Enhancement Energy Absorption in Flat Slabs Using Slurry Infiltrated Fibrous Concrete

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Abstract. In this paper, enhancing the energy absorption by using slurry infiltrated fibrous concrete (SIFCON) in flat slab-column connection is studied. Eight specimens of reinforced concrete slabs identical in reinforcement and dimensions were tested, six of them were casted as a hybrid reinforced concrete slabs [normal strength concrete (N.S.C) and SIFCON] and the remaining two slabs were casted with a N.S.C as control specimens. SIFCON was casted monolithically with a N.S.C with a different thickness by a square shape of side length (0.5 d) at the center of the specimens, once at all the thickness of cross section of the slab (80 mm) and the others at half thickness (40 mm) either at compression or tension face of the slabs. Two types of fiber were used in SIFCON. All specimens were tested under the same condition by applying a vertical load downward through a square column with dimensions of (100*100*200 mm). The results showed that the use of SIFCON increasing the energy absorption for all cases with a varying percentage according to the location of casting SIFCON within the cross section of the slabs and the type of fibers which used in SIFCON. The enhancement in energy absorption due to using SIFCON with a square shape at center of slabs (155 mm) was ranged from 36.04% to 77.37% compared with the control specimens.

Keywords: Energy absorption, slurry infiltrated fibrous concrete, SIFCON, hybrid concrete, punching test, flat slab.

1. Introduction
The flat plate slab is susceptible to punching shear failure. This type of failure is catastrophic because no visible signs are shown before failure. Therefore, it is important to control this type of failure through an increase the energy absorption and ductility that may give clear signs before failure in addition to the ability to withstand in the event that the building is exposed to sudden loads. Energy absorption capacity can be defined as that area under the load displacement curve of the tested slabs. This area was calculated up to the ultimate load and corresponding displacement. Ohno and Husain [1-2] identified the energy absorption capacity of reinforced concrete members as a measure of absorbed energy up to its ultimate state. The authors supposed that the energy absorption capacity up to the final status of the slabs is the most appropriate index in the structural response against ground motions. Therefore, increasing energy absorption was very important issue to preserve the buildings from sudden collapse, especially in the event that the buildings is exposed to sudden loads such as earthquakes and explosions. Further focus has been given to use advanced composite materials to strengthen especially fibers in all different types, to prevent sudden punching shear failure. In this study, using the slurry infiltrated fibrous concrete
SIFCON is a strengthening martial. SIFCON is a comparatively modern material differentiated from fiber reinforced concrete fiber reinforced concrete (FRC) in two aspects that is fiber volume fraction and manufacturing process. SIFCON was developed to incorporating large amounts of fibers in cement composites, to get a very high strength property. The researchers began to use a large variety of fibers. SIFCON has high strength as well as large ductility and far significant potential for structural applications [3-7]. The matrix does not contain coarse aggregate which, of course, cannot infiltrate through the tiny spaces between dense fibers network, but has a high cements content. However, it may contain fine or extra-fine sand and additives such as silica fume, fly ash, and slag. The mortar fineness must be designed to properly infiltrate the dens fiber layer placed in mold. Limited research work has been carried out on using SIFCON to improve punching shear, and all of this study depending on cast all the slab with SIFCON [8-10]. But this way not economical due to the need for large quantities of fiber. Therefore, in present study, improving the normal strength concrete slabs using small quantities of SIFCON as a hybrid slabs, to obtaining good results with great economy will be study. The influence of the variables studied in present work covers the thickness and position of SIFCON and the type of fiber used.

2. Experimental Work

The experimental work includes initialization and test of raw materials and making trail mixes right up to the required mix proportion of normal concrete and mortar. After that eight slabs were casted and tested to study the effect of using SIFCON on energy absorption index. Figure 1 shows the flowchart for the experimental work.

3. Materials Used for Cast Slabs

For the slab specimens, two types of concrete used N.S.C mixtures with compressive strengths of 25 MPa and the other type which is SIFCON with two types of fiber [steel fiber and hybrid fiber (50 % steel fiber and 50% synthetic polypropylene fiber)] with compressive strengths getting from trail mix of (92 and 62 MPa) Sequentially [11].

3.1 Materials Used for Preparing Normal Strength Concrete

Normal strength concrete was design according to (ACI Committee 211.1-91 [12]) American method of mix proportions selection. The concrete strength \( f'c \) target was 25 MPa.

