.27
11	RP,S 1	98.1	125.3	154	5.2	48.82
12	RP,S2	96.5	127.2	104	5.4	49.29
13	RPS,3	97.6	118.3	112	6.1	50.87
14	RP,S4	95.2	115.4	195	4.2	48.68
15	RP,O1	89.8	112.4	174	4.4	42.05
16	RP,O2	93.5	127.2	121	5.5	43.87
17	RP,O3	95.4	118.6	158	4.1	49.85
18	RP,O4	91.4	115.9	83	7.4	42.61
19	RP,M1	121.2	174.3	124	6.4	65.63
20	RP,M2	119.4	161.2	92	9.5	61.97
21	RP,M3	105.4	145.4	113	7.5	63.97
22	RP,M4	104.3	138.3	180	4.5	59.37
23	SCC1	52.3	–	42.35	15	34.43
24	SCC2	48.9	–	37.5	18	33.76
25	SCC3	57.6	–	77.85	12	38.22
26	SCC4	55.1	–	33	14.3	34.98
27	SCC5	44.2	–	37	16	31.51
28	C1	38.2	–	5.2	21.5	41.57
29	C2	36.5	–	4.8	33.3	37.53
30	C3	35.4	–	7.3	35.5	34.64

results and functions of each decision in this software start with a model in the form of a hierarchical tree. The simplest case is a hierarchy of three levels of purpose, criteria, and alternatives. Of course, each criterion can be divided into a set of criteria. The development of the model starts with the construction of the target and extends to the lower levels.

To build a model for the purpose of optimizing the RPC scheme, the RPC scheme was considered with regard to the subject and the purpose of the research. In the software simulation, five of the results obtained during the experiments were applied. For this purpose, compressive strength, elastic modulus, electrical resistivity, water penetration depth, and the cost of each reinforced concrete beam were chosen.

Weighting of the criteria can provide a very good framework for the presentation of a concrete mixing scheme according to the criteria. The software is able to dynamically select the optimal mixing scheme using the weighting between the criteria. A more suitable description of the multiple weighting of weights between the criteria, as well as the results achieved, is discussed in the following section.

The options were selected from among the 12 alternatives classified during the construction stages, according to Table 5. The material prices were also recorded, according to Table 6.

After recording the information and analysis of the information in the software, the results were obtained as presented in Figures 1–10.

According to the six weighting parameters used to compare the samples, the following framework can be described as the mix design of RPC. Five weighting criteria were considered with the values of one of the five criteria missing, and in one case, all criteria are taken with equal weights.

The optimal mix design scheme is shown in Figures 1–5 with respect to the weighting Criteria 1–5.

Tab. 5: Selection options in the software.

Mixtures, kg/m³	S62-63	S64-65	S72-73	S76	RPO	RPM	RPS	S68	S70	S77	SCC	C
Aggregate	**Ottawa sand**	**Sand (0–75 µm)**	**Crystal sand (0–75 µm)**	**Quartz (0–75 µm)**	**Quartz (0–75 µm), Ottawa**	**Sand + quartz**	**Quartz (0–1 mm)**	**Sand (75 µm–6 mm)**	**Crystal sand (0–5 mm)**	**Quartz (0–1 mm)**	**Gravel + sand**	**Gravel + sand**
Cement type	II	V	II	II	II	II	II	V	V	II	II	II
Silica fume	225	180	180	165	165	165	167	180	180	165	6–70	–
Powder nanosilica	90	18	–	–	85–165	–	–	18	18	–	74–120	–
Colloidal nanosilica	9	18	18	18	18	18	18	18	18	18	–	–
Concrete	RPC					MRPC					SCC	C

Tab. 6: Prices reserved for consumable materials.

Materials	Quartz (ton)	PCE (kg)	Cement (ton)	Silica fume (ton)	Colloidal nanosilica (kg)	Ottawa sand (kg)	Gravel + sand (ton)	Crystal sand (ton)
Price, $	4	1.6	16	44	4.8	3.2	1.2	1.6

For the case where equal weighting is considered for all criteria, the following information was presented:

- Weighting charts (Figure 6)
- The sensitivity graph of options to the weighting criteria (Figure 7)
- An example of the dynamic sensitivity of options to the weighting criteria (Figure 8)
- The slope chart of the sensitivity of options to the weighting criteria (Figure 9)

As shown in Figure 1, if the compressive strength criterion does not matter much, the optimal mixing design is S76, and the next optimal mixing design is RPS.

