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Cyclic Response of Beams Casted with Different Types of Concrete

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Abstract:
The structural response of the concrete beams to the effect of repeated load is investigated. The beams specimens manufactured from three various concrete types; conventional concrete, high strength-concrete and modified reactive powder-concrete. The exploration results point out that the ultimate capacity of high strength-concrete and modified reactive powder-concrete beams increase by about 127.3% and 154.5% if compared with normal strength-concrete specimen. Also, the first crack loads increase about 188.9% and 222.2% in the case of high strength-concrete and reactive powder-concrete beams respectively. The results are found the degradation in stiffness of normal strength-concrete beam is higher than the other two types of beams. In general, the structural behavior is significantly improved when casting the beams with high strength-concrete and reactive powder-concrete if compared with the normal strength-concrete beam.

***Keywords**: cyclic load, normal strength concrete, high strength concrete, reactive powder concrete.*

Introduction

In spite of huge construction materials improvement attained previously, in addition to diversity in concrete structures, cement is still the main material in the concrete industry. The nonlinearity of concrete behavior coming from the cement mortar split from aggregate particles in the first loading time. Reinforced concrete plastic behavior should be affected by steel to concrete bond behavior. Now, an additive added to conventional concrete to improve the bond properties between cement and aggregate from a side, and between concrete and reinforcing steel bars from another side. These additives contribute to strengthening the concrete members against different loading types; static and cyclic loading [1-4]. The degradation of concrete structures was improved by using new types of concrete [5-9], significant different outcomes for researchers working in different countries were attained previously. Bragium[10] and Olivier Filho [11] conducted investigations to explore the behavior of heavy beams with various types of concrete under repeated load. Ahmed Khalifa and Antonio Nanni [12] studied the shear performance of concrete beams reinforced with carbon fiber polymer sheets, the beams specimens were tested under cycle load. Oral Buyukozturk et.al [13] introduced the utilization of fiber-reinforced polymer in rehabilitation the concrete beams, the problems of bonding and brittleness of concrete have vanished, the mechanical behavior of beams was improved under repeated loading test. The hypothetical model suggested by Picons and Florez-Lopez [14] indicates test outcomes on the assessment of the possibility of suggested models to simulate different concrete types of beams under repeated load. This study highlights investigating the behavior of beam poured with normal strength-concrete, high strength-concrete, and reactive powder-concrete under the effect of repeated load. Increasing compressive strength and tensile strength of concrete in case of high strength-concrete and reactive powder-concrete respectively may improve the beams behavior in case of repeated load, this criteria may be achieved because of increasing the bonding of cement paste with aggregate and steel bars, this improvement in bond strength reflect on decrease the deterioration of structural members.

Materials and Methods

1. Construction Materials Properties

Cement

The kind of cement involved in this research is ordinary Portland cement (Type I) that is produced in plants of Iraq. To prevent atmospheric conditions, it is kept in a dry circumstances. Tables 1 and 2 indicate the chemical structure and physical characteristics of cement, testing was conducted at the Building Research Directorate in Baghdad, in accordance with the IQS requirements [15].

Table 1 Cement chemical composition

Compound Composition	Percentage By Weight	Limit of IOS:5/ 1984
Lime	63.11	------
Silica	20.37	------
Alumina	5.15	------
Iron Oxide	4.39	------
Magnesia	1. 68	<5
Sulfate	2.57	<2.8
Ignition losses	2.72	<4
Lime saturation factor	0.92	0.66-1.02
Tricalcium aluminates	6.22	------
Tricalcium silicate	49.23	------
Dicalcium silicate	21.50	------
Tricalciumalumona ferrite	13.34	------
Insoluble residue	0.69	<1.5

Table2Cement physical properties

Physical properties	Test result	Limit of IOS 5/1984
Finess modulus (cm2/g)	4426	> 2300
Initial setting time (min) Final setting time (hrs)	190 5:00	> 45 min < 10 hr
3 days compressive strength (MPa) 7 days compressive strength (MPa)	24 32	>15 > 23

Fine aggregate

Fine aggregate seems to have (5 mm)maximum aggregate size of. Table 3 and Table4 demonstrate the sieve analysis and the physical and chemical characteristics of the sand, that complies to the IQS [16].