3.1.1 Portland Cement. Type of cement used was limestone Portland cement (CEMII / A – L - 42.5R), that mate with the (IQS No. 5/1984) limitations [13].

3.1.2 Fine Aggregate. Natural local sand was used which conforms to the limits of Iraq specification (IQS No.45/1984) [13], Zone (2). Figure 2 explain the grading curve for the sand after sieving.

3.1.3 Coarse Aggregate. Natural rounded gravel with a maximum size of 10mm as shown in the grading curve was used as a coarse aggregate in this work. Mechanical and chemical properties meet the requirements of (ASTM C33 /86) [14]. The grading curve of the natural gravel shown in Figure 3.

3.2 Materials Used for Preparing SIFCON

In the experimental study, many trail mortar mixtures were performed to get the goal mixing proportions and with the assistance of some previous studies [15-17].

3.2.1 Portland Cement. Type of cement used was limestone Portland cement (CEM II/A-L- 42.5 R), that mate with the (IQS No. 5/1984) limitations [13].

3.2.2 Extra Fine Sand

Natural local sand was used as a fine aggregate. Only extra fine sand, which was pass through (600 \( \mu \)m) sieve to separating the coarser particles used in preparing mortar. It conforms to the limits of Iraq specification No.45/1984 [13], Zone (3). Figure 4 shows the grading curve after sieving process.
EXPERIMENTAL WORK

Preparing and testing raw materials

Trail Mix of Normal Strength Concrete to Adopt the Optimum Mix Proportion

Test on Fresh Normal Strength Concrete

Slump Test

Get the optimum mix proportion for normal strength concrete

Casting normal strength concrete samples (cubes, prisms and cylinders)

Test samples at ages (7 and 28 days)

Trail Mix of Mortar Infiltrated Fiber Concrete to Adopt the Optimum Mix Proportion

Test on Fresh Mortar Infiltrated Fiber Concrete

Mini Slump Flow Test

V-Funnel Test

Get the optimum mix proportion for mortar

Casting mortar infiltrated fiber concrete samples (cubes, prisms and cylinders)

Test samples at ages (7, 28 and 56 days) to get the best percentage of fiber to use in slabs

Casting slab column connection spacemens

Hybrid concrete (Normal strength concrete and mortar infiltrated fiber concrete with hybrid fiber (3% hooked end steel fiber and 3% polypropylene fiber) around the column

Normal strength concrete with shear reinforcement as a reference

Normal strength concrete as a reference

Hybrid concrete (Normal strength concrete and mortar infiltrated fiber concrete with 6% hooked end steel fiber around the column

Testing punching shear for all slabs column connection spacemens under monotonic load

Figure 1. Experimental program flow chart.
3.2.3 Silica Fume (SF)
In this work, silica fume (sf) used was commercially known as Mega Add MS (D) from the chemical company (CONMIX), with the replacement (10%) by weight of cement.
3.2.4 High-Range Water Reducing Admixture
High range water reducing admixture was used in this work for the preparation of mortar, known commercially as (Hyperplast PC200). It is a product of the company (DCP), and meets with the (ASTM C494/C494 M) requirements [18].

3.2.5 Fibers
Two different types of fibers were used. The first type was hooked end steel fibers with a length of (30mm), a diameter of (0.5mm) and the tensile strength of about (1100 MPa), the hooked fiber was supplied from JATLAS Company in Turkey. The second one was synthetic polypropylene fiber with a length of (27mm), a diameter of (0.27mm) and with a tensile strength of about (570-660 MPa), this type of fiber was manufactured by the FORTA -FERRO Company in U.S.A. The two types of fibers following the ASTM A820 /A820M-04[19]. Figure 5 shows these types of fibers.

3.3 Steel Reinforcement
Deformed steel bars with two different diameters were used in the specimens. Uniaxial tension tests were carried out on the (6 & 10 mm) nominal diameter bars to determine the yielding stress and the ultimate strength. Reinforced steel bars with diameter 10 mm with a yield stress of 554 MPa was used to be flexural reinforcement of the flat slab. While, (6 mm) in diameter bars has a yield stress of 560 MPa was used in column stirrups. Three samples were tested for each bar diameter and the average of the results was used. The test samples were placed in a computerized tensile test machines and tested until ruptures, according to ASTM A615 [20].