As shown in Figure 2, if the low cost criterion does not matter much, the optimal mixing design is S76, and the next optimal mixing design is S77.

As shown in Figure 3, if the water penetration criterion does not matter much, the optimal mixing design is S76, and the next optimal mixing design is S77.

As shown in Figure 4, if the SR criterion does not matter much, the optimal mixing design is S76, and the next optimal mixing design is S77.

As shown in Figure 5, if the modulus of elasticity criterion does not matter much, the optimal mixing design is S76, and the next optimal mixing design is RPS.

As shown in Figure 7, the sensitivity of options to different weights is shown, and naturally, by changing the weights between the criteria, the optimal results of the mixing plans are different. This allows us to select the best mixing design based on the desired conditions and prioritized criteria.

In Figure 8, an example of the dynamic sensitivity is shown by changing the weight of the criteria on the left and simultaneously prioritizing the mixing designs on the right.

Figure 9 shows the criteria for which the mixing designs are more sensitive, and for each criterion, there is a sensitivity analysis based on slope. The priority of mixing designs is clear at the intersection with the bold vertical line on the vertical axis on the left.

Overall, considering all the aforementioned criteria with the same weight, as presented in Figure 10, the optimal mixing design is related to S76, which uses quartz sand up to 1 mm, with a slight variation of RPM and RPS, which is also related to MRPC, indicating that the replacement of MRPC with RPC is more favorable due to its applicability.

The optimum frame of the RPC and MRPC design scheme is presented in Table 7. As can be observed, MRPC

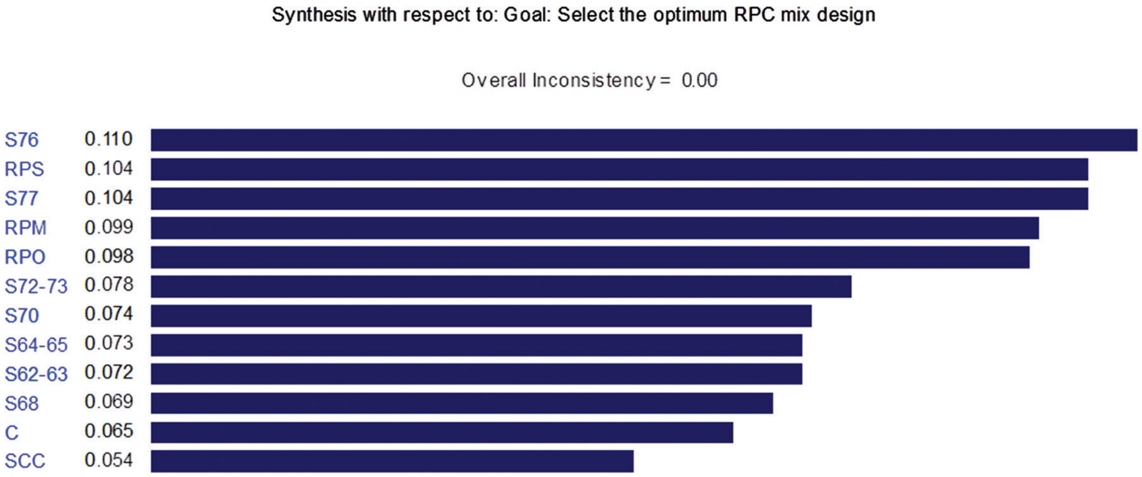

Fig. 1: Optimal mixing design with respect to the weight of the compressive strength effect.

