Al-Nahrain Journal for Engineering Sciences **NJES** 28(1)38-43, 2025
http://doi.org/10.29194/NJES.28010038

Behavior of Beams Casted with Different Types of Concrete under Monotonic Loading

Assel Qaddoori Makhool[1], Zainab A. Mohammed[2]*, Hiba Akram Atiyah[3]

Authors affiliations:
1) Civil Engineering Department, College of Engineering, Al Iraqia University, Baghdad, Iraq
aseel20071984@gmail.com

2*) Civil Engineering Department, College of Engineering, Al Iraqia University, Baghdad, Iraq
ezainab05@gmail.com

3) Civil Engineering Department, College of Engineering, Al Iraqia University, Baghdad, Iraq.
hiba.akram@aliraqia.edu.iq

Paper History:

Received: 16th Apr. 2024

Revised: 13th June 2024

Accepted: 29th July 2024

Abstract

The aim of the research work is to presents the result of experimental studies concerning the behaviour of different types of concrete beams. In this study, discus using different types of concrete for casting beams and record the effects on both mechanical properties and load versus deflection characteristics. The results shown that the maximum compressive strength is 107 MPa and the maximum splitting tensile 9 MPa of RPC comparison high and normal strength concrete. The result of the second part shown increased RPC reinforced concrete the firstcrack288 MPa and ultimate crack 380MPa comparison high and normal strength concrete and the mode of failure of RPC (flexural-shear).

Keywords: High and Normal strength concrete, Mechanical properties, Reactive powder concrete, Silica fume, Ultimate Load.

سلوك العتبات المصبوبة بأنواع مختلفة من الخرسانة تحت التحميل الرتيب

اسيل قدوري مكحول ، زينب عادل محمود ، هبة اكرم عطية

الخلاصة:

الهدف من البحث هو عرض نتائج الدراسات التجريبية المتعلقة بسلوك أنواع مختلفة من العتبات الخرسانية. في هذه الدراسة، تم استخدام أنواع مختلفة من الخرسانة لصب العتبات وتسجيل التأثيرات على كل من الخواص الميكانيكية وخصائص الحمل مقابل الانحراف. أظهرت النتائج أن أقصى مقاومة للضغط هي MPa107 وأقصى مقاومة شد انفصالية هي MPa9 للخرسانة RPC مقارنة بالخرسانة ذات القوة العالية والعادية. أظهرت نتيجة الجزء الثاني زيادة RPC للخرسانة المسلحة الشق الأول MPa288 والشق النهائي MPa380 مقارنة بالخرسانة ذات القوة العالية والعادية وكان نمط فشل RPC هو فشل (القص- الانثناء).

1. Introduction

RPC is a sort of concrete which shows excellent durability and mechanical properties [1]. Normal concrete is a heterogeneous material; in which gravel and cement exhibit unusual strength and young's modulus beneath stresses, this causes the bonds between the two components, The weakest areas in concrete lead to micro-cracks and internal flaws. Reactive Powder Concrete (RPC) operates on the idea that minimizing defects like cracks and internal voids allows the material to achieve higher strength and improved durability properties. Reactive powder concrete (RPC) is an actual concrete mixture, it is a special type of concrete because mix concrete (coarse and fine aggregate) replaced by fine sand size (150-400)µm. RPC has very fine particles like cement, silica fume, quartz powder with size fewer than 300 micron, fine sand , steel fibers of size (180) microns and (10) mm length and super plasticizer. RPC produced by concrete production methods compressive strength over160 MPa, fine frost resistance, bending strength over 20 MPa and impermeability of chloride. Produced by RPC has , low cost, light deadweight and the littler workload, use for facilities and bridge in Tibet [2]. Produce UHS (ultra-high-strength) concretes by RPC and theories packing density. After 28-day shown addition of steel fibers and higher water to binder ratio, improved the fr only in the case of ultra-high-strength mortars and the increased water uptake. The secondary main of this paper improve the mechanical properties and durability [3]. Shown RPC Samples having heat treatment at temperatures (20 °C - 250 °C) to understanding of the effect of temperature and effect silica fume shown the result dependent proved to be dependent on heat treatment temperature to improve the reactive powder concrete [4]. Concrete with high strength can be made by the addition of water-reducing admixtures that are well-known as superplasticizers and/or by using other admixtures like fly ash or silica fume with Portland cement to the concrete. Superplasticizer compounds significantly reduce the amount of water needed to produce a workable mix so that concretes with water/cement ratios of the amount less of 0.30 easily flow without extensive bleeding and segregation [5]. Use of concrete with high strength causes in designing sections with smaller dimensions, minimizing dead weights, allowing for longer spans, and getting extra buildings usable areas. In spite of concrete with high strength gets a super advantage in cost saving and performance fields, but the brittle behavior of materials is still a large problem in some treatments particularly in structures opposing for earthquakes. As the relationship between concrete ductility and strength is a reverse relation, therefore, concrete with normal strength is fewer brittle than concrete with high strength [6]. High strength concrete has been applied in many structural applications, such as in prestressed concrete beams, bridges, high rise buildings and structural repairs [7].