4. Specimens Casting Process
Eight slabs with a dimension of (900 *900 *80 mm) with a square column in the middle of the slab with dimensions (100*100 mm) and height of (200mm) were casted. Before casting, the selection materials were weighed according to the results obtained from the trail mixes as shown in Table 1. The mortar was mixed by electrical drill mixer with a suitable pan about (0.02m3) capacity, mixing time about (7-9) minutes. Before mixing operation, the pan was cleaned off. The binder material (cement and silica fume) were mixed in the pan to disperse the silica fume particles throughout the cement particles. Then the sand was added and the mixture was mixed to get a uniform dry mixture. The whole amount of high-range water-reducing admixture (Hyperplast PC9200) was mixed separately with (1/3) of mixing water, after that, (2/3) of mixing water was added to the mix, then HRWR with (1/3) of mixing water was fed to the mixer to obtain the required fluidity[21]. At the same time, the mixing procedure of normal strength concrete start by mixing the gravel with the dry sand in the electrical horizontal rotary drum mixer of (0.09 m3) volume capacity and mixed for several minutes. Then, added cement to the mixer and gradual adding the weighted water to the mix. Total mixing time was about (8-10 minutes).
Table 1. The optimal mixing proportions for normal strength concrete and SIFCON for (1 m³)

| Normal strength concrete | Slurry infiltrated fibrous concrete |
|--------------------------|-----------------------------------|
| Materials                | Proportions of mix (kg/m³)        | Materials | Proportions of mix (kg/m³) | Materials | Proportions of mix (kg/m³) |
| Cement                   | 368                                | Cement    | 872.1                      | Cement    | 872.1                      |
| Gravel                   | 900                                | Sand      | 969                        | Sand      | 969                        |
| Sand                     | 850                                | Silica Fume 10% rep | 96.9          | Silica Fume 10% rep | 96.9          |
| Water                    | 208                                | Hooked end Steel Fiber | 471.9     | Hooked end Steel Fiber | 235.95      |
| W/c ratio                | 0.57                               | W/b       | 0.32                       | W/b       | 0.32                       |
|                          | Super Plasticizer by wt. of Cementous (%) | 2.4       | Super Plasticizer by wt. of Cementous (%) | 2.4       |

All slabs used in present work were casted in plywood molds with a clear dimension of (900*900*80 mm), and steel mold used for isolation and limit the area will be cast with SIFCON square shape with dimensions (155*155 mm) have a clear height (80 mm). The reinforcing bar ratio was constant with ($\rho = 0.0158$) and the concrete cover for reinforcing bars was 15 mm for all sides in slabs. The two types of concrete casting together to achieve good bonding between them. The casting procedure steps is the following:

1. Before each casting, the plywood and steel molds were prepared by cleaning and lightly lubricating the internal faces by oil to prevent adhesion with hardened concrete and placed on horizontal ground.

2. After preparing the molds, the pre-equipped reinforcing steel was putted and centering it with cover 15 mm in all sides, then connect the column reinforcing steel in the center of the slab as explain in Figure 6.

Figure 6. Preparing molds and steel reinforcement.
3. Normal strength concrete preparing as mentioned previously, after many trails of casting SIFCON technique in the laboratory, multi-layers technique was adopted for incorporating fibers into the mortar matrix. The multi-layers technique involved initial placing and packing the fibers inside the steel mold as explain in Figure 7-A, which were oriented randomly, followed by filling the mold by the mortar up to this level as shown in Figure 7-B. The mortar has to be flowable enough to ensure infiltration through the fiber. At the same time, the normal strength concrete casting in the plywood mold around the steel mold reaching to the required level.

4. The contents of SIFCON in the steel mold were compacted using a steel rod with a diameter of (4 mm) to avoid honeycombing or voids. This process was repeated (for each layer) where the entire mold was filled with the required volume fraction of fiber.

5. Soon after filled all molds (plywood and steel) to the same level which required, the steel mold removed by a steady upward pull. Then using the vibration for normal strength concrete around the area cast with SIFCON to compact and achieve the bonding between the two types of concrete casting and, the specimens were leveled by hand trawling, and covered with polyethylene sheet in the laboratory for 24 hours to prevent evaporation of moisture from the fresh concrete.