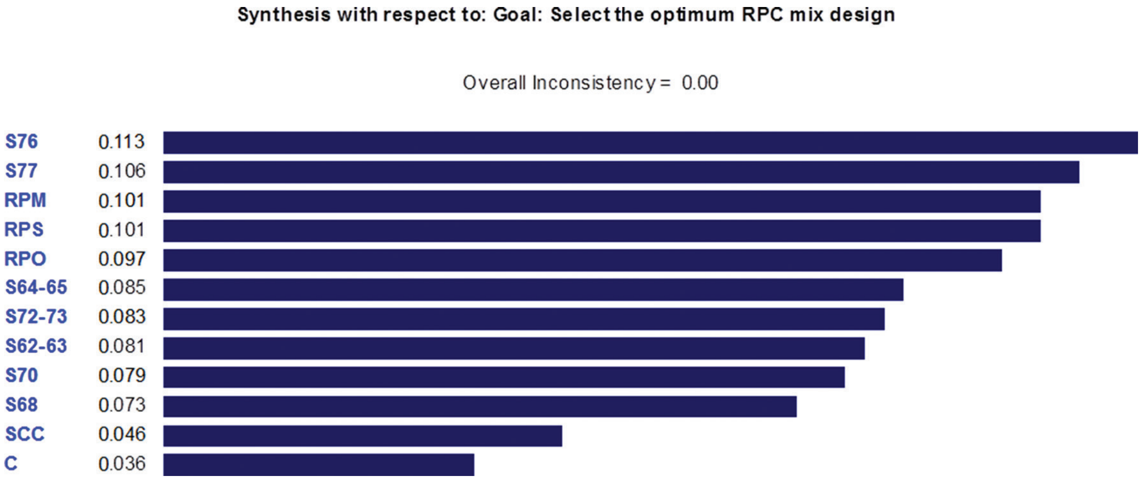

Fig. 2: Optimal mixing design with respect to the weight of the low cost effect.

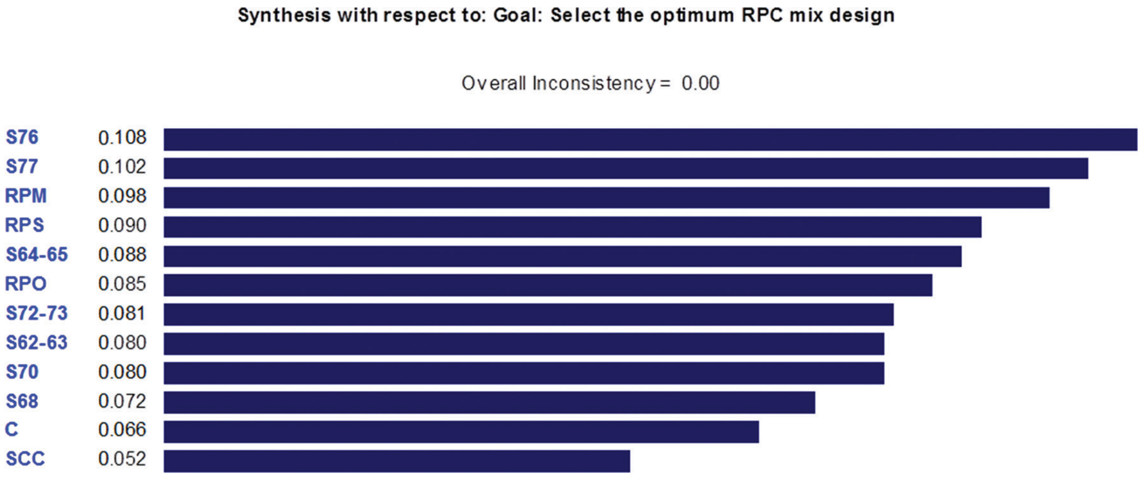

Fig. 3: Optimal mixing design with respect to the weight of the water penetration effect.

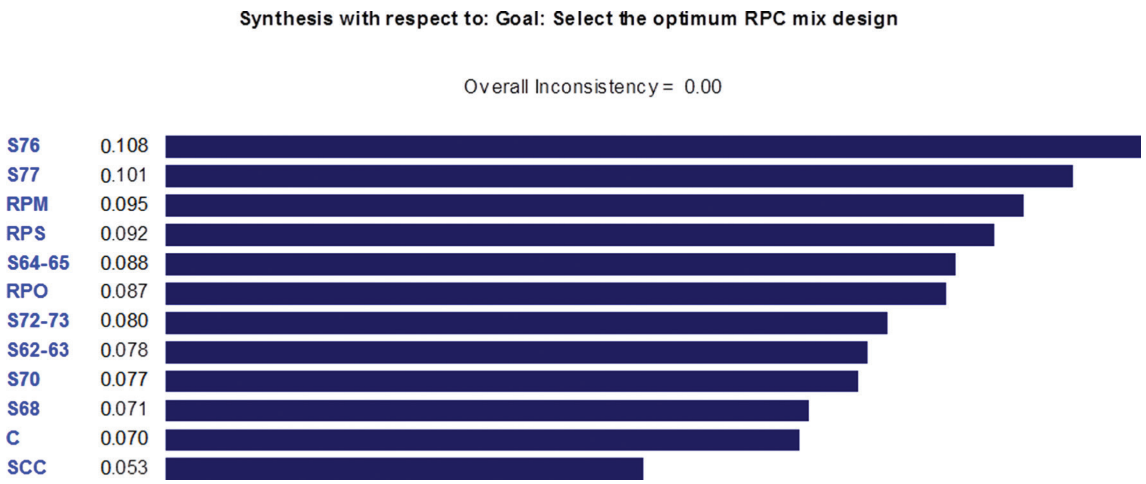

Fig. 4: Optimal mixing design with respect to the weight of the surface resistivity effect.

