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Influence of Loading Pattern Regime on Behavior of Self Compacting Concrete Voided Slab Strips under Repeated Load

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ABSTRACT

This study presents an experimental approach to investigate the structural behavior of normal and moderately high strength Self Compacted Concrete (SCC) voided slab strips under repeated loading system. The experiments were carried out on eight one-way simply supported slabs. Four of them have been tested under two types of repeated loading regime. The required number of cycles of the first load pattern (R1) to achieve permanent damage in the slab is more than 40 cycles, while the second type of repeated loading regime (R2) requires more than 20 cycles to achieve complete damage in the slab for the selected loading scheme. The remaining four additional slabs were tested under monotonically increasing loads. The loading techniques have been applied under the displacement control scheme. The experimental results show that for moderately thick reinforced SCC one way slab having (3 voids, dia. =75mm) under repeated load R1, the ultimate load is reduced by about 10% relative to the reference solid. In this research, the number of cycles required to achieve permanent damage is decreased by about 7% and the mid-span deflection at ultimate load is increased by about 3.4% relative to the reference solid slab. The ultimate load for slab having (3 voids, dia. =75mm) under repeated load R2 is decreased by about 6%, the deflection at ultimate load and the number of cycles are decreased by about 6.1%and 16.7% respectively concerning SCC reference solid slab.

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1. Introduction

Repeated loading occurs when the force is applied many times, which affects the material by inducing various stresses resulting from continuity of loading and unloading cases, within a certain amplitude[1]. In 2008 Sivagamasundari[2] tested twenty one Glass Fiber Reinforced Polymer

(GFRP) bars reinforced concrete one- way slabs under monotonic, constant amplitude repeated and variable amplitude repeated loading. The slabs were divided into three groups with seven slabs in each group. The first category of slabs was tested under static loads and the second category of slabs was subjected to constant repeated load. The first crack load and initial propagation of cracks had been observed at a low load level of 10% of the ultimate static load. And the failure occurred at a load level of 80% of the ultimate static load. The third group of slabs was subjected to the variable amplitude of fatigue loading with percentages of 20%, 40%, 60%, and 80% of the static ultimate loads of the slabs. It was observed that with the increase in the number of load cycles, the corresponding deflection at ultimate load, number, and width of the cracks were increased. An experimental study was carried out in 2015 by Al-Sulayvani[3]. He tested thirteen two way slab specimens under repeated loading. The slab specimens were simply supported at all edges. The repeated loads have been applied at the center of the slabs for many cycles. The load was started at(5 kN) and increased by (5 kN) for each successive cycle up to failure by using a hydraulic jack. The interval time between cycles was kept constant. At the tension face of the slab, radial cracks were continuously formed for each stage of loading. It was also observed that the cracks became wider and permanent and extended beyond the loaded area directly toward the slab edges. As per the flexural behavior of eight normal and high strength SCC slabs, it was shown experimentally that, the improvement in high strength SCC slabs in terms of first crack load, ultimate load, and deflection at ultimate load was less than that of corresponding normal strength SCC slabs. However, for all the tested slabs, the concrete was cracked and the cracks initiated at the center of the tension face (bottom face) of the slabs and extended radially toward the edges. The crack pattern at failure showed that the cracks were narrow and multiple [4]. A comparative study has been presented in 2011 by Sivagamasundari [5] between voided flat slabs with the solid slab. It was noticed that a reduction of 35% in the overall weight of the solid plate slab was achieved, and the results showed that the voided slabs had lower stiffness than that of the solid slabs. Also, there was a reduction in stiffness due to the presence of spherical balls which were about 10% to 20% of the values of the solid slabs.

2. Purpose of Research

The main objective of the experimental work is to understand the effectiveness of different repeated load patterns on the SCC slabs tested under two-point external repeated loads. The obtained ultimate strength and mode of failure of the voided slabs are compared to those of reference solid slab. Also to study experimentally the structural behavior of one way reinforced SCC slab strips with longitudinal voids, the cracking and ultimate loads and the load-mid span deflection response investigated, and the load-carrying capacity is also studied.