The compressive strength was measured for each casting series by testing three standard concrete cubes with dimensions of (100*100*100 mm) for compressive strength of SIFCON. And cubes (150*150*150 mm) for compressive strength of normal strength concrete. After (24) hours remove the plywood mold and cast the column using square steel mold with dimensions (100*100*200 mm height) as shown in Figure 8, the column cast with normal strength concrete.
The conventional curing method was used to simulate the practical site conditions. Thereafter, slabs specimens were cured by saturated burlap and covering with a polyethylene sheet to prevent evaporation of curing water.

5. Test Procedure
The tested specimens were simply supported at the four edges and loaded centrally through square column stubs with a dimension of 100 mm sides and 200 mm in height for all specimens. All slabs supported by a large reaction steel frame and tested using a hydraulic jack with maximum capacity of 600 kN as shown in Figure 9-A. The deflection of the specimens at the center of the tension face of slabs was measured using a dial gauge with capacity of 30 mm as shown in Figure 9-B. An electric pressure transducer was used to measure the applied load as shown in Figure 9-C. The specimens were tested until reach failure load. The specimens were tested in the structural laboratory/College of Engineering / Department of Civil Engineering / University of Babylon.
6. Description and Identification of the Tested Slabs Specimens
To facilitate the comparison between the slabs, each slab specimen is identified by symbols as listed in Table 2. Two specimens casted with normal strength concrete (N.S.C) were tested as reference specimens. Other specimens were cast with N.S.C except the square area with the dimension of (155 mm) in the middle of the slab which casted with SIFCON with different thickness (80 and 40 mm). Each case casting with two types of fiber (hooked end steel and hybrid fiber 50% hooked end steel, with 50% synthetic polypropylene fiber).

| Symbol | Area cast with SIFCON | Type and percentage of fiber (%) by volume | Shapes showing the area casting with SIFCON each case cast with two types of fiber |
|--------|-----------------------|---------------------------------------|---------------------------------------------------------------------------------|
| N.S.C. | Cast with only normal strength concrete | --- | |
| 0.5 d.S | Square (155*155 mm) mid span with thickness 80mm | 6% hooked end steel | |
| 0.5 d.S.C | Square (155*155 mm) mid span with thickness 40mm upper column side at compression face | 6% hooked end steel | |
| 0.5 d.S.T | Square (155*155 mm) mid span with thickness 40mm down opposite column side at tension face | 6% hooked end steel | |
| 0.5 d.H | Square (155*155 mm) mid span with thickness 80mm | Hybrid fiber (3% hooked end steel + 3% synthetic) | |
| 0.5 d.H.C | Square (155*155 mm) mid span with thickness 40mm upper column side at compression face | Hybrid fiber (3% hooked end steel + 3% synthetic) | |
| 0.5 d.H.T | Square (155*155 mm) mid span with thickness 40mm down opposite column side at tension face | Hybrid fiber (3% hooked end steel + 3% synthetic) | |

7. Results and Discussion of Tested Specimens
All eight specimens failed in punching shear with different ultimate load after relatively large deflection for some cases as shown in Table 3. The energy absorption index calculated through the load-deflection curve as defined by [2]. Where the energy absorption index is the ratio of the total area under load-deflection curve to that under the ascending portion only as explained to the specimen (0.5d H C) in Figure 10. The energy absorption index is determined for all tested specimens according to reference [2] and the value of it tabulated in Table 3.
Figure 10. Determination of the energy absorption index for specimen (0.5\(d\) H C).

Table 3. Test result of slabs.

| Specimen | \(\gamma'c\) for N.S.C | \(\gamma'c\) for SIFCON | First crack load | Ultimate load | Max. deflection | A1 | A2 | Energy Absorption Index | Increase in Energy Absorption Index |
|----------|-----------------------|-----------------------|-----------------|---------------|----------------|-----|-----|------------------------|-------------------------------|
|          | MPa                   | MPa                   | kN              | kN            | mm            | mm² | mm² |                      |                               |
| N.S.C *  | 26.2                  | ---                   | 38              | 114.30        | 5.30          | 373.50 | 741.80 | 2.98                  | reference                     |
| 0.5 d. S | 25.89                 | 72.98                 | 40              | 118.38        | 6.95          | 238.00 | 732.50 | 4.07                  | 36.55                         |
| 0.5 d. H | 25.89                 | 49.06                 | 42              | 125.85        | 8.70          | 415.66 | 1323.60 | 4.18                  | 40.12                         |
| 0.5 d. S. C | 25.89              | 72.98                  | 38              | 115.48        | 5.80          | 256.00 | 904.20 | 4.53                  | 51.77                         |
| 0.5 d. H. C | 25.89              | 49.06                 | 41              | 134.87        | 7.20          | 304.05 | 1306.40 | 5.29                  | 77.37                         |
| 0.5 d. S. T | 25.89              | 72.98                 | 41              | 116.73        | 7.30          | 271.85 | 832.50 | 4.06                  | 36.04                         |
| 0.5 d. H. T | 25.89              | 49.06                 | 38              | 120.28        | 5.50          | 302.32 | 1100.00 | 4.63                  | 55.33                         |

