

Impact Response Analysis of NNRG and RSNN Concrete Structures

Navid Mohammadnia^{1*}, Hadi Mahdizad Nami²

¹ MA graduate, structure, Industrial Sahand University, Tabriz, Iran.

² MA graduate, marine structures, Industrial Sahand University, Tabriz, Iran.

ABSTRACT

Plain concrete is a heterogeneous material (containing fine cement to coarse sand aggregates) in which aggregates are harder than paste. Unlike plain concrete, RPC exhibits high ductility and energy absorption due to the presence of steel fibers. Due to its excellent strength properties, this study examines the impact strength (aka impact toughness) of this concrete and compares it with other types of widely used concrete. Experimental specimens include steel fiber reinforced reactive powder concrete (SFR-RPC) specimen without reinforcement and FRP coating (RSNN) and plain concrete specimen without steel fibers with reinforcement and GFRP coating (NNRG). Specimens consist of concrete beams of dimensions 120 cm × 120 cm × 120 cm. Due to their reaction to free fall of weight from a constant height, they provide information that can be considered as a good basis for comparing the impact performance of concrete. The image processing software is used to measure and compare the behavior of beams.

Keywords: Reactive Powder Concrete (RPC), High-Strength Concrete, Steel Fibers, Impact, Image Processing Software

Corresponding author: Navid Mohammadnia

e-mail ✉ navid.mohammadnia66@gmail.com

Received: 06 September 2020

Accepted: 12 December 2020

1. INTRODUCTION

Specific structures such as nuclear power plants are built in areas far from surrounding structures and transport lines. Distance is considered to be one of the most important risk-reducing factors due to high-strain dynamic loads such as explosions, while it is not possible to create such distances for conventional commercial and residential structures as well as bridges. Therefore, it is important to examine the behavior of different structural members (e.g., beams, columns, and slabs) against such loads. Projectiles are obtained, directly or indirectly, at all of the unconventional loads above; the major damage caused to the structure is due to the impact of these projectiles. For example, as a result of the bomb blast, the chips from the bomb bay explosion, as well as the collision of high-pressure (HP) front with peripheral objects, causes a series of projectiles with different speeds and energies. RPC is a type of concrete with high strength, low porosity, and high ductility. RPC constituents include cement, fine quartz sand, cracked quartz, microsilica, steel fibers, and superplasticizer. In addition to high strength, RPC also has other specifications such as low permeability, high wear and corrosion resistance, and high durability, all of which are considered valuable in the concrete construction industry. Moreover, RPC is of interest because it reduces structural weight and is highly resistant to blast or impact loading (Malik and Foster, 2010).

A limited number of structures have so far been built by RPC worldwide, mostly footbridges. In construction, an RPC with ready-mixed solids available in the market in packages is used, known as ductal.

Materials should be used to build unconventional-load-resistant structures capable of absorbing and dissipating

energy, exhibiting appropriate behavior against local breakdowns, in addition to adhering to design criteria and using non-engineering approaches (e.g., fencing and separation of structures from transport lines) in the prevention and reduction of casualties and damages. Military and civil engineers Concrete have long been focused and still are focused on concrete as one of the appropriate materials for the design and construction of projectile impact/explosion-resistant structures. Various breakdowns may occur in reinforced concrete structures due to their type (i.e., beam, column, and slab), impact velocity, and projectile deformation (Li et al., 2005).

Many studies have been conducted to date on the behavior of different structural members (e.g., beams, columns, and slabs) under different loadings such as projectile impact and retrofitting of reinforced concrete structures against static and quasi-static loads. Nevertheless, few studies have been conducted on the behavior of FRP-retrofitted reinforced concrete structures against the projectile impact load. There are a handful of articles in the scientific literature in this regard.

Mohammad and Parvin (2011) conducted a study on the retrofitting of reinforced concrete beams against projectile impact load. In this study, reinforced concrete beams were retrofitted using a U-shaped CFRP composite. Furthermore, beam dimensions, material specifications, reinforcement type, and loading type/method were selected according to the specifications and conditions of the study by Fujikake et al. (2009) to compare the results. This research has used LS-DYNA for finite element modeling (Mohammad and Parvin, 2011).

