Reinforced Concrete Beams Capacity with Various Concrete Compressive Strengths

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Abstract. The use of high-strength concrete (HSC) started about four decades ago in world. Using (HSC) supports the applications in civil engineering such as reduce the size of buildings columns, increase the girders length, increase the buildings stores as well as the economics benefits. The paper aims to investigate the effect of using various compressive strength of concrete mixes on the behavior and load capacity of reinforced concrete beams in terms of cracking, yield, failure loads, deflection and ductility. The experimental program included the cast of six reinforced concrete beams with 1.75 m length and cross section of 200 × 300 mm. The beams specimens were tested under two points loads. Several concrete mixes were tried to obtain the concrete compressive strengths 30.9, 40.3, 51.2, 60.1, 71.6 and 89 MPa that used for every specimen beam. The experimental results showed that the increase of concrete compressive strength developed the load capacity strength and ductility. By increasing the compressive strength ratio with (30%, 67%, 95%, 132%, and 188%) caused increase in cracking load by 25%, 66%, 94%, 116% and 152% respectively, and increased the yield and failure loads by (18%, 31%, 41%, 51%, and 69%), (14%, 32%, 47%, 59% and 77%) respectively. As well as the deflection in yield was decreased by (13%, 22%, 33%, 26% and 13%), while it was increased by 10%, 16%, 23%, 26%, and 39% respectively in failure stage as a result of increased of load failure. Adding to that, ductility is increased by 27%, 50 %, 84%, 70% and 61%, respectively with the of increasing of compressive concrete strength in ratios mentioned above.

Keywords: High strength Concrete, Beams, Strength, Deflection, Ductility.

1. Introduction,
High strength concrete (HSC) could be defined as a concrete with a specified cylinder compressive strength of 41 MPa or more, considering shall not include concrete made using exotic material or techniques [1,2]. Current concrete code of practice, specification and quality control procedures are not necessarily applicable
to HSC. Also, the batching, mixing, transporting and placing procedures for HSC are almost similar to the principle from procedure utilized for normal strength concrete. Changes, refinement and increased emphasis on some certain parts of right now utilized concrete quality control procedures may be needed to insure successful concreting operations [1.3].

As results of late advancements in material innovation and requirements for HSC, it is now employed over a much broader range of member types including columns; beams and long- span bridge girders [1, 3, 4]. HSC life time cost may be less than NSC in several cases of construction, since the former requires less repair and renovations [5,6] in addition to that, structural performance and even more economical than the less expensive NSC [5,7].

Using HSC in tall buildings allows for smaller column sizes, thus increasing rentable floor space; also, deflections of tall slender buildings can be reduced because of the increased modulus of elasticity of HSC [1, 2]. As in the bridge girders, utilizing high strength concrete would take into account the utilization of longer spans, which in turn would decrease the number or size of piers required for support then reduce the cost of instruction [3,8].

For standard precast prestressed bridge girders, increasing concrete compressive strength from (34.5 to 48.3 MPa) increases span capabilities of AASHTO girders by about 15% [9,10]. Using HSC increases the available number of stores that can be constructed in buildings subject to a given maximum permissible height [10,11,12].

The present paper points to investigate experimentally the impact of using different compressive concrete strength on the capacity of reinforced concrete beams in terms of cracking, yield, failure loads, deflection and ductility. Six different values of compressive strength were used (30.9, 40.3, 51.2, 60.1, 71.6 and 89 MPa) for this purpose. As well as to predict the benefits of using the HSC in reinforced concrete beams in construction of multi-story buildings and girders.

2. Experimental Program

In this article, the details of the experimental program of the present work are presented, these include materials used, beams specimen’s preparation and test procedures.

2.1 Description of Beams Specimens and details

The six beams are identical simply supported reinforced concrete beams were reinforced, molded, cast and tested to assess and evaluate the viability of utilization of a different compressive concrete strength on the load capacity of reinforced concrete beams. All of the beams specimens were of 1.75m length and cross area of 200 x 300 mm. As well as, the specimens have the same ratio of shear span to effective depth which was equal to \((a/d= 2.25)\). 2\(\Phi\)12 mm deformed steel bars were used in the main longitudinal tension reinforcement. Additionally, the beams were strengthened with 2\(\Phi\)8 mm bars in compression zone and 8@150mm used as stirrups which were given along the shear span to avoid shear failure. Figure 1 illustrates geometry and reinforcement detailing of the beam specimens; this figure shows likewise the configuration of the test. The tensile steel ratio was kept constant as 0.46%. Table 1 sum up the properties of the used steel reinforcement, while Table 2 show the details of concrete compressive strength and steel reinforcement of specimens. All specimens were tested under the effect of two-point loads. All the beams were tested up to failure and the beams central deflections were measured using mechanical strain gauges with a precision of 0.01 mm which was situated at the beam middle-span.
Figure 1. Beam specimen's details