*The value of N.S.C is the average of two specimen

From the test results the energy absorption index for all the specimens are increased with deferent percentage. The increasing ranged from (36.04 to 77.37 %) according to the area casted with SIFCON, distribution of SIFCON at the cross section and the types of fibers. It is also illustrated that SIFCON exhibit a high values of energy absorption capacity, this is due to the higher content of fibres in SIFCON that significantly enhance the ductility. Also, it provides additional strengthening advantages for buildings in areas vulnerable to extreme earthquakes. Here, the light will be focused on the reasons that led to the variation in the value of the energy absorption index.

7.1 Effect of Distribution of the SIFCON within the Cross-Section of the Slab on the Energy Absorption

Distribution of SIFCON within the cross section of the slabs has an important effect on improving the energy absorption index. Form the results in Table 3 the perfect zoom to use the SIFCON is the (40 mm) at the compression face as shown in Figure 11. Where the results of energy absorption index for the cases (0.5 d S C and 0.5 d H C) are (51.77 and 77.37 %) respectively comparing with control. The increase in this case because of that the high ductility and high values of energy absorption capacity of SIFCON, addition to that using SIFCON in this zoom works on strength this weak area where this area does not have any steel.
While using SIFCON with thickness of (40 mm) at the tension face as shown in Figure 12 leads to increase the EAI (36.04 and 55.33) for the specimens (0.5d S T and 0.5d H T) respectively with respect to the control specimen.

For the remaining two cases that (0.5d S and 0.5d H) were the MIFC casted with the thickness of 80mm at all the cross-section of the slab as explain in Figure 13 the increase in the EAI was (36.55 and 40.12 %) respectively with respect to the control specimen.
7.2 Effect of the Type of Fiber Used in SIFCON on the Energy Absorption Index

Clearly from the results that listed in the Table 3 that the slabs casted using hybrid fiber in SIFCON, gave higher energy absorption from that casted using steel fiber. This is because of the good distribution for hybrid fiber within the cross section of mortar as shown in Figure 14-A. Where, the synthetic polypropylene fiber works on carrying the steel fiber and prevent it from plunging and pool near the bottom as shown in Figure 14-B, and leads to maintaining the structure of concrete and trying to controls the micro cracks and prevent it from growth. Thus, more energy needed to dissolve or cut fibers scattered over a wider range within the cross section of the slabs which increases the ultimate load.
8. Conclusions

The energy absorption index of flat slabs casted using mortar-infiltrated fiber concrete was investigated in present study. Eight slabs-column connection were casted and tested under vertical load. The position and thickness of the SIFCON, types of fibers submerged in mortar varied in different specimens. The conclusions bellow was based on the test results:

1. Using SIFCON, improving the energy absorption index for all cases with varying percentage according to the location of SIFCON and the type of fiber used. The improvement percentage ranged from 36.04% to 77.37% with respect to the control specimen.
2. Using SIFCON, leads to increase deflection and change mode of failure from sadden to gradually failure.
3. Using hybrid fiber in mortar have a significant impact through provide a perfect spread of fiber crossing the SIFCON section.
4. Casting SIFCON with a half thickness of slab directly under the column at compression face, led to distribute the load on the bigger area and pushed away the line of failure from the critical punching shear area near the column towards the supports thus leads to increasing the energy absorption index.