Saadatmanesh and Tang (2003) performed an in-vitro study on the effect of retrofitting with various fibers on the dynamic behavior of reinforced concrete beams. In this study, reinforced concrete beams were retrofitted using carbon and

aramid (Kevlar) fibers. Besides, a 9.5mm diameter rebar is used to reinforce the beams. Shear bars are not used in beam reinforcement due to a high ration of beam cross-section height to beam length. In this study, beams were loaded by a cylindrical weight of 127 mm in two ways, namely, the fall of weight and the successive fall from a given height. The dynamic load cell is also used to measure the support reaction at one of the beam supports (Erki and Meier, 1999).

Erki and Meier (1999) conducted a study on the retrofitting of reinforced concrete beams against an impact-induced dynamic load. In this study, reinforced concrete beams, with cross-section and reinforcement, were reinforced by CFRP composite (i.e., BF1 and BF2 beams) and steel sheet (1G and 2G). In CFRP composite-retrofitted beams, the total tensile strength of these sheets is equal to the tensile strength of the steel sheet. These beams are loaded so that one end of the beam is released from different heights and the other end is connected to the support articularly (Fujikake et al., 2009).

Kaouzunori Fujikake, Tukanori Senga et al. conducted a study on the impact response of an RPC beam and its analytical model. This study aims to conduct an in-vitro evaluation of the impact response of an RPC beam and develop an analytical model to determine its impact response. For this purpose, a drop hammer test is performed to examine the impact of the hammer height on the impact response of the RPC beam. Then, a loading test is performed to determine the residual load-bearing capacity of the RPC beam. In the impact analysis, the mass-spring-damper system model with two degrees of freedom is considered. Given high local damping for the impact site, the analytical results would be more consistent with the experimental results (Fujikake et al., 2009).

Kishi et al. (2002) conducted a study on the behavior of concrete beams without a shear bar against the projectile impact load. In this study, about 27 beams were loaded under the weight of 300 kg from different heights to investigate the behavior of reinforced concrete beams without shear reinforcement. The beams are divided into different series based on variations in the values of the ratio of net span to effective height (a/d), static shear strength to static flexural strength (α), beam net span length, and diameter of bars, with their ends, welded to a steel plate to prevent the bars from sliding inside the concrete (Kishi et al., 2002).

Nowadays, there is a need to evaluate, revise, and redesign existing structures to retrofit them if necessary due to various factors such as changing loading codes, changing usages, damage, or lack of proper implementation. Given the unique properties of RPCs, this study investigated the role of using this type of new concrete in the impact behavior of a structure.

2. MATERIALS AND METHODS

RPC has just been introduced in our country. Therefore, this study investigated its behavior in response to impact loading. For this purpose, two types of experimental specimens have

been used to compare impact responses. Experimental specimens include SFR-RPC specimen without reinforcement and FRP coating (RSNN) and plain concrete specimens without steel fibers with reinforcement and GFRP coating (NNRG).

It should be noted that the reinforcement used in specimens are in shear and longitudinal forms 6mm in diameter. Furthermore, GFRP is bonded around the specimens for shear strength. Comparing the impact behavior of each of these specimens yielded useful results and will gain more initiative in similar future projects.

RPC Mix Design

Table 1 shows the materials used for the RPC.