2. Literature Review

To understand the properties of reactive powder, shown in this few of researches. Gongale et al. [8], used conventional coarse aggregates are changed by fine sand and very low water-cement ratio, on three stage method mix. The results shown improve the compressive strength of RPC up to 150 - 200MPa and improve the concrete. Peng Zhu et al. [9] recycled powder from demolition and construction wastes in RPC, also developing environmentally-friendly and low cost- mixtures. By use recycled powder replace silica fume or cement in (RPC) to develop powder properties and maximum packing theory, the result show when used the standard curing instead of steam curing normally and the recycled reactive powder replace the silica fume and cement to increase properties the concrete. Yanzhou et al. [10] produced phosphorous slag powder, silica fume treatment in steam for a given duration with 95 °C. The results shown durability properties freeze–thaw and sulfate resistance verified excellent. Hannawayya [11] studied the flexural behavior and shown effect properties mechanical of reactive powder concrete (study the effect of Vf, Sf) theoretically special computer programs: first method, considers horizontal equilibrium of forces on the beam section (compatibility of axial strains). The second method is the finite element (a three-dimensional non-linear finite element). Shown the results increases compressive strength (38% and 16%) Vf by 2% and Sf - 5% to 15% respectively and the failure load was higher than analytical ones, except for beams having <0.0819. Voo, et al. [12] examined seven RPC reinforced deep beams. The test variables a/d, and variables percentage of silica fume. The results found both results in good agreement (results compared with model of ACI 318M-11 Code. Rohdena et al. [13] shows the mechanical properties of RPC and effect of fine quartz powder to instead of fine aggregate, also Nano silica, and inorganic pigments. In the first part, mix-proportions of RPC considering different sizes maximum aggregate (1.2- 0.6- 0.075- 0.045) mm. In the second part, the effect of Nano silica on the properties of RPC was evaluated. In the third part, the influence of the addition of yellow, orange, green, and blue inorganic pigments to the RPC. Results show that influences the compressive strength, the maximum aggregate size of the RPC. A decrease (1.2 - 0.045) mm the resulted of increase in the compressive strength in 156 MPa and did not influence the type of pigment to the compressive strength. Al Jubory, [14] Study on RPC to define its mechanical properties comprising mineral admixtures. use pure RPC and RPC strengthened with 1% - 2% vf of steel fibers compared by locally obtainable material (cuting20°C - 80°C). Two sets of samples contain54 cubes of (50×50×50) mm, 18 cylinders of (100×200) mm and 18 prisms of (50×50×300) mm. The result shown the maximum value of compressive strength was 74 MPa (curing at 20°C) and Vf (2%) steel fiber and when used steel fibers were the result increasing of properties the strength of compression, splitting tensile, and also modulus of rupture. Tawashi & AlAmoudi [15], three mixtures of Self-Compacting Concrete (SCC) were created, with one mixture containing 550 kg/m³ of cement demonstrating excellent performance in both fresh and hardened states. This mixture exhibited a 12% increase in compressive strength and a 13% reduction in the water-cement ratio compared to the reference samples. The stress-strain (σ,ε) curve for these mixtures was measured and compared to the reference curves, showing partial similarity with an alignment of up to 80%.Tawashi A, Al Amoudi [16], In this research, three concrete mixtures were created using three different cement quantities (550, 500, and 450-475 kg/m³) and three types of chemical plasticizers labeled as 3500, NN, and S. Two plasticizer ratios (2% and 2.5% of the cement weight) were also tested. Experiments were conducted to confirm the fresh properties of the concrete mixtures, determine the cylindrical strength at 28 days, and measure the stress-strain (σ, ξ) behavior of the samples.