3. Experimental Program

The tested slabs were 1500 mm in length, with a width of 600 mm and a thickness of 150 mm and all the slabs had the same amount of reinforcement. They were designed according to the ACI 318M-2014 Code. The flexural reinforcements were 4-Ø8 longitudinal bars and 8-Ø8 transverse bars for tested slabs designated as (SN and 3V75**N**), as shown in Fig1. The symbol (S) refers to **S**olid slab and the symbol (V) refers to the **V**oided slab,

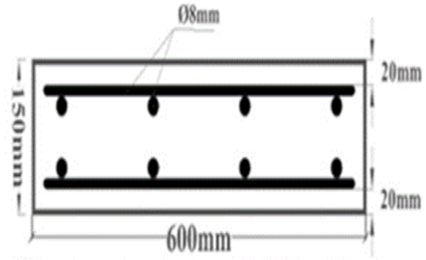
symbol (N) refers to **N**ormal strength SCC and the symbols, (3) refer to the number of voids as listed in Table 1. The slabs were tested with an overall clear span of 1380 mm. These specimens were classified according to concrete type normal or high strength SCC, concrete compressive strength (f'c), presence of voids, size and number of voids. Table 3 shows some tests which have been carried out on fresh SCC and compared with related standard limitation. The slump flow test, $T_{500mm,}$ and L-box test were conducted. as shown in Figure 2. It also presents the properties of reinforcing steel bars used in this work as shown in Table 2.

Table 1: Characteristics of the tested slabs

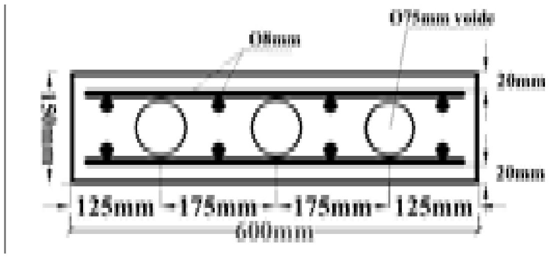
Slab designation	Type of concrete	Main rienf.	No. of voids	voids dia. (mm)	flexural steel ratio (ρ)	Void ratio%
SN	NSCC	Ø8@180 mm	-	-	0.0027	-
3V75N	NSCC		3	75	0.0027	14.7

Table 2: Properties of steel reinforcements

Nominal Diameter (mm)	Measured diameter (mm)	Surface texture	Bar area (mm^2)	Yield stress (MPa)	Ultimate stress (MPa)
8	7.9	deformed	49	440	655



Voided slab (3V75N)



Solid slab (SN)

Figure 1: Cross sections of slab specimens SN and 3V75N

Table 3: Test results of fresh properties of SCC were obtained according specifications and limitations guidelines of EFNARC[6]

Mix designation	Slump flow (mm)	T_{500mm} test (sec)	L – box test (H_2/H_1)
NSC	690	3.5	0.85
HSCC	720	4.3	0.90
Limits of EFNARC	650-800	2-5	0.8-1
Limits of ACI-237	450-760	2-5	0.8-1

Figure 2: T_{500} mm, Slump flow test

The normal strength SCC has a compressive strength (f'c < 41 MPa) according to ACI 363R[7].While the high strength SCC has (f'c > 41 MPa). In this work, the presented strength for SCC depended on the average test results of three of 150mm x 300mm cylinders. The concrete compressive strength (fc'), splitting tensile strength (fct), modulus of rupture (fr) and modulus of elasticity (Ec)are shown in Table 4.The values presented in this table also represent the average results of three specimens.

4. Instruments Used in the Study

The instruments that have been used to measure the response of concrete surface strains and the tensile strain occurred in flexural reinforcement were two types of pre-wired (120Ω) electrical strain gauges that applied at the top and bottom faces of concrete and at flexural typical steel rebar. Strain gauges were mounted on smooth cleaned surfaces that were prepared before. The vertical deflection of all specimens was measured using linear variable transformer (LVDT) cable connected to a data logger to measure the deflection at the center of the span of specimens, as shown in Figure 3.