Table 1: RPC mix design

Material	Amount (kg/m ³)
Cement	850
Silica sand	935
Silica powder	180
Microsilica	212.5
Superplasticizer	45
Water	204

Table 2: Plain non-fibrous concrete mix design

Material	Amount (kg/m ³)
Cement	300
Water	150
Sand	1050
Pea gravel	534
Almond sand	356

RPC Construction Method

The mixing process of this concrete is very important and should be done with greater consideration. After dry materials are mixed, water and superplasticizer are added and mixed; finally, steel fibers are added and mixed. This mixing should be done so that the resulting mixture is completely homogeneous. Temperature plays an important role in the curing of this concrete. According to research, an improvement in many of the properties of RPC is achieved through high-temperature curing. Specimens can also be pressurized before and during the setting, which in turn affects its specifications. Curing at temperatures of 20-90°C yields a concrete with a strength of 200 MPa. Specimen strength can increase up to 800 MPa under pressure at temperatures above 200°C. Pressurized specimen eliminates entrapped air and increases specimen density. RPC 800 requires pre-setting pressure and curing at 250°C and can be used solely for ready-made elements. It also has high impact resistance, applicable to military structures and equipment (Richard and Cheyrez, 1995).

The newly mixed RPC can be considered as mortar.

The cement used for the RPC is 1-525 type of Shahr-e Kord cement, whose physical and chemical specifications are presented in the following tables.

Table 3: Physical specifications of 1-525 type of Shahr-e Kord cement

Standard	Blaine Cm ² /g	Setting Time-Min		Compressive Strength(kg/Cm ²)				%Autoclave Expansion
		First	Last	Day2	Day3	Day7	Day28	
ISIRI-389	≥2800	≥45	≤360	≥200	---	---	≥525	≤0.8

ASTM	---	---	---	---	---	---	---	---
BS EN 197-1	---	≥45	---	≥200	---	---	≥525	---
Shahrekord cement	≥3200	85-110	110-190	≥200	≥240	≥350	≥530	≤0.20

Table 4: Chemical specifications of 1-525 type of Shahr-e Kord cement

Standard	SiO2	AL2O3	Fe2O3	CaO	MgO	SO3	CL	InR	L.O.I	Total Alkali	F.Cao
ISIRI-389	-	-	-	-	≤5.0	≤3.0	-	≤0.75	≤3.0	-	-
ASTM	-	-	-	-	-	-	-	-	-	-	-
BS EN 197-1	-	-	-	-	-	≤4.0	≤0.10	≤5.0	≤5.0	-	-
Shahrekord cmenet	20.70-21.10	5.10-5.40	3.80-3.95	65.00-65.40	≤1.65	≤2.0	≤0.03	≤0.65	≤1.30	≤0.70	≤1.30

The silica sand used in this project is less than 0.7 mm in diameter, manufactured by Babak Silica Co.

The silica powder used in this study is of mesh 120 type with the lowest alkali content so that concrete does not lose its hardness in the long run.

The microsilica used in this study is the microsilica from Azna-Lorestan whose specifications are presented in the following tables.

Table 5: Specifications of microsilica used in the project

Factory Name	Azna (Lorestan)
Structure	Amorphous
Particle shape	Spherical
Approximate diameter	0.1 μm
Specific surface area	Approximately 20 m ² /gr
Bulk specific gravity	3250 Kg/m
Color	Light gray to white
Moisture content	Up to 3%
Maintenance	In a dry, covered area

Table 6: Chemical composition microsilica from Azna-Lorestan

Material	H ₂ O	SiC	C	SiO ₂	Fe ₂ O ₃	Al ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅	SO ₃	CL	LO1750C
%	0.8	0.5	0.3	96.4	0.87	1.32	0.49	0.97	0.31	1.01	0.16	0.1	0.04	0.94

The superplasticizer used in this study is a FARCO PLAST P10-3R. P10-3r, a modified third-generation modified polycarboxylate-based superplasticizer, has been manufactured while retaining the concrete slump properties in the long run. The mechanism of action of this superplasticizer is as follows:

Steel fibers were used in this study, manufactured at the Gmbh & Co.KG Co., whose strength properties are presented in Table 8.

Table 7: Strength properties of steel fibers

Tensile Strength	>1.200N/mm ²
Gross Density	7.85 kg/dm ³
Number of bending	≥ 2
Bending Angle	180°
Storage temperature	20 ~ 60 ° C

Impact Test

Experimental specimens include concrete beams of dimensions 120 cm × 20 cm × 10 cm. Numerous specimens have been fabricated from each of the types of concrete tested, with varied responses under impact tests. A device was constructed according to Figure 1 to perform the impact test. The weight used in the test is 115 kg, which is dropped on the specimen from a height of 30 cm. The device is designed such that the

supports at both beam heads function in a simple articulated manner.