Table 3 Grading of fine aggregate

No.	Sieve size(mm)	Cumulative passing (%)	Limits of Iraqi specification No.45/1984 zone 2
1	10	100	100
2	4.75	90.55	90-100
3	2.36	87.31	75-100
4	1.18	63.1	55-90
5	0.6	43.51	35-59
6	0.3	14.64	8-30
7	0.15	0.02	0-10

Table 4Fine aggregate properties

Physical properties	Test result	Limit of Iraqi specification No.45/1984
Bulk Specific gravity	2.53	-
Apparent Specific gravity	2.7	-
Bulk density (Kg/m3)*	1690	-
Sulfate content(SO3)	3.56%	≤0.5%
Absorption	2.25%	-
Fineness modulus*	3.1	-

Coarse aggregate

The coarse aggregate need to be clean, crushed aggregate with a minimum of flat and elongated particles. Table 5 and Table 6 illustrate the grading and chemical composition of the coarse aggregate that corresponds to the IQS[16].

Table 5 Coarse aggregate grading

No.	Sieve size (mm)	(% Passing)	Limits of Iraqi specification No.45/1984
1	20	100	100
2	14	100	90-100
3	10	74.5	50-85
4	5	3.5	0-10
5	2.36	---	---

Table 6 Coarseaggregate chemical properties

Physical properties	Test result	Limit of Iraqi specification No.45/1984
Bulk specific gravity	2.3	-
Apparent specific gravity	2.6	-
Bulk density(Kg/m3)	1546	-
Sulfate content	0.09%	≤0.1%
Absorption	6.2%	-

Steel reinforcement

The reinforcing steel bars are placed as flexural reinforcement in the tensile region of the beams. Three samples of diameters (8 mm, 10mm and 12mm) with length (500 mm) were examined, the properties of steel bars are shown in Table 7.

Table 7Properties of steel bar

Nominal diameter (mm)	Actual diameter (mm)	Yield stress(Fy) (MPa)	Ultimate strength(Fu) (MPa)	Elongation %
8	7.92	391	562	10.6%
10	9.97	412	577	10.2%
12	11.94	404	569	10.3%

Steel Fibers

Generally, the steel fibers were used in the mixes of RPC; using steel fibers in concrete mixtures help to improve the concrete tensile strength. Table 8 illustrates the properties of steel fibers. It is satisfied the American standards ASTM A820 [17].

Table 8 Steel fibers properties

Type	Density (kg/m^3)	Fiber length (mm)	Fiber diameter (mm)	Aspect ratio	Tensile strength (MPa)	Elastic modulus (GPa)
Straight	7800	15	0.2	75	2850	210

Silica Fume

Using silica fume in this work in production of RPC to achieve high concrete properties. Tables 9 illustrate the main chemical and physical properties of silica fume, which satisfied the American Standards ASTM C 1240-04 [18].

Table 9 Chemical and physical properties of silica fume

Requirement	Results (%) *	Specifications limits (ASTM C 1240)
SiO_2	86.46	>85.0
Moisture content	0.68	<3.0

L.O.I	4.02	<6.0
Percent retained on 45-µm (No.325) Sieve, Max.	7	<10
Accelerated pozzolanic strength activity Index with Portland cement at 7 days, Min. percent of control	128.6	>105
Specific surface, min, cm2/g	210000	>15
Specific gravity	2.2	-

Superplastisizer

Tables 10 illustrates the main chemical and physical properties of superplastisizer, which satisfied the American Standards ASTM C494[19].

Table 10 Specifications of superplastisizer

No.	Main action	Concrete superplasticizer
1	Color	Light brown
2	Labeling	No hazard label required
3	pH. Value	6.6
4	Form	Viscous liquid
5	Chlorides	Free of chlorides
6	Relative density	1.08 – 1.15 gm/cm^3@ 25°C
7	Viscosity	128 ± 30 cps @ 20°C
8	Transport	Not classified as dangerous

2. Mix Design

Three concrete mixes have been used among three trial mixes[20]. Table 11 gives detailed information of these mixes.