3. Objective of Study

This paper check the behavior of reinforced concrete beams by seek ultimate load capacity, initial cracking load, failure patterns, and their load versus deflection characteristics.

4.Experimental Program

4.1 Experimental Procedure

This study's experimental work involved four specimens, examining the effects of using Reactive Powder Concrete (RPC), High Strength Concrete (HSC) with strengths of 50 MPa and 70 MPa, and normal concrete in casting beams. The beams were simply supported, with dimensions of 100 mm in thickness, 400 mm in total depth, and a center-to-center span of 1000 mm between supports. Two-point loads were applied at mid-span, with a distance of 400 mm between the load points (see Fig. 1). To study the concrete characteristics, compressive strength tests were conducted using 100 mm x 100 mm x 100 mm cubes, flexural strength tests were performed using 100 mm x 100 mm x 500 mm beams, and modulus of elasticity and splitting tests were carried out using 300 mm x 150 mm cylinders.

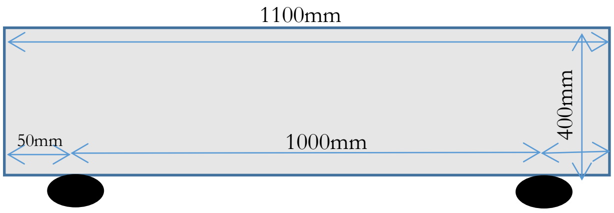

Figure (1): The Beam Sample Structure

4.2 Materials

4.2.1. Cement

Ordinary Portland cement type (1) were used for casting normal strength concrete, high strength concrete, and reactive powder concrete, as shown in Tables 1 and 2 respectively, Limit of with the Iraqi standards specification No.5 (2019) [17] .

Table (1): Chemical Properties of Cement

Symbol	By The Weight %No.1	Limit of IQS 5/2019
L.O.I	2.83	Not More than 4%
SiO_2	20.71	---
Al_2O_3	4.625	---
Fe_2O_3	3.945	---
CaO	62.605	---
MgO	1.74	Not more than 5%
SO_3	2.28	Less than 2.8%
I.R	0.78	Less than 1.5%
C_3A	5.74	----
L.S.F	0.931	0.66-1.02
C_3A	6.0	----
C_3S	50.0	----
C_3S	21.0	----
C_4AF	13.0	----

Table (2): Physical Properties for Cement

Name	Test Result	Limit of IQS 5/1984
Specific Surface Area (cm^2/g)	3630	not less than 2300
Initial setting time (min)	170	not less than45
Final setting time (hrs)	5	not more than 10
Compressive strength at 3 days (MPa)	22	not less than 15
Compressive Strength at 7 days (MPa)	30	not less than 23
Soundness by Autoclave Method %	0.40	not more than 0.8

4.2.2 Fine Aggregate

The fine aggregate applied in this paper according to Iraqi standard No.45 (1984) [12]. The chemical and physical properties of sand showed in Table 3 and the sieve analysis were showed in figure .2

Table (3): Chemical and Physical Properties

Properties	Test Result	I.S.O45/1984
Specific gravity	2.5	-
-Apparent Specific gravity	2.68	-
Sulfate content (SO_3)	0.4 %	≤ 0.5 %
Absorption ratio.	0.78 %	-
Passing 0.075 mm	0.4 %	≤ 5(%)
Clay (%)	0.04 %	≤ 1 %
Organic (%)	0.466 %	≤ 0.5

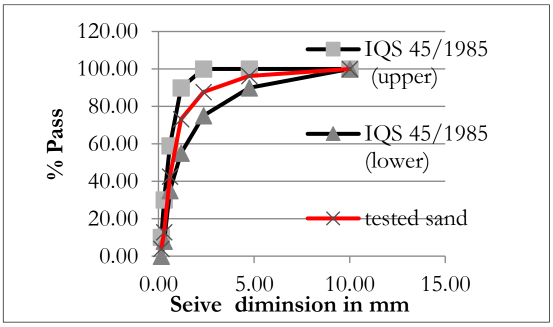

Figure (2): Fine Aggregate Sieving Analysis

4.2.3 Fine Sand

Extra fine sand or silica sand, as shown in Figure.3, has been used to produce RPC, it has a maximum particle size (600µm). Sika company is a supplier of this type of fine aggregate. The extra-fine aggregate properties conformed to IQS No.45/1984 [18]. Tables (4) demonstrate the grading and physical properties of extra fine aggregate as shown below