The number of impacts, beam cracking, longitudinal strain, and beam deflection can be considered as some good criteria to discuss their impact behavior.

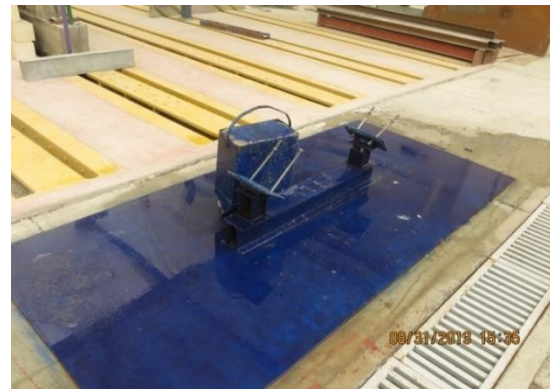


Figure 1: Schematic of the experimental setup

Image Processing Software

Image processing was inevitably used due to the inaccessibility of the dynamic strain gauge to determine longitudinal strains and beam deflections. To do so, we coded how to convert video

into multiple frames and follow the process of changes in the coordinates of each frame's points in MATLAB. Useful results were obtained with an acceptable error by filming each test with a 1200 fps video camera and introducing it to the program.

3. RESULTS AND FINDINGS

Different aspects of the impact response of various types of concrete can be studied according to the results obtained by image processing software. As the results were reviewed, several graphs were drawn to illustrate the trend of changes in the longitudinal strain for each impact on the concrete beam. Furthermore, three bar graphs are drawn for an overall comparison of concrete specimens. No deflection or strain is defined for specimens broken by the first impact. It should be noted that these graphs represent the average laboratory results for each specimen.

Unlike non-fibrous-reinforced RPC, SFR-RPC endures three impacts. The only reason for this remarkable difference is the presence of steel fibers. The application of steel fibers greatly improves the properties of RPC. The cracks created by the first impact for RPC concrete are very fine and can be seen as capillary with a slight consideration of beam height. Besides, its longitudinal strain and initial deflection are negligible compared to other specimens.