Table 4: Mechanical properties of SCC at age of testing slabs

Mix designation	f'_c (MPa)	f_t (MPa)	f_r (MPa)	E_c (MPa)
NSCC	31.52	3.16	3.49	25390
HSCC	45.17	4.3	5.11	32527

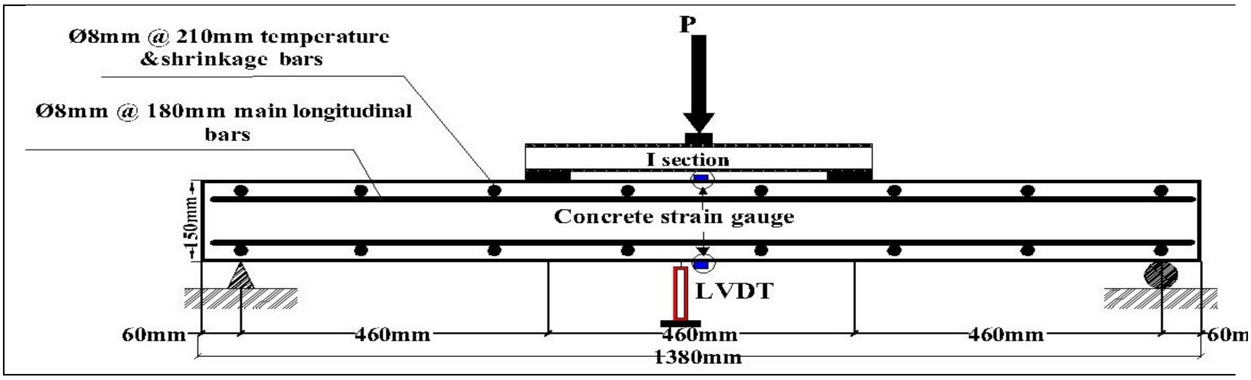


Figure 3: Longitudinal section in slab.

5. Specimens Tested under Repeated Loads

The experimental program of slabs tested under repeated loading pattern consisted of four one-way SCC simply supported slabs, included two as solid slabs (SNR1 and SNR2) and the remaining two as voided slabs, 3 voids of 75mm diameter (3V75NR1), and (3V75NR2). All the slabs had the same properties as normal SCC. Each one of these slabs has been tested under repeated loading system depending on the results of the corresponding reference monotonically tested slab. The repeated loading history which was applied to the specimen represented a modified load history of cyclic load recommended by the Federal Emergency Management Agency[2]. The adopted loading history was two types of repeated load patterns, the first category (R1) was applied according to the positive loading scenario shown in Fig 4. This scenario simulates the track loading applied on bridges. The loading history included the number of stages, the first stage represents low cycle fatigue which was conducted by applying ten cycles of repeated load. Each cycle has a deformation amplitude equal to 10% of the ultimate deformation of the monotonically tested reference slab (i.e. $\Delta 1 = 10\% \Delta ult$). Then the second stage consisted of three more cycles of the value of deformation that equal to 1.2 times the deformation value of the first stage (i.e.$\Delta 2 = 1.2\Delta 1$). For each of the successive stages, the deformation amplitude was increased subsequently by 0.2 ((i.e.$\Delta 3 =1.2\Delta 2$), ($\Delta 4 = 1.2\Delta 3$), ($\Delta 5 = 1.2\Delta 4$), ($\Delta 6 = 1.2\Delta 5$), ($\Delta 7 = 1.2\Delta 6$...etc)). These stages were continued to apply until permanent damage has occurred. The second category (R2) was applied as per the positive loading scenario shown in Fig 5. The loading history is started at the first stage by executed eight cycles has lowest deformation amplitude of the monotonically tested reference slab (i.e. $\Delta 1 = \Delta_{cr}$), then the second stage consisted of two cycles which had deformation value is equal to 0.048 of ultimate deformation of the monotonically tested reference slab (i.e. $\Delta 2 = 4.8\% \Delta ult$). The third stage consisted of two more cycles of the value of deformation that equal to 1.4 times the deformation value of the second stage (i.e.$\Delta 3 = 1.4\Delta 2$). For each of each remaining successive stages, the deformation amplitude was increased subsequently by 0.4 ((i.e.$\Delta 3 =1.4\Delta 2$), ($\Delta 4 = 1.4\Delta 3$), ($\Delta 5 = 1.4\Delta 4$), ($\Delta 6 = 1.4\Delta 5$), ($\Delta 7 = 1.4\Delta 6$...etc.)).