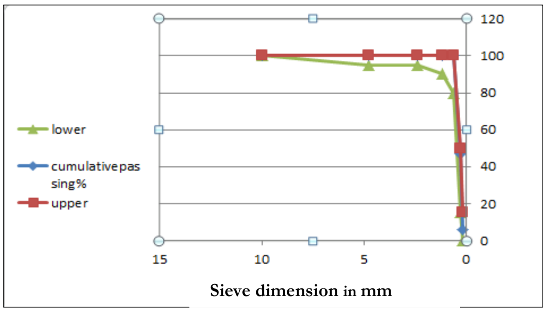

Figure (3): Grading of Fine Sand

Table (4): Physical Properties of Fine Sand

Physical properties	Test results	Limits of Iraqi specification No. 45/1984
Specific gravity	2.63	-
Amount of sulfate %	0.21%	≤ 0.50 %

4.2.4 Coarse Aggregate

The grading of Coarse Aggregate used in this search is reliable with the IQS No.45 (1984) [19] between (5 to14) mm for NC and HC , max size 20mm, as shown in Fig. 4.

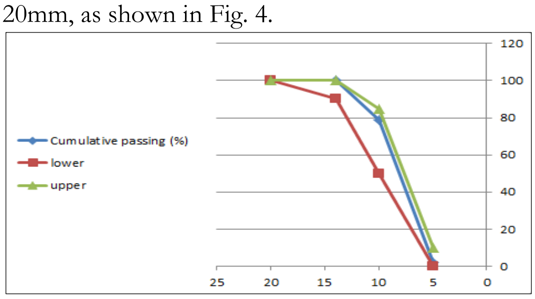

Figure (4): Grading of Coarse Aggregate

4.2.5 Super plasticizer

The third generation super plasticizer type (F) which is called commercially Glenium 51 was used in this search. Table 5 shows the properties for this produce according to ASTM C494-04 [20].

Table (5): Typical Properties of Glenium 51*

Main action	Concrete Superplasticizer
Color	Light brown
PH	6.6
Relative density	@ 20°C/1.1
Viscosity	@ 20°C/ 128 +/-30 cps
Form	Viscous liquid
Recommend Dosage	0.5-2.5 liter /100kg of cement

* Supplied by the manufacturer.

4.2.6 Silica fume

In this study silica fume [14]. was used as pozzolanic admixture to enhancing the mechanical properties of concrete, such as toughness by reducing the permeability. As shown in Table 6.

Table (6): Properties of Silica Fume

Chemical Composition		ASTM C1240 [14]
Oxides	Content%	
SiO_2	88.22	≥ 85
Al_2O_3	1.51	
Fe_2O_3	1.60	
CaO	2.5	
MgO	1.09	
SO_3	2.4	≤ 4
L.O.I	3.82	≤ 6
Physical Properties		
specific surface area m^2/g	20	≥15
specific gravity g/cm^3	0.75	-

4.2.7 Steel Fiber

Hooked end steel fibers used with (L/d) of 64. Steel fibers benefit to increase concrete's tensile strength. As shown in Table 7.

Table (7): Type of steel

Type of steel	Hooked-Ends
Relative Density	7850 kg/m3
Yield strength	1100 MPa
Modulus of Elasticity	210 000 MPa
Average length	(L) 35 mm
Nominal diameter	(d) 0.55 mm

4.2.8 Reinforcement bars

Deformed steel bars have a nominal diameter of 8 mm were used as tensile longitudinal reinforcement with yield stress 545 Mpa, and deformed steel bar of size (Ø5) was used in shear reinforcement with yield stress 615 Mpa as shown in Figure 5. The tensile test was carried out for each bar type with length (100mm) these bars were tested under tensile force using a hydraulic tensile testing system with power (1000kN).