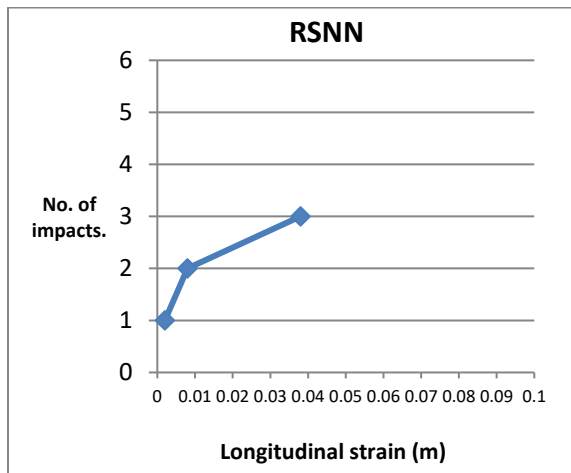


Figure 2: Longitudinal strain-impact graph for RSNN concrete

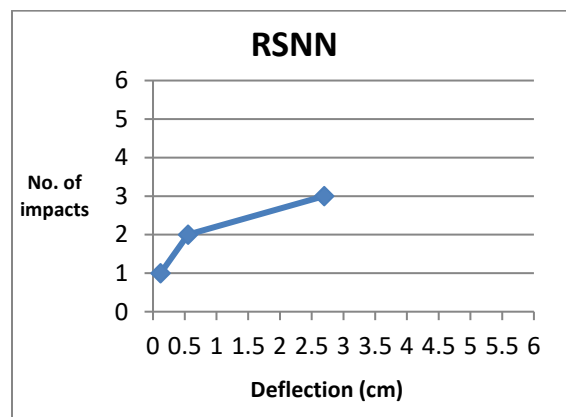


Figure 3: Concrete deflection-impact graph for NNRN concrete

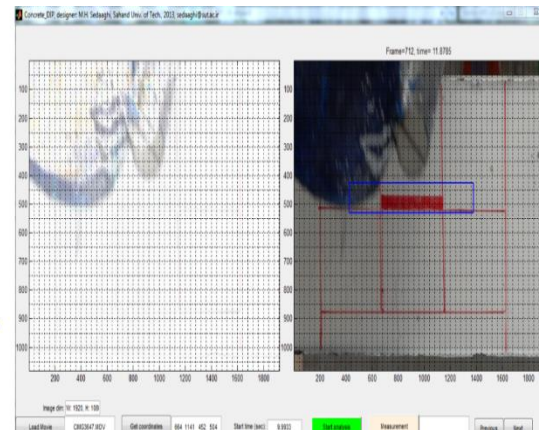


Figure 4: Software output for the first impact of RSNN Concrete

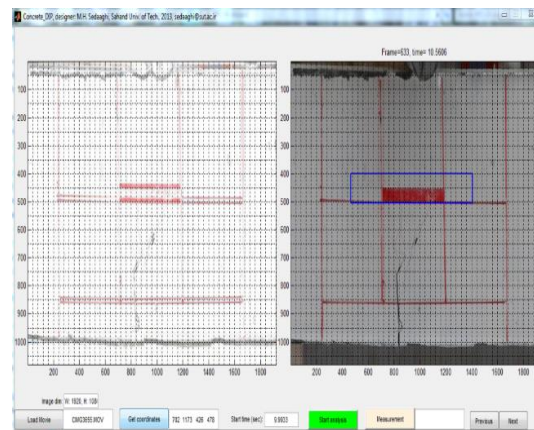


Figure 5: Software output for the second impact of RSNN Concrete

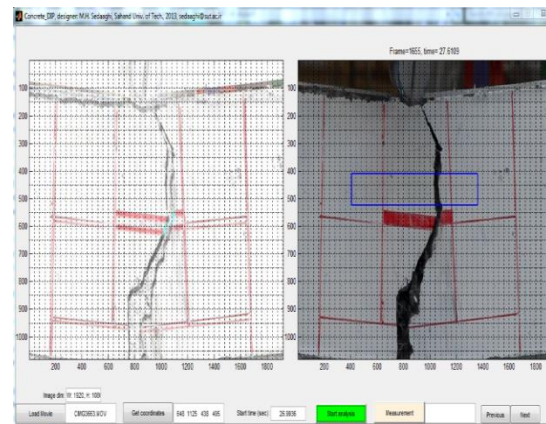


Figure 6: Software output for the third impact of RSNN Concrete

NNRG concrete is the only FRP-reinforced specimen, of which the type of FRP is glass. It is reinforced so that it has the highest performance concerning shear strength. That is, FRP shows no resistance to flexural failure. As shown in Figure 7, the NNRG specimen is broken by five impacts. This type of FRP reinforcement seems to have little impact on the impact response.