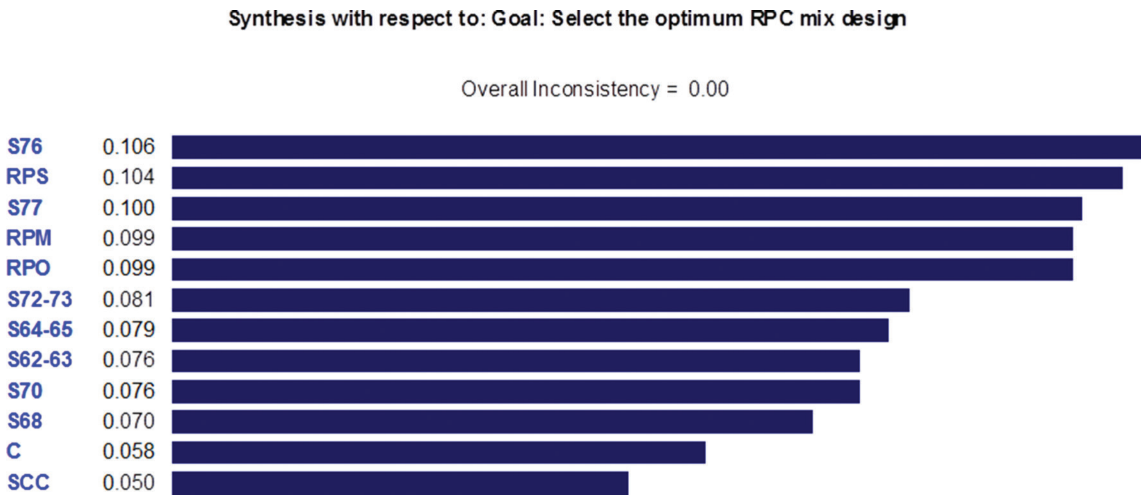

Fig. 5: Optimal mixing design with respect to the weight of the modulus of elasticity effect.

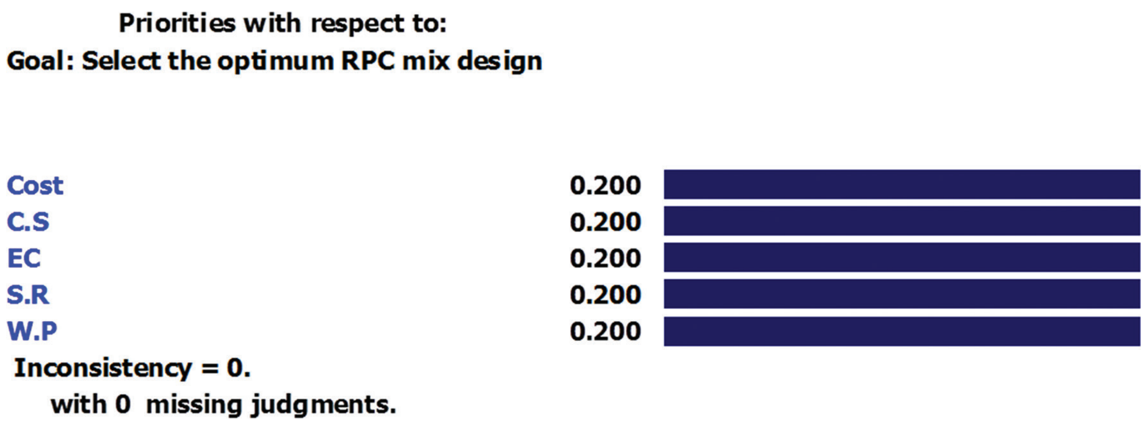

Fig. 6: Equal weighting between the criteria.