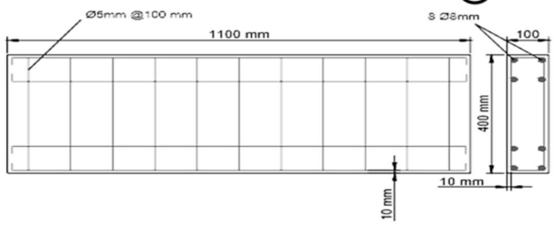

Figure (5): The Reinforcement Details

5. Concrete Mix Design and Mixing Procedure

Four concrete mixes were designed, normal strength concrete, high strength concrete HSC 50 MPa, high strength concrete HSC 70 MPa and reactive powder concrete. The procedures for mixing for the four types of concrete as follow:

Normal Strength Concrete NSC, at first mix the aggregates for 2 minutes then add the binder material (cement) and continue mixing for an additional 3 minutes to have a homogeneous dry mixture, add water to the mixture and mix for another 3 minutes until a uniform consistency is obtained the total mixing time eight minutes.

High Strength Concrete (HSC 50 MPa and HSC 70 MPa) add a portion of the water to the dry mixture initial Mixing, mix all components for 2 minutes, combine the superplasticizer with the remaining water, and add this mixture to the dry mixture. Finally mix the fresh concrete for an additional 3 minutes.

Reactive Powder Concrete (RPC), for initial Mixing Mix the fine sand and silica fume for 4 minutes add cement and mix the dry materials for an additional 5 minutes, mix the superplasticizer with water, add the prepared liquid to the dry mixture while the mixer is running, fresh Concrete Mixing Continue mixing for 3 minutes, gradually add steel fibers by hand over a period of 2 minutes while continuing to mix. as shown in Table 8.

Table (8): Properties of Concrete Mixes design

Water (W) (Liter/m³)	Super plasticizer (%)	Steel Fiber (%)	Silica Sand (kg/m³)	Silica fume (kg/m³)	Sand (kg/m³)	Gravel (kg/m³)	Cement (kg/m³)	Type
193	--	--	--	--	542	1200	418	NC
164	*1	--	--	--	590	1000	510	HC50
195	*1	--	--	--	435	1130	650	HC70
153	3	1	1050	191	---	-	851	RC

6. Results and Discussion

The mechanical properties of hardened concrete are presented in Table 9 and Figure 6. From the results, it can be observed that the maximum compressive strength (fc') for cylinders with dimensions of 100 mm in diameter and 200 mm in height was 107 MPa for the reactive powder concrete (RPC) mixture, while the minimum value was 29 MPa. This indicates that the compressive strength of RPC is approximately three times that of normal strength concrete.

Additionally, Table 9 shows that the splitting tensile strength of the same cylinders recorded a reference value of 2.0 MPa, while the maximum value for RPC was 9.0 MPa. For prisms, the modulus of rupture had a reference value of 3.0 MPa, with the maximum value for RPC reaching 14.0 MPa. The modulus of elasticity for the reference concrete was recorded at 26.0 GPa, whereas the maximum value for RPC was 48.0 GPa. From these results, it is evident that the properties of reactive powder concrete surpass those of other types of concrete. This enhanced performance can be attributed to the mixture composition of RPC, which includes replacing 1% of steel fiber by volume and using silica fume and silica sand by weight instead of cement. These very fine materials effectively fill the concrete matrix, significantly improving its mechanical properties in the hardened state.

Table (9): The Mechanical Properties of Hardened Concrete

Mix Symbol	f'c, MPa	Increase of NSC%	Ft, MPa	Fr, MPa	Ec, GPa
M1(NSC)	29.0	-	2.0	3.0	26.0
M2(RPC)	107.0	3	9.0	14.0	48.0
M3(HSC(70Mpa)	68.0	1	5.0	7.0	34.0
M4(HSC(50Mpa)	46.0	0.6	4.0	5.0	31.0