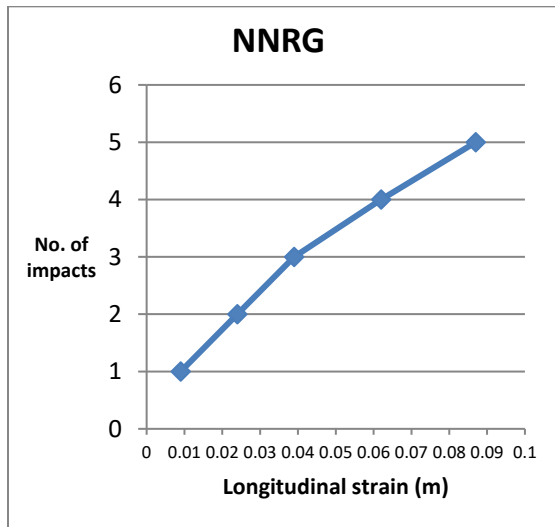


Figure 7: Longitudinal strain-impact graph for NNRG Concrete

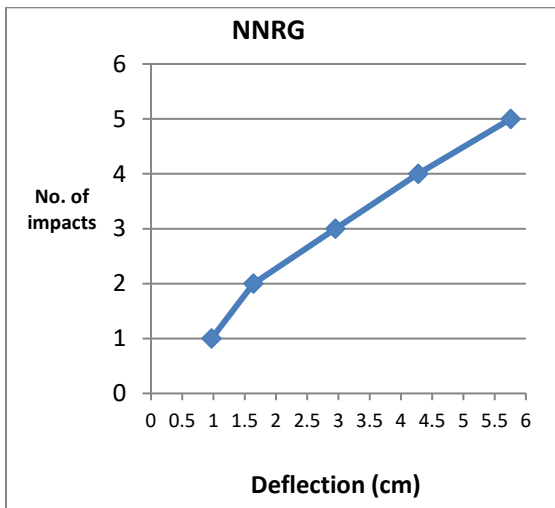


Figure 8: Concrete deflection-impact graph for NNRG Concrete

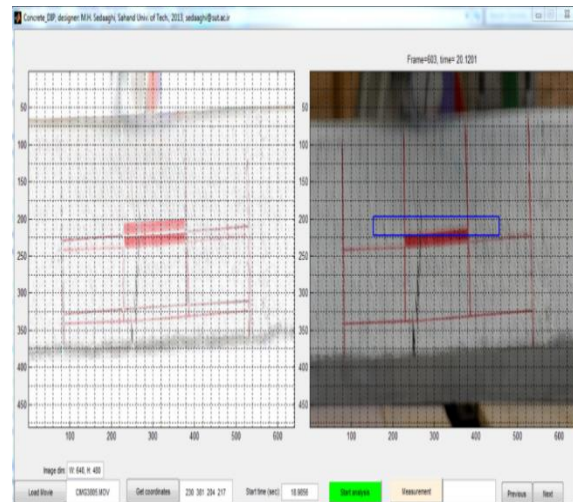


Figure 10: Software output for the second impact of NNRG Concrete

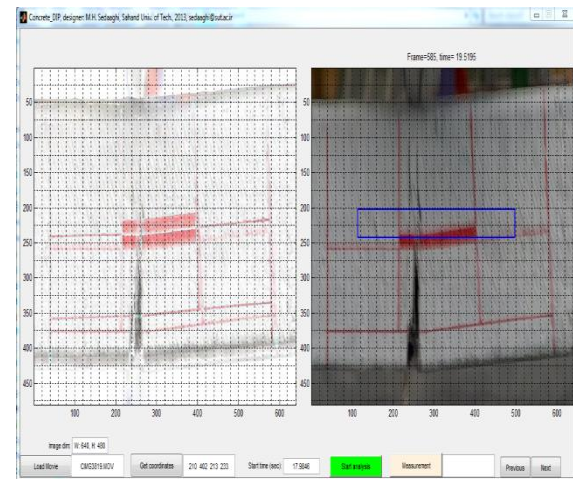


Figure 11: Software output for the third impact of NNRG Concrete

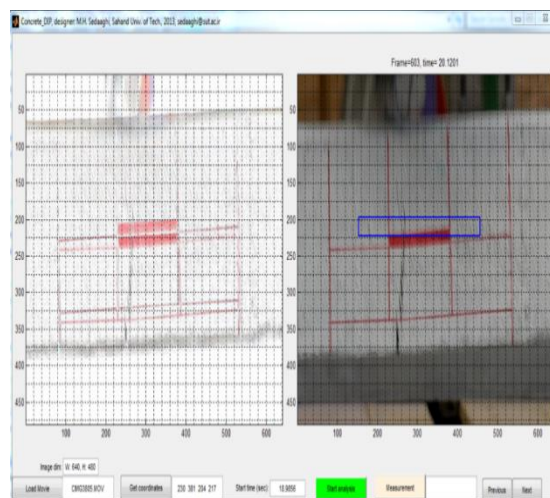