Table 11 Trial mixes

Concrete Type	Cement kg/m^3	Sand kg/m^3	Gravel kg/m^3	Silica fume %	w/c	Superplasticizer (L/m^3)	Steel fiber content %	Steel fiber content kg/m^3
NSC	400	600	1200	-	0.45	-	-	-
RPC	1100	1100	-	25	0.2	5	1	78
HSC	510	590	1000	-	0.32	4	-	-

3. Specimens Details

Three simple supported beams were cast and tested under repeated load, two-points loads were applied through hydraulic test machine, the distance between points loads was 300mm. The dimensions and reinforcement ratio were kept constant, the beams width, height, and length were 150mm, 280mm and 1100mm respectively. The tensile reinforcement of the beams was $3\Phi12$, the compression reinforcement was $3\Phi10$, and the shear reinforcement was $\Phi8$@150mm.

Analysis of Results

Observed failure modes

The modes of failure are depended on the maximum levels of stress in the beam. Specimens that resisted at least 280 kN of load without fracture are supposed to have a longer fatigue life. This specimen exhibited low strength decreasing if compared with the reference specimen after loading. Table 12 illustrate the peak load of each cycle, the maximum applied static peak load, the number of cycles until failure, and the modes of failure noticed through the tests.

Specimens loaded at peak load equal to 80% of the ultimate load displayed failure relying upon stress amplitude and concrete type. Failure modes in these beams distinguished by fatigue failure of the concrete with subsequent fracture of the concrete along with the bottom reinforcement. After yielding of the reinforcement, the lack of bonding between the steel bar and concrete will occurred. The high strength-concrete beam showed no visible attention of stress prior to failure of the reinforced bars, as the cracks had ceased to extend in length.

Normal concrete and reactive powder-concrete beams that achieved of failure along the beam are characterized by visible attention of damage through loading. Typically a crack formed at the tension zone during early loading cycles, and later propagated along with the section height higher than the tensile bars level. The visible crack initiated usually in the mode of flexural cracks within the beam flexure span causing severe crack width within this zone.

Table 12 Failure characteristics of tested beams

Specimens configuration	Peak load (kN)	Cycle No.	Maximum applied static peak load (kN)	First crack load (kN)	Failure mode
N	110	3rd	138	45	Flexural
H	250	3rd	313	145	Flexural
R	280	3rd	350	130	Flexural

Deflection

The mid-span deflection initially increased in all beams, followed by a stable state where the deflection continue fairly stable through a first or a second cycle period followed by a significant increase in deflection at cycle three just before failure. It can also be noted that the deflections increase substantially with an increasing in the fatigue life of the tested beams. For reactive powder-concrete and high strength-concrete samples, the mid-span deflection decreases with the same cycles number as compared to normal strength-concrete beams. For reactive powder-concrete beam, the increase in deflection at the 3rd cycle was 90.9 percent, while the decrease in deflection was 100 percent at the same number of cycles when the high strength-concrete beam was tested.

Ultimate load

The term load-carrying capacity refers to the final total capacity transferred to the beam related to the variation of concrete forms, specimen (R) showed an increase of nearly (154.5 percent) in the ultimate capacity rather than that of the corresponding normal concrete sample (N) that failed under (110) kN of the third cycle center loading. On the other side, specimen (H) failed under flexural loading (250) kN, sample (H) reported an increase of about (127.3%) if compared with normal strength-concrete specimen, see Table 13. The difficulty of growing cracks in high-strength concrete and reactive powder-concrete specimens is the reason of increasing the ultimate load, in accordance with the function of the steel fibers in reactive powder-concrete lead to keeping cracks from extending by bridging.

Table 13 Load characteristics of tested beams

Specimens configuration	Peak load (kN)	Percentage of increasing in peak load (%)
N	110	R*
H	250	127.3
R	280	154.5

R*: Reference specimen.