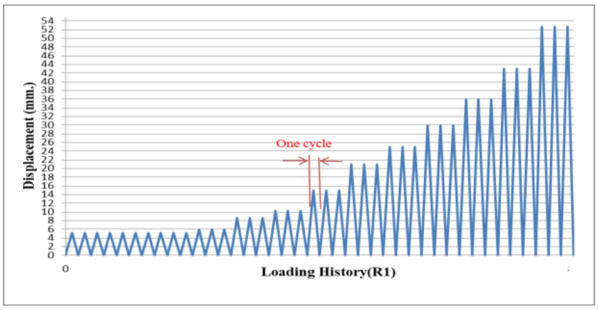


Figure 4: Loading history of tested slab 3V75NR1 under repeated loading pattern (R1)

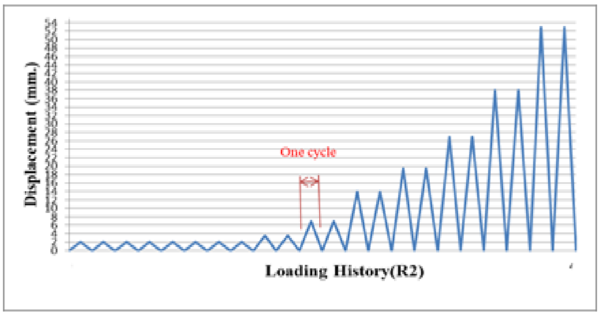


Figure 5: Loading history of tested slab 3V75NR2 under repeated loading pattern (R2)

6. Test Results and Discussion

I. Load Deflection Response and Crack Patterns

The deflection was recorded using an LVDT fixed at mid-span of the specimen. It has been observed that the first crack appeared in the middle region of the clear span of the tested slabs then running upward vertically through the thickness of the specimen. Usually, it has been observed at the initial stage that, the cracks had opened within loading face and closed completely during unloading face. But when the number of cycles was progressively increased through the test, the developed cracks remained open even though at unloading face. For repeated load pattern (R1), the deformation amplitude of every cycle was represented by 0.1of the deflection at the ultimate load of control specimen which was already tested monotonically. The cracks of specimen 3V75NR1, as shown in Fig 6. have been occurred at range magnitude between $0.1\Delta_{ult}$ to $0.3\Delta_{ult}$. These cracks at first cycles of initial stages were opened during applying load and, they remained open through the unloading stage. The cracks developed widely and extended vertically upward at displacement level equal to $1\Delta_{ult}$. However, for a similar specimen under repeated load pattern (R2), as shown in Fig 7. no cracks at the initial stage of cycles were observed, then the sudden crack occurred at $0.13\Delta_{ult}$. The cracks were taken place until $0.8\Delta_{ult}$ then the complete damage occurred at $0.99\Delta_{ult.}$

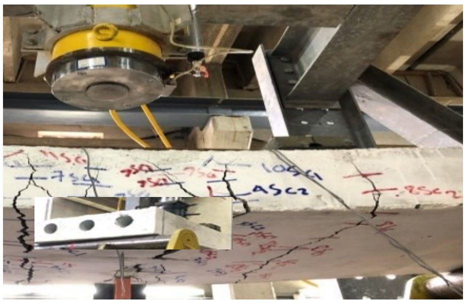


Figure 7: Bottom face of tested slab 3V75NR2 under repeated load pattern (R2)

II. Effect of Repeated Loading Regime on Cracking and peak ultimate Loads

The cracking and peak ultimate loads of the tested specimens are given in Table 5. The first cracks of specimens (SNR1 and 3V75NR1) under repeated loading pattern R1 were observed in the range (47% and 60.7%) respectively of the peak ultimate load of slabs, while the first cracks of the specimens (SNR2 and 3V75NR2) under repeated loading pattern R2 were observed at (46% and

55.8%) respectively of the peak ultimate load of the slabs. Furthermore, it can be noticed that the ultimate load of specimens (SNR1,3V75NR1, SNR2 and 3V75NR2) which were tested under two types of repeated loading regimes (R1 and R2) were decreased by about (17.2%, 10%, 11%, and 6%) respectively, concerning the corresponding load of control specimen that was tested under monotonic loading.

III. Load deflection response under repeated loads

The deflection values at a first cracking load of the slabs are recorded in Table 6. These cracks are almost compatible with those occurred at the control specimens that were tested under monotonic load. The value of deflection at the ultimate load was increased for the specimen (3V50NR1), tested under repeated load pattern R1 by about (17.5%) for control specimens. As shown in Figs (8, and 9). In contrast, there was a decrease in deflection for SNR1and SNR2 specimens by about 17.7% and 28% respectively relative to the control specimen. Figs (10 and 11).

Table 5: Cracking and ultimate loads of the tested slabs (SNR1, 3V75NR1, SNR2 and 3V75NR2).