Figure 9: Software output for the first impact of NNRG Concrete

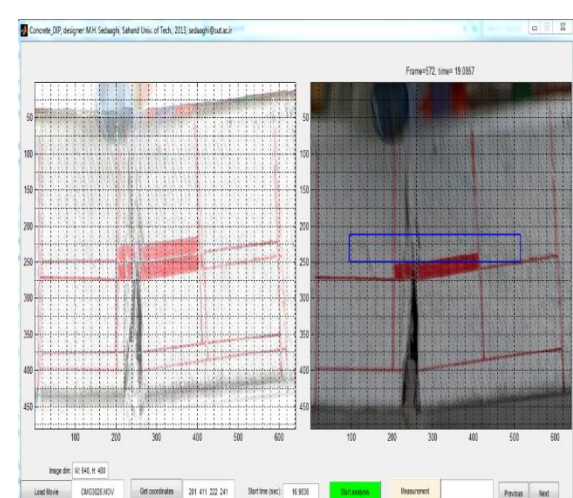


Figure 12: Software output for the fourth impact of NNRG Concrete

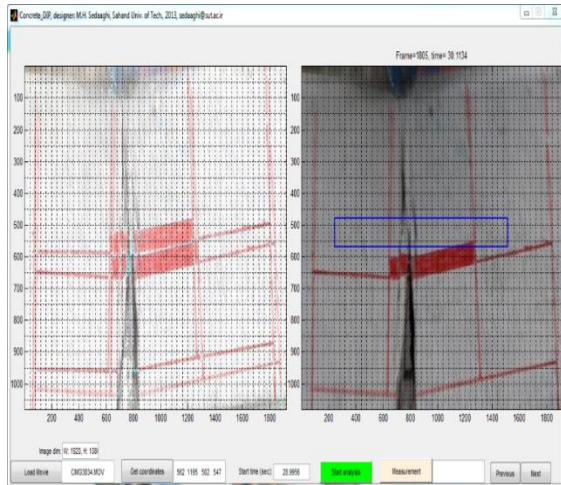


Figure 13: Software output for the fifth impact of NNRG Concrete

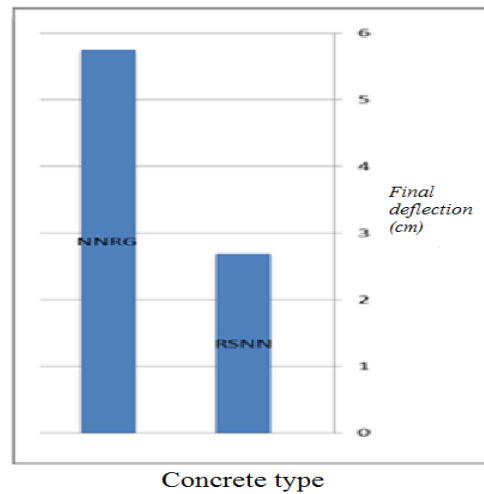


Figure 16: Comparative diagram of concrete type-final deflection

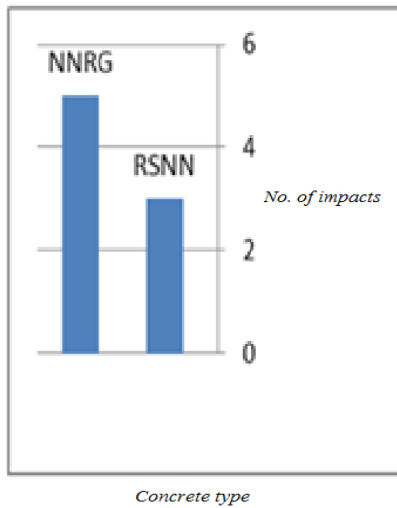


Figure 14: Comparative diagram of concrete type-number of impacts
(Caption: /)