First Crack Load

All specimens subjected to periodic load attained first crack load throughout the second cycle; The first flexural cracks of high strength-concrete beam appeared in the constant moment region at 130 kN (1.88 times the cracking load of reference beam N), Beam (N) started to appear first crack load at (45)kN. In the reactive powder-concrete beam, the main flexural crack formed at a load of approximately 145 kN, higher than the reference sample by approximately (222.2%), this may be due to increasing in the bond of the concrete component by steel fibers and thus delaying the growth of cracks. see Table 14.

Table 14First crack load of tested beams

Specimens configuration	First load (kN)	Improvement (%)
N	45	R*
H	130	188.8
R	145	222.2

Load –deflection relationships

Fig.1, 2 and3 indicates the load versus deflection of cyclically tested specimens. From these curves, two stages can be recognized; the first linear stage reflects the elastic stage of the action, beginning at the start of the load until the first crack appearing. The second stage describes the elastoplastic pattern of the beam, characterized by a growth in the number of cracks and a failure of the reinforcing steel. The yield of the reinforcing steel took place at the end of this point. Beam failure begins beyond the yield of reinforcing steel, the significant part of the stiffness of the beam lacked at this stage due to an increase in the number and dimensions of cracks as well as a significant extension of cracks toward the top face of the beam. In normal strength-concrete specimen, at the same point of the loading stage, the magnitude of the central deflection of specific cycle is higher than the deflection in reactive powder-concrete and high strength-concrete beams.

For the first run in the first cycle of load-deflection graphs as seen in Fig.4-23, it is observed that the deflection of the control beam (N) is higher than other specimens with reactive powder-concrete and high strength-concrete, other runs of all cycles behaved in the same pattern as in the first run.

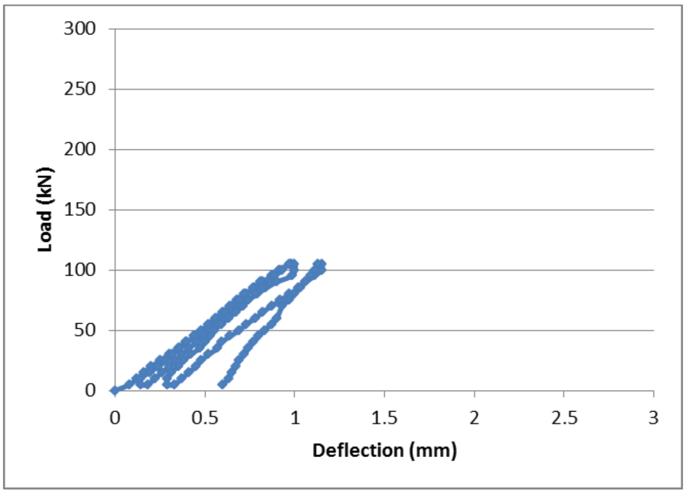

Fig.1 Load versus displacement curve of the beam (N)

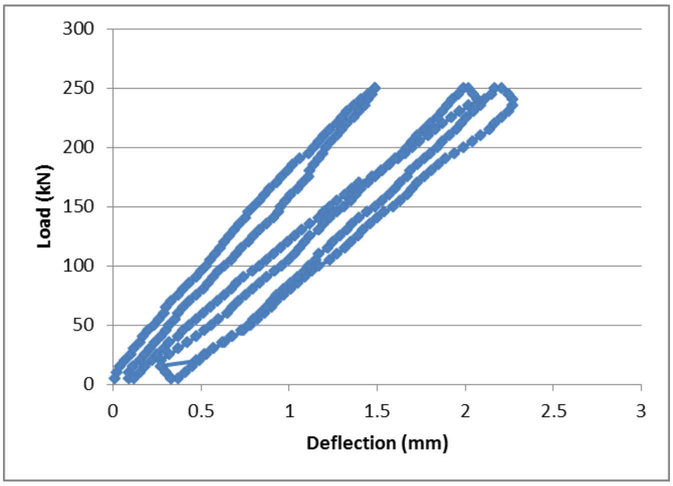

Fig.2 Load versus displacement curve of the beam (H)