Specimen designation	Monotonic Load (Control) specimen	Repeated Load(R)		Monotonic Load (Control) specimen	Repeated Load(R)	%Decrease in ultimate load with respect to control specimen
	Cracking load (Pcr) (kN)	Cracking load (Pcr) (kN)		Ultimate load (Pu) (kN)	Ultimate load (Pu) (kN)	
SN	23.9	22.2	R1	57.4	47.5	17.2
3V75N	25.9	24.8	R1	45.8	41	10
SN	23.9	23.5	R2	57.4	51	11
3V75N	25.9	24	R2	45.8	43	6

Table 6: Mid-span deflation at cracking and ultimate loads under repeated load of tested slabs (SNR1, SNR2, 3V75NR1 and 3V75NR2).

Specimens designation	Monotonic Load(M) (Control) specimen	Repeated Load(R)		Monotonic Load(M) (Control) specimen	Repeated Load(R)	% Increase in deflection at ultimate load with respect to control
	Deflection at first crack load (mm)	Deflection at first crack load (mm)		Deflection at ultimate load (mm)	Deflection at ultimate load (mm)	
SN	3	٢.٨	R1	58.5	48.12	-
3V75N	2.8	3	R1	45.8	53.8	17.5
SN	3	2.6	R2	58.5	42	-
3V75N	2.8	3	R2	45.8	53	15.7

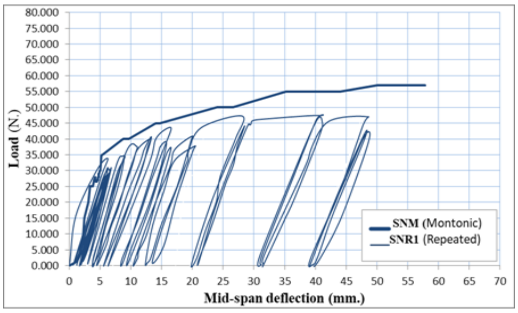


Figure 8: Load mid-span deflection curve for solid slab (SNR1)

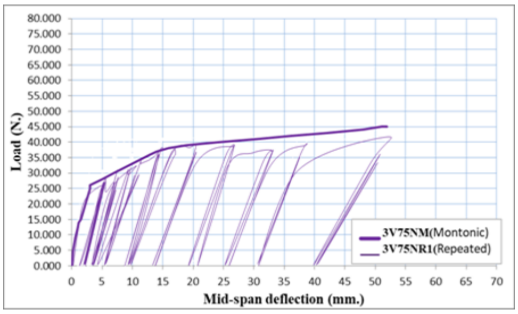


Figure 9:Load mid-span deflection curve for voided slab (3V75NR1) ,void ratio= 14.7%

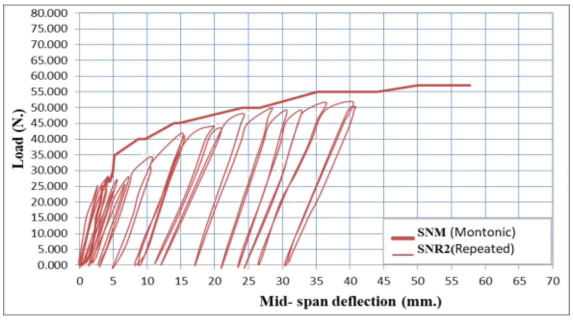


Figure 10: Load mid-span deflection curve for solid slab (SNR2).

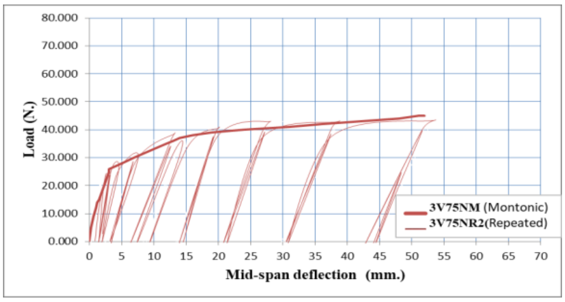


Figure 11: Load mid-span deflection curve for voided slab (3V75NR2) ,void ratio= 14.7%.

It is worth noting that the presence of voids which affects the number of required cycles to cause failure. It was found that the specimen under repeated load R1 (SNR1) failed at (43) cycles which were more than the number of cycles required to cause the failure of specimens (3V75NR1). Besides, the capability of the specimen (3V75NR1) to withstand cycles was decreased by about (7%). Also, the ability of the specimens to withstand more cycles under repeated load pattern R2 was decreased by about (16.7%) in specimen 3V75NR2 with respect to SNR2.