Table 1. Steel reinforcing proprieties

| Reinforcing bar | Nominal bar Diam. (mm) | Measured bar Diam. (mm) | Steel Yield stress (fy) MPa | Ultimate steel strength (fu) MPa | Elastic Modulus of elasticity (Es) (GPa) |
|-----------------|------------------------|-------------------------|----------------------------|---------------------------------|----------------------------------------|
| Main reinforcement | 12                     | 12.35                   | 460                        | 648                             | 207                                    |
| Shear reinforcement | 8                      | 8.01                    | 460                        | 663                             | 202                                    |

The outcomes are the average of testing three samples from each size of bars with 1000mm long.

Table 2. Properties of beam specimens

| Beam | f’c (MPa) | Ten. Reinforcement | Comp. Reinforcement |
|------|-----------|--------------------|---------------------|
| G1   | 30.9      | 2Ø12               | 2Ø8                 |
| G2   | 40.3      | 2Ø12               | 2Ø8                 |
| G3   | 51.2      | 2Ø12               | 2Ø8                 |
| G4   | 60.1      | 2Ø12               | 2Ø8                 |
| G5   | 71.6      | 2Ø12               | 2Ø8                 |
| G6   | 89        | 2Ø12               | 2Ø8                 |

2.2 Concrete Ingredients

The most important step in production (HSC) is the selection of the proper types of materials. Also, the proportioning of HSC mix design is more critical than the NSC design mixtures. In the present work, efforts were made to choose acceptable materials to get good quality of concrete mix or HSC.

Ordinary Portland cement is usually used in production of HSC because of the high C3S content percentage (about 60%). Kubaysa cement was chosen to be used in this work. This cement was found to satisfy the ASTM C150-16 [13]. It should be mentioned that, prolonging the curing period was adopted to provide enough time for C2S to hydrate in adequate amount sum to acquire the necessary compressive quality. Tables 3 and 4 show respectively the chemical and physical properties of the used cement.
Table 3. Cement Chemical Results

| Compositions     | symbol | (% by weight) | ASTM, C150-16 [8] |
|------------------|--------|--------------|-------------------|
| Lime             | CaO    | 61.0         | -                 |
| Silicon dioxide  | SiO₂   | 21.0         | -                 |
| Aluminum oxide   | Al₂O₃  | 5.40         | -                 |
| Ferric oxide     | Fe₂O₃  | 3.0          | -                 |
| Magnesium oxide  | MgO    | 2.82         | 5 (max.)          |
| Sulfur trioxide  | SO₃    | 2.37         | 2.5 (max. 3)**    |
| Loss on ignition | L.O.I  | 2.5          | 4 (max.)          |
| Insoluble residue| I.R    | 1.22         | 1.5 (max.)        |
| Lime saturation factor | L.S.F  | 0.83         | 0.66-1.02         |

Bogie's equation: (ASTM C150-04)

|                     |        |
|---------------------|--------|
| Tricalcium aluminate| C₃A    | 9.25     |
| Tricalcium silicate | C₃S    | 41.33    |
| Dicalcium silicate  | C₂S    | 29.1     |
| Tetracalciumaluminoferrite| C₄AF  | 9.25     |

Table 4. Cement Physical Results

| property                          | Test outcomes | ASTM, C150-16 [8]. |
|-----------------------------------|---------------|--------------------|
| Fineness, (Blain air permeability apparatus) (m²/kg) | 280           | 230.0 (min.)       |
| Soundness (by autoclave method)   | 0.41%         | 0.8%               |
| Setting Time                      |               |                    |
| Initial Setting Time, (min)       | 190           | 00:45 (min.)       |
| Final Setting Time, (hr)          | 4.5           | 10 (max.)          |
| Compressive Strength (MPa)        |               |                    |
| 3 Days,                           | 19.35         | 15.00 (min.)       |
| 7 Days,                           | 27.23         | 23.00 (min.)       |
| 28 Days,                          | 41.20         | Not applicable     |
| 56 days,                          | 56.87         | Not applicable     |

Regular sand taken from Al-Rahalia region(zone) is utilized as a fine aggregate, while crushed gravel from Al-Nibaey region(zone) was utilized to be the coarse aggregate with (14 mm) maximum size. Both fine and coarse aggregate were fulfilling the ASTM C33-11 specification limits [14]. Table 5 shows grading of the used natural sand. Table 6 illustrates the grading of the used crushed gravel aggregate after being sieved on (14 mm) sieve to evacuate particles with size more than 14 mm.