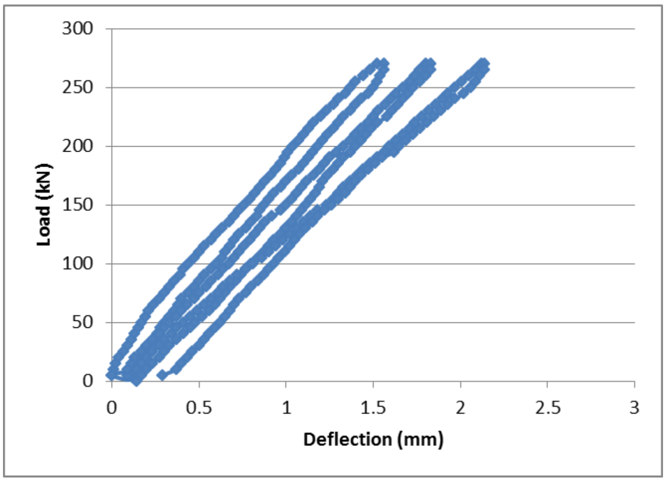

Fig. 3 Load versus displacement curve of the beam (R)

Stiffness

As shown in Table 15, the type of concrete effected on the degradation of stiffness. The specimen (N) achieved stiffness (110 kN / mm) at the first cycle. At the second cycle, the stiffness of the specimen (N) decreased by 13.63 percent. At the third cycle, beam (N) stiffness decreased approximately (24.5 percent) relative to its first cycle stiffness. beam (H) reached stiffness approximately (166.6kN / mm) during the first cycle. In the second cycle, the stiffness decreased by about 21%. In the third cycle, the reduction in stiffness of the beam (H) was 31.8%. The specimen (R) lost in the second cycle about 6.3 percent from its stiffness in first cycle at first cycle. In the third cycle, the beam lost about 24.9 percent of its stiffness at first cycle. From previous, it shows that the amount of decrease in the stiffness of beams loaded cyclically is higher in the high strength-concrete beam, while the reactive powder-concrete specimen is considered the best specimen in terms of loss its stiffness through loading stages, the main reason is due to the difficulty in extension the cracks through the beam.

Table 15 First crack load of tested beams

Specimen configuration	**Stiffness at first cycle kN/mm**	**Stiffness at second cycle kN/mm**	**Reduction in stiffness at second cycle (%)**	**Stiffness at third cycle kN/mm**	**Reduction in stiffness at third cycle (%)**
N	110	95	13.63	83	24.5
H	166.6	131.6	21	113.6	31.8
R	183.3	171.8	6.3	137.5	24.9

Strain Characteristics

The strain was measured in the tensile reinforcement for each beam, to allow comparison of different beams strains specimens.

The strain of normal strength-concrete tested beams at tensile reinforcement recorded higher strain in first, second and third cycles than specimens poured with high strength-concrete and reactive powder-concrete as shown in Table16. It is clear that the degradation in stiffness of normal strength-concrete specimen is higher than those other specimens; specimen (N) achieved an increase in strain at cycle two about 56% in comparison to its stain at cycle one, while specimens (H) and (R) recorded an increase in strain about 42.8% and 42.1% respectively over the strain at the first cycle. Furthermore, the increase in steel strain of normal specimen in cycle three is higher than the increase in steel strain of high strength-concrete and reactive powder-concrete specimens; the normal strength-concrete beam achieved 61.8% an increase in strain between cycle two and cycle three, specimen (H) achieved an increase in steel strain between cycle two cycles about 48%, and specimen (R) achieved an increase in steel strain between two cycles about 45.9%.