IV. Load-Strain response

The load-strain relation is necessary for a better understanding of the behavior of reinforced SCC voided slabs under repeated loads. Hence, the electronic strain measurement was monitored at the top and bottom face of the concrete. Also, the strain measurement was recorded at the flexural reinforcement bars. The strains have been measured at the top and bottom fibers (compression face and tension face of concrete), and flexural reinforcement of the specimen under repeated loading. It was found that The flexural steel bars were yielded at (1980and1400) microstrain for normal SCC slabs (SNR1) and voided slabs (3V75NR1) respectively, as shown in Figs (12 and 13).

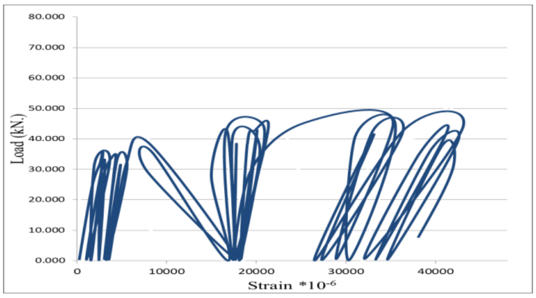


Figure 12: Load–strain curves at typical flexural steel reinforcing bars of the specimen (SNR2)

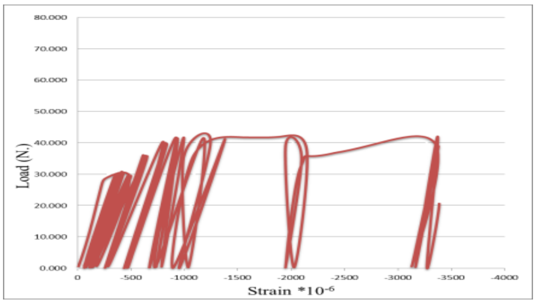


Figure 13: Load–strain curves at the top face of concrete of specimen (3V75NR1)

7. Conclusions

Based on the experimental results of solid and voided slabs, the main conclusions can be summarized as follows:

1. The failure mode of specimens that were conducted under repeated loads was almost similar to that occurred in corresponding specimens tested under monotonic load.
2. Some cracks of slab specimens that tested under repeated load regime were larger than those that took place incomparable specimens which were tested under monotonic load.
3. The value of the maximum load of the specimen tested under repeated load regime was smaller than that of slab specimen which was tested under monotonic load in the range between (6% - 17.2%).
4. The capability of specimen that tested under repeated load regime R1 to withstand loading cycles was decreased by about 7% with the presence of voids and for the specimen tested under repeated load regime R2 for the peak ultimate load decreased by about 16.7% as compared with to the solid slabs tested under similar load pattern.
5. The deflection at peak ultimate load of the specimens tested under repeated load regime was greater than that of corresponding specimens tested under .

References

[1] A.A. Allawi and A.H. Jabir, "Response of laced reinforced concrete one way slab to repeated loading". Journal of Engineering, 22(9): p. 36-54, 2016.

[2] R. Sivagamasundari and G. Kumaran "A comparative study on the flexural behaviour of one-way concrete slabs reinforced with GFRP reinforcements and conventional reinforcements when subjected to monotonic and repeated loading," Open Civil Engineering Journal, 2: p. 24-34, 2008.

[3] B.J. Al-Sulayvani and D.N Al-Talabani, "Strengthening and repair of circular RC slabs with openings using CFRP strips under repeated loading". Construction and Building Materials, 84: p. 73-83, 2015.

[4] M.A. Ismael "Flexural behavior of steel fiber self-compact concrete slabs," Diayala Journal of Engineering, 8(4): p. 83-99, 2015.

[5] R. Sivagamasundari and G. Kumaran, "Experimental study on the behaviour of concrete one way slabs reinforced with GFRP reinforcements under constant and variable amplitude repeated loadings," International Journal of Civil & Structural Engineering, 2(2): p. 556-578, 2011.

[6] Concrete, Self-Compacting, "The european guidelines for self-compacting concrete," BIBM, et al 22 (2005).

[7] ACI Committee 363, "State-of-art report on high-strength concrete (ACI 363R-92)," American Concrete Institute, Farmington Hills, Michigan, 55 pp. Council, A.T., 1992.