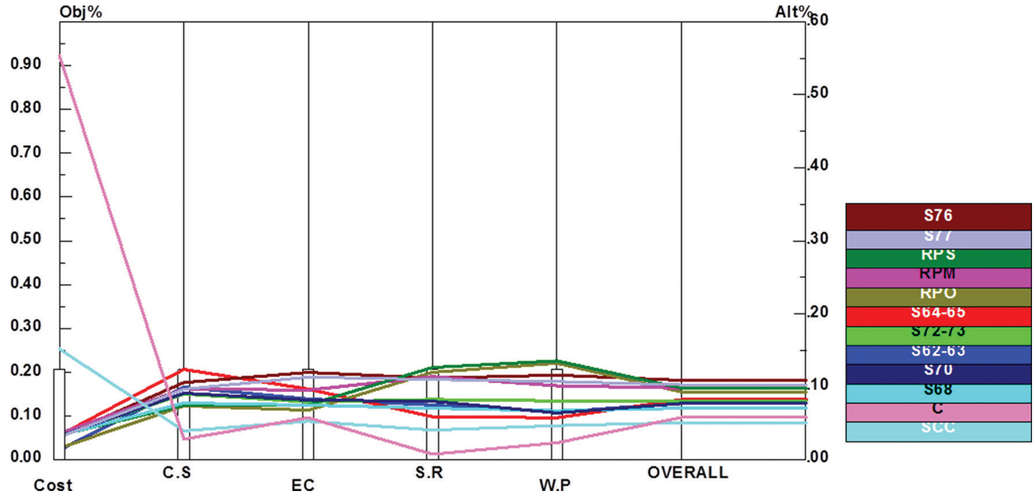

Fig. 7: Performance sensitivity of the options.

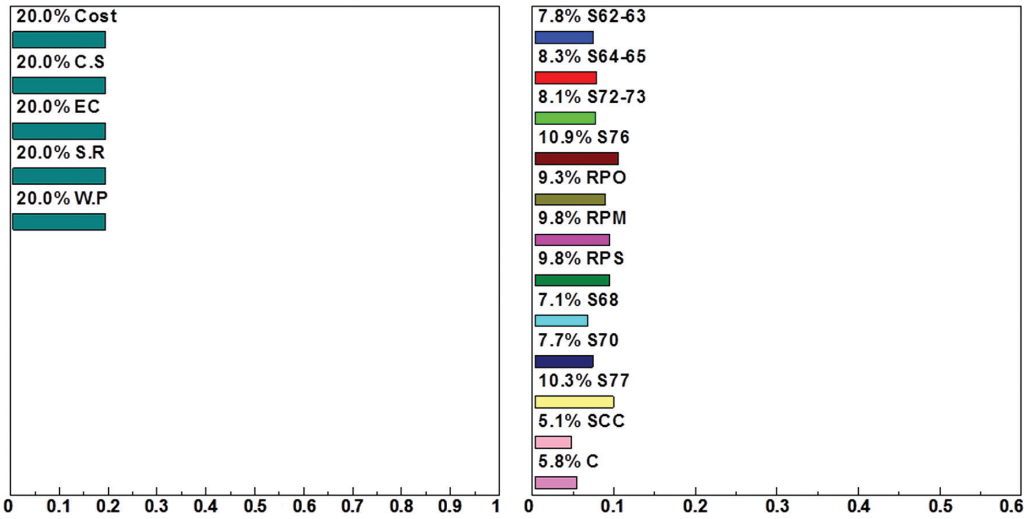

Fig. 8: An example of the dynamic sensitivity of the options.

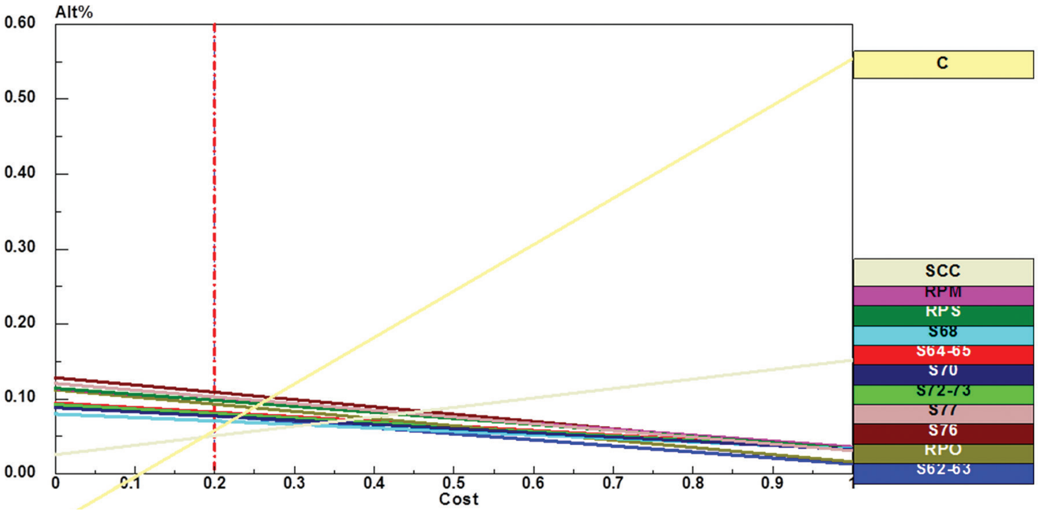

Fig. 9: The gradient sensitivity of the options.