Table 16 Strain of reinforcing steel

Specimen	strain at 1st cyclex10^{-3}	strain at 2nd cyclex10^{-3}	Variation in strain between 1st and2nd cycles (%)	strain at 3rd cyclex10^{-3}	Variation in strain between second and third cycles (%)
N	0.25	0.39	56	0.631	61.8
H	0.21	0.3	42.8	0.444	48
R	0.19	0.27	42.1	0.394	45.9

For each beam, the concrete strain was measured at mid-span of in tension face beams. The concrete strains for each cycle are shown in Table 17, to allow a comparison of concrete strains in a different specimen. It is noticed that the reference specimen (N) has a larger maximum strain than other specimens with high strength-concrete (H) and reactive powder (R). When the strain was measured in the first cycle, the specimen (N) recorded (0.38x10-3) maximum strain, while specimens with high strength-concrete and reactive powder-concrete (H) and (R) achieved maximum strains about (0.31x10-3) and(0.29x10-3) respectively. On the same way, the maximum strain at the second cycle was (0.654x10-3), (0.450x10-3)and (0.420x10-3) for specimens (N), (H) and (R) respectively, the variation in strain between two cycles reached (72.1%), (45.2%) and (44.8%) for normal strength-concrete, high strength-concrete and reactive powder-concrete beams respectively. For the third cycle, the normal strength-concrete recorded a significant increase in strain, this specimen achieved (51.2%) increase in strain over that of the second cycle. On the contrary, the high strength-concrete and reactive powder-concrete specimens recorded an increase in strain about (34.4%) and (20.23%) respectively over the strain readings at the second cycle.

Table 17 Concrete strain in tension zone

Specimen	strain at 1st cyclex10^{-3}	strain at 2nd cyclex10^{-3}	Variation in strain between 1st and 2nd cycles (%)	strain at 3rd cyclex10^{-3}	Variation in strain between 2nd and3rd cycles (%)
N	0.38	0.654	72.1	0.989	51.2
H	0.31	0.450	45.2	0.605	34.4
R	0.29	0.420	44.8	0.505	20.23

As illustrated in Tables18, when made a comparison between concrete strains under repeated load at the compression zone of specimens, it can be concluded that strains at the second cycle under repeated load were increased in reference specimen by about 70.3% and 44.5% in high strength-concrete specimen. In specimen (R), the strain was increased by about 33.3% between the first cycle and the second cycle. While, when strain measured at a third cycle, the strains were increased by about 52.72%, 34.21% and 25% over the second cycle for normal strength-concrete, high strength-concrete, and reactive powder-concrete beams.

Table 18 Concrete strain in compression zone

Specimen	strain at 1st cyclex10^{-3}	strain at 2nd cyclex10^{-3}	Variation in strain between 1st and 2nd cycles (%)	strain at 3rd cyclex10^{-3}	Variation in strain between 2nd and3rd cycles (%)
N	0.323	0.55	70.3	0.84	52.72
H	0.263	0.380	44.50	0.51	34.21
R	0.24	0.320	33.3	0.40	25

Conclusions

Under the effect of repeated load on beams behavior of different concrete, the following conclusions can be achieved:

1. High strength-concrete and reactive powder-concrete are effective in fabrication of beams in seismic zone.
2. High strength-concrete and reactive powder-concrete succesed to improve the general behavior, ultimate load, first crack load, and stiffness of beams under repeated load.
3. The deflection of beams was reduced due to pouring the beams with high strength-concrete and reactive powder-concrete.
4. The strain of reinforcing steel and concrete was reduced as a result of pouring the beams with high strength-concrete and reactive powder-concrete.
5. Under the effect of repeated load, the failure of reactive powder-concrete are characterized by ductile mode due to the efficiency of steel fibers in reactive powder-concrete mix.

REFERENCES

1. C. Gheorghiu, P. Labossière, J.: Proulx, Response of CFRP-strengthened beams under fatigue with different load amplitudes, Constructio nand Building Materials. 21 (2007): 756-763.
2. R. Gussenhoven, S.F. Breña, Fatigue behavior of reinforced concrete beams strengthened with different FRP laminate configurations, ACI Special Publication SP. 230-236 (2005): 613-630.
3. L.C. Meneghetti, Análisedocomportamento àfadiga de vigas de concretoarmadoreforçadas com PRF de vidro, carbono e aramida, 275.Tese (DoutoradoemEngenharia Civil) – Escola deEngenharia, Universidade Federal do Rio

Grande doSul, Porto Alegre,(2007).