Table 5. Fine aggregate grading

| size of Sieve (mm) | Percent passing (%) |
|-------------------|---------------------|
|                   | Present work results | the ASTM C33-11 specification limits [9] |
| 5.0               | 98                  | 89-100                           |
| 2.36              | 93                  | 65-100                           |
| 1.18              | 68.1                | 45-100                           |
| 0.60              | 57                  | 25-80                            |
| 0.30              | 14.5                | 5-48                             |
| 0.15              | 6                   | 0-15                             |
The commercially known Melment L-10 (Melamine formaldehyde condensate) was utilized as a super plasticizing admixture in the production HSC in present work, in view of the facility of more than 12% water reduction. This admixture is classified as type F according to ASTM C 494[15]. The optimal dosage was found to be 4% by the weight of cement and the reduction in water for this dosage was about 25%. A special consideration was taken to govern the water- cement ratio in the HSC mix.

### 2.3 Mix Design

Several trial mixes had been made in order to get the desired compressive strength. British Standard BS 5328-83[16] mix design method was used because it yields mixes with strength range higher than the compressive strength ACI 211 method [17]. The concrete compressive strength was 30.9, 40.3, 51.2, 60.1, 71.6 and 89 MPa. The experimental program had been done in the structural laboratory of civil engineering department/ university of Diyala. The mix proportions details are shown in Table 7.

### 2.4 Preparation of Beam specimens

The main steel reinforcing bars were cut to the chosen length, and formed at the end of each bars with a 90-degree hook according to ACI 318-14 code [18]. No stirrups were used in middle third zone (pure bending zone). After the reinforcement placement in the molded form, it was fixed carefully to prevent its movement during casting and vibration of concrete. In adding to the beam specimens, standard cylinders control specimens were cast from each batch of concrete. The control specimens and the beam were vibrated after casting in their molds by using table vibrator. The concrete was cast in two layers with a compaction time of about 1-2 minute for each layer. The beams and control specimens were covered with moist burlaps and left in the laboratory for twenty-four hours. After that, the molds removed and all specimens placed in water paths for curing with 24C° temperature degree. All the casted specimens were tested at the age of 32 days after their curing time and drying for about 4 days. The test of compressive strength had been done according to ASTM C39 [19] utilizing (150*300mm) standard cylindrical specimens which was cast with every concrete beam specimen. A computerized testing machine of 2000kN was utilized for concrete compressive strength.
3. Results and Discussion…

3.1 Beams General behavior

The six beam specimens were tested with two-point loads. The load was applied using a hydraulic testing machine with increments of 10kN. Figure 2 shows the shape of the failed G6 specimen. All tested beams showed an elastic behavior and they were free of cracks in early stages loading. After increasing the applied load, the flexural cracks in mid span were appeared gradually. Then the shear cracks were developed and expanded in the shear span zone (range zone) with the loads further increasing. In general, the planes of failure were formed alongside the diagonal line joining the supports and the loading points. This was also noticed by Amer et al [20]. The first crack was recorded by microcrack equipment and the yield loads are recorded according the load deflection curves.

![Figure 2: loading configuration of specimen G6](image)

3.2 First cracking, Yielding and Ultimate Loads Capacity

Table 8 presents the experimental results concerning the first cracks, yield and ultimate loads capacity of the six beam specimens adopted in the present work. The results of beam (G1) were served to be as a control one and the results of the other specimens of beams were compared to G1. As well as concrete compressive strength (f'c) values are presented in Table 8. It can be seen that the initial cracks developed at a higher load with the increase of compressive strength, the increase in compressive strength provide a good restraint to the crack’s growth [21]. Also, test results demonstrate that the beam with higher compressive strength values gave more load capacity due to reduce in block stress in compression zone. For example, increasing the compressive strength form 30.9MPa for (G1) to 60.1MPa for (G4) causes improving in the ultimate load capacity by 47%. It could be notified from Table 8 that the highest value for the ultimate load capacity was recorded for beam (G6) which was about 77% higher than that of the control one.

| Beam name | f'c (MPa) | % Different | Cracking loads (kN) | % Different | Yield load (kN) | % Different | Ultimate load (kN) | % Different |
|-----------|-----------|-------------|---------------------|-------------|----------------|-------------|--------------------|------------|
| G1        | 30.9      | ---         | 32                  | ---         | 90             | ---         | 133                | ---        |
| G2        | 40.3      | 30          | 40                  | 25          | 106            | 18          | 152                | 14         |
| G3        | 51.2      | 67          | 53                  | 66          | 118            | 31          | 176                | 32         |
| G4        | 60.1      | 95          | 62                  | 94          | 127            | 41          | 196                | 47         |
| G5        | 71.6      | 132         | 69                  | 116         | 136            | 51          | 212                | 59         |
| G6        | 89.0      | 188         | 76                  | 138         | 152            | 69          | 236                | 77         |
3.3 Load-Deflection Responses
The performance of the beams under different phases of loads for different compressive strength could be described through Load-deflection relation. The central deflection of all tested beams specimens at yield and ultimate loads is presented in Table 9. As expected, the values of deflection depend mainly on the values of compressive strength for the tested beams. At the ultimate load, the central deflection was increased with increasing the compressive strength in companyed with capacity strength [22]. The highest value for mid deflection at ultimate load was recorded for beam (G6) which was about 39% higher than that of the control one (G1) companied with 77% increasing in load capacity as mentioned in paragraph 4.2.