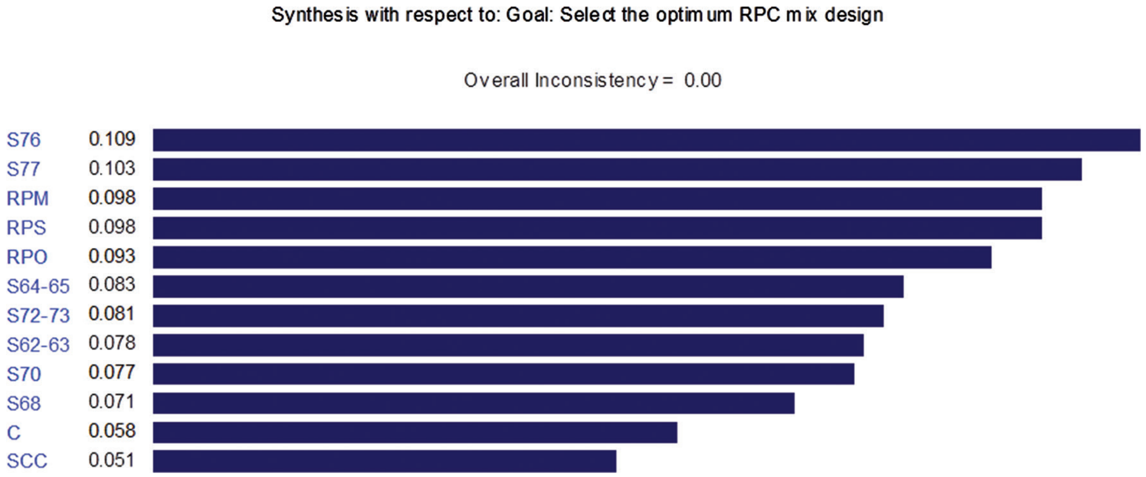

Fig. 10: Optimal mixing design with equal weighting between the criteria.

Tab. 7: Optimal framework for mixing design of the concrete.

No.	Optimum mixture	Aggregate	Cement (kg)/ type	Silica fume (kg)	Powdered nanaosilica (kg)	Colloidal nanosilica (kg)	Concrete
1	S76	Quartz (0–75 µm)	900/II	165	–	18	RPC
2	S77	Quartz (0–1 mm)	900/II	165	–	18	MRPC
3	RPM	Quartz + sand (0–1 mm)	900/II	165	–	18	
4	RPS	Quartz (75 µm–6 mm)	900/II	165	–	18	
5	RPO	Quartz + Ottawa (0–75 µm)	900/II	165	85–165	18	RPC
6	S64-65	Sand (0–75 µm)	900/V	180	18	18	
7	S72-73	Crystal sand (0–75 µm)	900/II	180	–	18	
8	S62-63	Ottawa sand	900/II	225	90	9	
9	S70	Crystal sand (0–5 mm)	900/V	180	18	18	MRPC
10	S68	Sand (0–5 mm)	900/V	180	18	18	
11	C	Gravel + sand	900/II	–	–	–	C
12	SCC	Gravel + sand	900/II	60–70	74–120	–	SCC

mix designs have very good results with a slight difference, and MRPC can be used in many cases.

Of course, a dynamic and practical framework was proposed as the main purpose of the search in the software, which can achieve optimal mixing design by changing the weighting or adding criteria.

5 Conclusions

According to the results of the Expert Choice software in different weighting, the optimal arrangement of the proposed mix design was minimized, and the success of the proposed MRPC mix design was proved. The benefits and results of the MRPC mix design are similar, compared to RPC. From the practical point of view, the ease of using MRPC is incomparable and very desirable. According to the final results, although the optimal design of the S76 is an RPC, the next three preferred designs are MRPC, indicating that, depending on the expected mode of performance, this kind of concrete can be selected, and the cost of production and operation can be selected.

It is important to note that, a quartz aggregate is the top priority for optimal designs. Type II cement is observed in the optimal mixing design, and Type V cement is of lower priority. In the optimal mixing design, 165 kg of silica fume is used per cubic meter of concrete, and more of it is in lower priorities. As a result, 18.33% of silica fume based on the weight of cement is a desirable content. Due to the lower cost of ordinary concrete compared to SCC, yielding result with only a slight difference, the priority of ordinary concrete over SCC is higher. The optimized mix designs of powdered nanosilica were not used.