4. A.J.F. Ahi, Análise de Fadigaem Pontes Rodoviáriasde ConcretoArmado, 2009. 154p. Dissertação(MestradoemEngenharia Civil) – Faculdade deEngenharia, Universidade do Estado do Rio deJaneiro, Rio de Janeiro, 2009.
5. A. Lindorf, M. Curbach, S-N curves for fatigue of bond in reinforced concrete structures under transverse tension, Engineering Structures.10 (2010): 3068-3074.
6. A. Lindorf, L. Lemnitzer, M. Curbach, Experimental investigations on bond behaviour ofreinforced concrete under transverse tension andrepeated loading, Engineering Structures. 7 (2009): 1469-1476.
7. F.E.G. Reyes, Análise da aderência entre barras deaço e concretos (CC, CAA e CAAFA) sob influênciade açõesmonotônicas e cíclicas, 2009. 215p.
8. Dissertação (MestradoemEngenharia de Estruturas)Escola de Engenharia de São Carlos, Universidadede São Paulo, São Carlos, (2009).
9. C. M. Castro, Concreto de alto desempenho: estudoda aderência com a armadura sob açõesrepetidas.(2002). 194p. Dissertação (MestradoemEngenharia deEstruturas) –Escola de Engenharia de São Carlos,Universidade de São Paulo, São Carlos, (2002).
10. R. M. Fernandes, A influência das açõesrepetidasnaaderênciaaço-concreto, 2000. 155p. Dissertação(MestradoemEngenharia de Estruturas) – Escola deEngenharia de São Carlos, Universidade de SãoPaulo, São Carlos,(2000).
11. J.R. O. Braguim, comportamentoemserviço devigas de concretoarmado sob carregamentocíclico, (1995) 114. Tese (Doutorado) – EscolaPolitécnica,Universidade de São Paulo, São Paulo, (1995).
12. J. Oliveira Filho, Estudoteórico-experimental dainfluência das cargascíclicasnarigidez de vigas deconcretoarmado. 2005. 218p. Tese (DoutoradoemEngenharia de Estruturas) – Escola de Engenharia deSão Carlos, Universidade de São Paulo, São Carlos,(2005).
13. A. Khalifa, A. Belarbi, A. Nanni, Shear Performance of RC Members Strengthened with Externally BondedFRP Wraps, Proc., 12th World Conference on Earthquake Engineering, Auckland, New Zealand,Jan 30- Feb 04, (2000).305-310.
14. O. Buyukozturk, O. Gunes, E. Karaca, Progress on understanding debonding problems in reinforced concrete and steel members strengthened using FRP composites, Construction and Building Materials. 18 (2004): 9–19.
15. R. A. Picón, J. Flórez-López, Evolución de ladegradación de rigidez en pórticos de concretoarmado. In: JornadasSudamericanas de IngenieriaEstructural, 29 (2000), Punta delLeste. Anais... PuntadelLeste, (2000). 1 CD-ROM.
16. Portland Cement, Central Agency for Standardization and Quality Control, Planning Council, Baghdad, Iraq, Translated from Arabic Edition. IQS No.5/(1984)
17. Iraqi Specification Limit, "Aggregate from Natural Sources for Concrete and Construction", Central Agency for Standardization and Quality Control, Baghdad, IQS No.45/(1984).
18. ASTM A820 / A820M-16,:Standard Specification for Steel Fibers for Fiber-Reinforced Concrete, ASTM International, West Conshohocken, PA, (2016)
19. ASTM C1240-04, :Standard Specification for the Use of Silica Fume as a Mineral Admixture in Hydraulic Cement Concrete, Mortar and Grout", ASTM International,West Conshohocken, PA,(2004).
20. ASTM C494/C494M-16, :Standard Specification for Chemical Admixtures for Concrete,. 04.02, (2016).20
21. ACI 211.1-91, :Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete, American Concrete Institute, ACI 211.1-91, ReaPProved(2009). 38