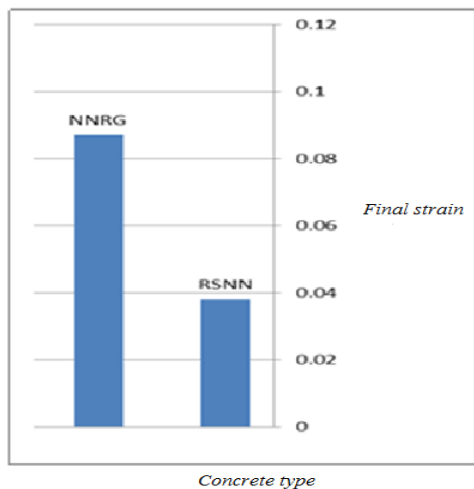


Figure 15: Comparative diagram of concrete type-final strain

4. DISCUSSION AND CONCLUSION

The importance of the application of fibers in RPC is illustrated by the comparison between SFR-RPC and non-fibrous-reinforced RPC. Non-fibrous-reinforced RPC is easily broken by the first impact, while its impact strength is greatly enhanced by the addition of fibers, which is resistant to a third impact.

It is conceivable that the high-strength concrete specimen is a non-reinforced concrete that utilizes the same fibers used in the RPC having similar conditions to this concrete, easily broken by the very first impact. This means that the fiber performance depends on the concrete mix design, although the fibers play an important role in the concrete performance against impact load. Hence, it can be said that the fibers used and the concrete mix design should supplement each other concerning efficiency to achieve the desired results.

It can be stated that the non-fibrous-reinforced RPC lacks the properties required for impact behavior, capable of exhibiting its unique specifications only in the presence of fibers. As can be seen from Figures 7 and 8, SFR-RPC exhibits a very slight longitudinal strain in response to the first impact, not observed in any of the other specimens, an example of the SFR-RPC strength behavior against impact. Since reinforcements have not been used in RPCs and considering the impact strength of SFR-RPC up to the third impact, RPC can be definitively considered as an impact-resistant concrete. It should also be noted that RPC does not perform well against the impact in the absence of fibers.

In general, according to the experimental results, it can be claimed in the first place that reinforcements play a strong role against impacts resulting in flexural failure, and in the second place, the role played by the fibers. However, the important point is the efficiency of the fibers and the concrete constituent materials, which must be considered.

REFERENCES

1. Erki MA, Meier U. Impact loading of concrete beams externally strengthened with CFRP laminates. Journal of Composites for Construction. 1999 Aug;3(3):117-24.

2. Fujikake K, Li B, Soeun S. Impact response of reinforced concrete beam and its analytical evaluation. *Journal of structural engineering*. 2009 Aug;135(8):938-50.
3. Fujikake K, Senga T, Ueda N, Ohno T, Katagiri M. Study on impact response of reactive powder concrete beam and its analytical model. *Journal of advanced concrete technology*. 2006;4(1):99-108.
4. Kishi N, Mikami H, Matsuoka KG, Ando T. Impact behavior of shear-failure-type RC beams without shear rebar. *International Journal of Impact Engineering*. 2002 Oct 1;27(9):955-68.
5. Li QM, Reid SR, Wen HM, Telford AR. Local impact effects of hard missiles on concrete targets. *International Journal of impact engineering*. 2005 Dec 1;32(1-4):224-84.
6. Malik AR, Foster SJ. Carbon Fiber-Reinforced Polymer Confined Reactive Powder Concrete Columns-- Experimental Investigation. *ACI Structural Journal*. 2010 May 1;107(3).
7. Mohammed TA, Parvin A. Impact load response of concrete beams strengthened with composites. In *First Middle East Conference on Smart Monitoring, Assessment and Rehabilitation of Civil Structures*, Dubai, UAE 2011 Feb.
8. Richard P, Cheyrezy M. Composition of reactive powder concretes. *Cement and concrete research*. 1995 Oct 1;25(7):1501-11.