As a result, a dynamic and practical framework is presented using the Expert Choice software with regard to an optimal RPC mix design.

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References

Abid, M., Hou, X., Zheng, W., & Raja, R. H. (2017). High temperature and residual properties of reactive powder concrete – A review, *Construction and Building Materials, 147*, pp. 339-351.

ACI 238.1R (2008). Report on Measurements of Workability and Rheology of Fresh Concrete.

Ahmadvand, M., Hoornahad, H., & Moghaddam, F.Gh. (2006). Plural approach to values of “Strength durability” in concrete. The first international conference concrete in recent advances in concrete technology Washington, DC, USA.

Andrade, C., Sanjuan, M. A., & Alonso, M. C. (1993). Measurement of chloride diffusion coefficient from migration tests. *Proceedings of the NACE Corrosion, 93*, pp. 289-298.

ASTM C1240 (2015). Standard specification for the use of silica fume as a mineral admixture in hydraulic cement concrete. *Mortar, and Grout, 4*(2), pp. 1-7.

ASTM C150 (2015). Standard Specification for Portland Cement. ASTM International.

ASTM C 1260 (2015). Standard Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method). ASTM international.

ASTM C39/C39M (2015). Standard test method for compressive strength of cylindrical test specimens. 4(2), pp. 1-9.

ASTM C494/C494 M (2018). *Standard Specification for Chemical Admixtures for Concrete*. ASTM International, West Conshohocken, PA, 10pp.

Aydın, S., Baradan, B. (2013). Engineering properties of reactive powder concrete without Portland cement. ACI Materials Journal.

Ban, F. S., Ayad, A. R., & Mohannad, H. S. (2018). Properties of reactive powder concrete with different types of cement. *International Journal of Civil Engineering and Technology, 9*(10), pp. 1313-1321.

BS EN-12390-8 (2000). Depth of Penetration of Water Under Pressure, British Standards Institution.

Chithra, S., Senthil, K., & Chinnaraju, K. (2016). The effect of Colloidal Nano-silica on workability, mechanical and durability Properties of High Performance Concrete with Copper slag as partial fine aggregate. *Construction and Building Materials, 113*, pp. 794-804.

Cwirzen, A. (2007). The effect of the heat-treatment regime on the properties of reactive powder concrete. *Advances in Cement Research, 19*(1), pp. 25-33.

Cwirzen, A., Penttala, V., & Vornanen, C. (2008). Reactive powder based concretes Mechanical properties, durability and hybrid use with OPC, Concretes Mechanical Cement and Concrete Research.

Danna, W., Wei, Z., Yanfeng, R., Xun, Y., & Baoguo, H. (2018). Enhancements and mechanisms of nanoparticles on wear resistance and chloride penetration resistance of reactive powder concrete. *Construction and Building Materials, 189*, pp. 487-497.

FM 5-578. (2004). Florida method of test for concrete resistivity as an electrical indicator of its permeability.

Grzeszczyk, S., Matuszek-Chmurowska, A., Černý, R., & Vejmelková, E. (2018). Microstructure of reactive powder concrete. *Cement, Wapno, Beton, 1*, pp. 1-15.

Hongfang, S., Zishanshan, L., Shazim, A. M., Qiwu, Z., Yaocheng, W., Bing, L., et al. (2015), Influence of ultrafine 2CaO SiO_2 powder on hydration properties of reactive powder concrete. *Materials, 8*, pp. 6195-6207

Ju, Y., Liu, J., Liu, H., Tian, K., & Ge, Z. (2016). On the thermal spalling mechanism of reactive powder concrete exposed to high temperature: Numerical and experimental studies. *International Journal of Heat and Mass Transfer, 98*, pp. 493-507.

Kadhem, E., Ali, A., & Tobeia, S. (2018). Experimental comparative study of reactive powder concrete: Mechanical properties and the effective factors. *MATEC Web of Conferences, 162*, 04004.

Kessler, R. J., Powers, R. G., Vivas, E., Paredes, M. A., & Virmani, Y. P. (2008). Surface resistivity as an indicator of concrete chloride penetration resistance. In: *Proceedings of the Concrete Bridge Conference*.

Kushartomoa, W., Balib, I., & Sulaimana, B. (2015). Mechanical behavior of reactive powder concrete with glass powder substitute. *Procedia Engineering, 125*, pp. 617-622.