9. References

[1] Ohno and Nishioka, (1984) “An experimental study on energy absorption capacity of columns in reinforced concrete structures,” Doboku Gakkai Ronbunshu, vol. 1984, no. 350, pp. 23–33.
[2] M. Husain, A. S. Eisa, and R. Roshyd, (2017). “Alternatives to enhance flat slab ductility”. Int. J. Concr. Struct. Mater., vol. 11, no. 1, pp. 161–169.
[3] Gilani, Adel Mohamed, Various durability aspects of slurry infiltrated fiber concrete. 2007, Ph. D Dissertation in Middle East Technical University.
[4] Kuldeep Dagar, 2012 “Slurry Infiltrated Fibrous Concrete (SIFCON)”. International Journal of Applied Engineering and Technology, Vol. 2, pp.99-100
[5] Patil Deepesh and Kanase Jayant, 2016 “Study of Mechanical and Durability Properties of SIFCON by Partial Replacement of Cement with Fly Ash as Defined by an Experimental Based Approach”. International Journal of Innovative Research in Science, Engineering and Technology. Vol. 5, Issue 5, May.
[6] Thomas, Arun Aniyan, Jeena Mathews, 2014 “Strength and Behaviour of Sifcon with Different Types of Fibers.” International Journal of Civil Engineering and Technology (IJCIET) 5, no. 12 (2014): 25-30.
[7] Farnam, Y., M. Moosavi, M. Shekarchi, S.K. Babanajad, and A. Bagherzadeh. 2010 “Behaviour of Slurry Infiltrated Fibre Concrete (SIFCON) Under Triaxial Compression,” Cement and Concrete Research 40, no. 11 (November 2010): 1571–1581.
[8] Pannem, Rama Mohan Rao, 2009 “Punching Strength and Impact Resistance Study of SIFCON with Different Fibres.” International Journal of Civil Engineering and Technology (IJCIET) 8, no.4 (2017): 1123-1131.
[9] H. Sudarsana Rao, N.V. Ramanab and K. Ganeswarc 2009 “BEHAVIOUR OF RESTRAINED SIFCON TWO WAY SLABS PART 2: PUNCHING SHEAR” ASIAN JOURNAL OF CIVIL ENGINEERING (BUILDING AND HOUSING) VOL. 10, NO. 4 (2009) PAGES 481-494
[10] Jafer, Abdulkhaliq Abdulymah. 2015 “Experimental Investigation on The Ferrocement Slabs with A Sifcon Matrix.” Wasit Journal of Engineering Sciences 3, no. 1 (March 9, 2015): 40–54.
[11] Ali, M. A. 2018 "Properties of slurry infiltrated fiber concrete (SIFCON)." PhD diss., Ph. D Thesis, civil engineering dep., UOT, Iraq, 2018.
[12] ACI 211.1-91 Standard Practice for Selecting Proportions for Normal Heavyweight, and Mass Concrete
[13] Iraq Specification No.45, "Natural Sources for Gravel that is used in concrete and construction", Baghdad (1984).
[14] ASTM C33/86, Standard Specification for Concrete Aggregates
[15] Giridhar, R., P. Rama, and M. Rao. 2015 "Determination of mechanical properties of slurry infiltrated concrete (SIFCON)." International Journal for Technological Research in Engineering 2, no. 7 (2015): 1366-1368.
[16] Khamees, Shahad S., Mohammed M. Kadhum, and Nameer A. Alwash. 2020 “Effects of Steel Fibers Geometry on the Mechanical Properties of SIFCON Concrete.” Civil Engineering Journal 6, no. 1 (January 1, 2020): 21–33.
[17] Krishnan, M Gopala, D Elavarasi, 2014 “Experimental study on slurry infiltrated fibrous concrete with sand replaced by Msand.” International Journal of Engineering Research & Technology 3, no. 5 (2014): 534-537.
[18] ASTM C494/C494M, Standard Specification for Chemical Admixtures for Concrete, 2017.
[19] ASTM A820 / A820M – 16 Standard Specification for Steel Fibers for Fiber-Reinforced Concrete
[20] ASTM A615 / A615M-16, Standard Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement, ASTM International, West Conshohocken, PA, 2016, www.astm.org.
[21] Hashim, Ali Mudhafar, and Mohammed Mansour Kadhum. 2020 “Compressive Strength and Elastic Modulus of Slurry Infiltrated Fiber Concrete (SIFCON) at High Temperature.” Civil Engineering Journal 6, no. 2 (February 1, 2020): 265–275.
[22] E. Rizk, H. Marzouk, A. Hussein, and M. Hossin 2011 “Punching Shear of Thick Plates with and Without Shear Reinforcement.” ACI Structural Journal 108, no. 5 (2011).