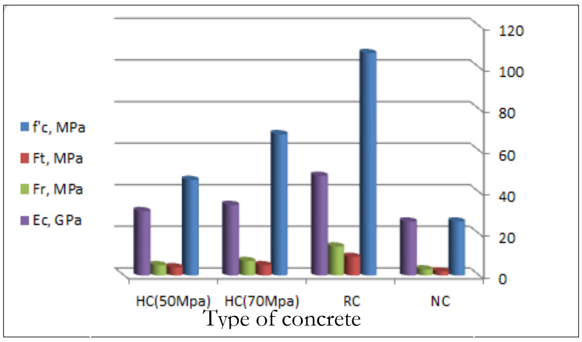

Figure (6): The Mechanical Properties of Hardened Concrete

7. Behavior of Beams

The general behavior of beams is illustrated in Table 10 and Figure 7. From the data, it can be noted that the first crack load for the reference beam (BN) was 85 kN. However, there was a noticeable decrease in the first crack load due to the reduced inertia in the solid specimen. The beam with reactive powder

concrete (BR) showed a significant increase in the first crack load by 239% compared to BN. This increase can be attributed to the filling effect of the reactive powder material and the enhanced tensile strength in the tension zone.

For the high-strength concrete (HSC) with a compressive strength of 70 MPa, the first crack load increased by 21% compared to BN, whereas the HSC with 50 MPa showed an increase of 6%. The ultimate load capacity of the reference beam (BN) was 215 kN. In comparison, the ultimate load percentages for BR, HSC 70 MPa, and HSC 50 MPa were 74%, 34%, and 1%, respectively, of the BN value. The mode of failure differed among the types of concrete. Normal concrete exhibited diagonal compression failure, reactive powder concrete (RPC) demonstrated flexural-shear failure, and both high-strength concretes (50 MPa and 70 MPa) experienced diagonal splitting failure. These differences are due to the variations in the mechanical properties of the materials.

The deflection behavior also varied among the specimens. The BR specimen exhibited lower deflections compared to other samples under the same loading conditions, indicating increased stiffness. Similarly, the B1 specimen showed lower deflections than others at the same loading level, which can be attributed to its higher stiffness.

Overall, the use of reactive powder concrete significantly enhances the mechanical properties of beams, including first crack load, ultimate load capacity, and deflection characteristics. The improved performance is primarily due to the material's ability to fill the concrete matrix effectively and its superior tensile strength, resulting in more efficient load distribution and resistance to cracking and failure.

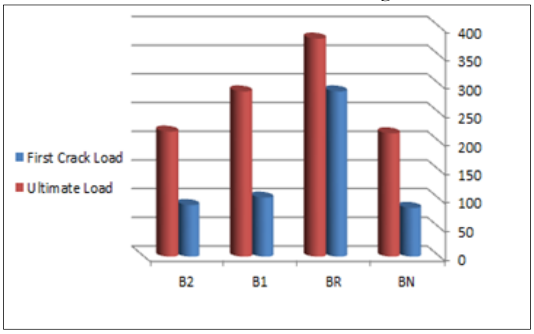

Figure (7): General Behavior of Beams

Table (10): General Behavior of Beams

Specimens	First Crack Load (Pcr) kN	Increasing percentage of First Crack load BN %	Ultimate Load (Pu) kN	Increasing percentage of Ultimate Shear Load with BN%	Deflection (mm)	Mode of Failure
BN	85.0	-	215.0	-	2.7	Diagonal compression failure
BR	288.0	239	380.0	74	4.2	Flexural-shear failure
B1	103.0	21	288.0	34	2.8	Diagonal splitting failure
B2	90.0	6	218.0	1	2.3	Diagonal splitting failure

8. Conclusions

- The superior mechanical properties and high performance of the concrete types (i.e. reactive powder concrete and high strength concrete) produced high efficiency in improving the structural behavior of the beams and resulting in an ability to decrease the deflection values through-loading life

compared to normal concrete due to the increase in stiffness.
• Due to the high tensile strength and ductility of RPC, the fully reactive powder concrete beam achieved a greater ultimate deflection at mid-span and a higher failure load compared to all other specimens.
• Incorporating steel fibers at a volumetric ratio of 1% in high strength concrete specimens results in increased ultimate load, stiffness, and energy absorption compared to normal strength concrete solid beams. This improvement is due to the steel fibers reducing crack propagation that begins in the shear zone at the bottom of the beam.
• The benefits of high performance concrete like RPC and HSC made reduction in deflections.
• Reactive powder concrete contain a so dense microstructure, which offers significant features for water protection and durability, it could, be a modern choice once and for all atomic dissolution.

Acknowledgments

The authors are grateful for the support towards this research by to Al-Iraqia University, College of Engineering, Civil Engineering Department.

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