Liu, X., & Zhang, M. H. (2010). Permeability of high-performance concrete incorporating presoaked lightweight aggregates. *Magazine of Concrete Research, 62*(2), pp. 79-89.

Maroliya, M. K. (2012). Mechanical behavior of modified of reactive powder concrete. *IJERA, 2*(5), pp. 2062-2067.

Moghaddam, F. G. H. (2008). Investigating effective of the Nano material on self consolidating concrete SCC. In: *The Second International Nano Technology Conference*, Iran.

Moghaddam, F. G. H. (2014). Investigation of effective super-plasticiser admixtures in mechanical properties of no-slump concrete. In: *2nd International Conference on Advances in Chemically Activated Materials*, Changsha, China.

Najim, A. A., Haider, A.H., & Adnan, Q. T. (2016). Variation in the mechanical properties and temperature of modified reactive powder concrete. *IJCIET, 7*(5), pp. 457-465.

Polder, R. B. (1997). Chloride diffusion and resistivity testing of five concrete mixes for marine environment. In: *Proceedings of the RILEM International Workshop on Chloride Penetration into Concrete*, St-Remy-les-Chevreuses, RILEM.

Polder, R. B., & Peelen, W. H. A. (2002). Characterization of chloride transport and reinforcement corrosion in concrete under cyclic wetting and drying by electrical resistivity. *Cement and Concrete Composites, 24*(5), 427-435.

Rahmani, H., Ramazanianpour, A. A. (2008). Effect of binary cement replacement materials on sulfuric acid resistance of dense concretes. *Magazine of Concrete Research, 60*(2), pp. 145-155.

Ramezanianpour, A. A., Ghiasvand, E., Nickseresht, I., Mahdikhani, M., & Moodi, F. (2009). Influence of various amounts of limestone powder on performance of Portland limestone cement concretes. *Cement and Concrete Composites, 31*(10), 715-720.

Ramezanianpour, A. A., Mahdikhani, M., & Ahmadibeni, G. (2009). The effect of rice husk ash on mechanical properties and durability of sustainable concretes. *International Journal of Civil Engineering, 72*, 83-91.

Ramezanianpour, A. A., Pilvar, A., Mahdikhani, M., & Moodi, F. (2011). Practical evaluation of relationship between concrete resistivity, water penetration, rapid chloride penetration and compressive strength. *Construction and Building Materials, 25,* pp. 2472-2479.

Sujatha, T., & Basanthi, D. (Jan-June, 2014). Modified reactive powder concrete. *International Journal of Education and Applied Research, 4*(Spl-2).

Tam, C. M., Tam, V. W. Y., Ng, K. M. (2012). Assessing drying shrinkage and water permeability of reactive powder concrete produced in Hong Kong. *Construction and Building Materials, 26*(1), pp. 79-89.

Tao, J., Yu, Y., Mao-Yuan, F., Bao-chun, C., & Hwai-Chung, W. (2017). Optimum design of reactive powder concrete mixture proportion based on an artificial neural network (ANN) and harmony search (HS) algorithm. *ACI Materials Journal, 114*(1), pp. 41-47, 7p.

Wang, D., Shi, C., Farzadnia, N., Shi, Z., & Jia, H. (2018). A review on effects of limestone powder on the properties of concrete. *Construction and Building Materials, 192*, pp. 153-166.

Author biographies

ACI member Farid Ghaffari Moghaddam is a PhD candidate at the Department of Engineering and Construction Management, Science and Research Branch, Islamic Azad University, Tehran, Iran. He received his BS and MS in Structural Engineering from the Islamic Azad University, South Tehran Branch, in 2003 and 2006, respectively. He is also a member of board of directors of the ACI, Iran chapter, since 2010. His research interests include ultrahigh-performance concrete, as well as concrete technology.

ACI member Abbas Akbarpour is an Assistant Professor at the South Tehran Branch, Islamic Azad University, Tehran, Iran. He received his MS and DSC in Structural Engineering and Structures & Dynamics from the George Washington University in 1980 and 1987, respectively. He is also a member of the board of directors of ACI, Iran chapter, since 2000. His research interests include structural reliability and fatigue propagation in concrete, as well as concrete technology.

Afshin Firouzi is an Assistant Professor at the Science and Research Branch, Islamic Azad University, Tehran, Iran. He received his PhD and Postdoctoral degree in Engineering and Construction Management from the Amir Kabir University in 2010 and RMIT Melbourne University in 2014, respectively.