| Beam name | f’c | % Difference | Deflection at yield load (mm) | % Difference | Deflection at ultimate load (mm) | % Difference | Ductility μ | % Difference |
|-----------|-----|--------------|------------------------------|--------------|--------------------------------|--------------|------------|--------------|
| G1        | 30.9| ---          | 5.5                          | ---          | 31                             | ---          | 5.6        | ---          |
| G2        | 40.3| 30           | 4.8                          | -13%         | 34                             | 10%          | 7.1        | 27%          |
| G3        | 51.2| 67           | 4.3                          | -22%         | 36                             | 16%          | 8.4        | 50%          |
| G4        | 60.1| 95           | 3.7                          | -33%         | 38                             | 23%          | 10.3       | 84%          |
| G5        | 71.6| 132          | 4.1                          | -26%         | 39                             | 26%          | 9.5        | 70%          |
| G6        | 89.0| 188          | 4.8                          | -13%         | 43                             | 39%          | 9.0        | 61%          |

The load-central deflection curves for all values of the adopted compressive strength are given in Figure 3. These curves seem to be identical in profile to their reference one (G1) with diverse extremes. It could be seen from Figure 3 that in the pre-cracking stage, the deflection is linearly increased with applied load increasing for all the tested beams because at this stage, the strains in the concrete as well as in steel reinforcements are comparatively small and both materials are in elastic portion of their respective responses. Gradually, the slope of the load-deflection curves is changed as results for concrete cracks with increasing the load in the post-cracking stage. The cracks caused a reduction in the effective moment of inertia value for the cross sections of beams. The deflection again increases almost linearly with the further increase of the applied load up to the point at which the tensile steel starts to yield. After steel yielding stage (post-yielding stage), the deflections immediately increased non-linearly due to the reduction of neutral axis depth. Each beam showed a different post-yield load-deflection response.
For comparison, the curves of load versus central deflection are exhibited in Figure 3 for all the tested beams. This comparison curves shows that the maximum compressive strength value (89MPa) gave a higher deflection value companied with more quality limit, more strength capacity and more protection from cracks developed and cracks propagations.

**Figure 3.** load-central deflection curves for the tested beams

**Figure 4.** load-central deflection curves of all tested beams specimens
3.4. Ductility

Ductility could be defined as a measure of a material's ability to undertake plastic deformation before breaking or rupture. Ductility could be expressed as percent from the ultimate load to the yield load for the concrete members or the deflection value at ultimate stage to the deflection at yield stage [23,24].

Member ductility is best expressed in terms of deflections. In this work, the deflection ductility index is taken as in Eq. (1) below:

\[ \mu_d = \frac{\Delta_u}{\Delta_y} \]  

(1)

Where: \( \Delta_u \) is the member deflection at ultimate load and \( \Delta_y \) is member deflection at yielding of the tension steel bars. Ultimate is definite as the stage beyond which the specimen would not be able to sustain further deformations at the same load intensity. For the present work, the ductility index for the six tested beams is given in Table 8. This table includes also a summary of the test results for deflection at yield and ultimate stages as mentioned previously.

It could be seen by Table 8 and Figure 3 that the ductility index increases with increasing the concrete compressive strengths for the equal amount of longitudinal reinforcements [25,26 and 27]. This may due to increasing in \( \rho_b \), thus at a constant value of \( \rho \) the value of \( \rho/b\) ratio decrease and then the ductility increase. Knowing that \( \rho_b \) could be calculated according to ACI 318M-2014[18] as in eq.(2) below

\[ \rho_b = \beta_1 \frac{f'c}{fy} = \beta_1 \cdot \frac{0.003}{0.003 + \frac{\sigma_y}{fy}} \]  

(2)

Here, \( f'c \): concrete compressive strength;
\( fy \): reinforcing steel's yield strength
\( \beta_1 = 0.85 \) for \( f'c \leq (17-28) \) MPa[13]
\( \beta_1 = 0.65 \) for \( f'c > 56 \) MPa[13]
\( \beta_1 = 0.85 - (0.05 \cdot \frac{f'c}{28}) \) for \( 28 < f'c < 56 \) MPa[13]

4. Conclusion

Based on the present work experimental investigation, the following conclusions are made: -

1- It could be noticed from the experimental results and the load deflection curves that the increasing of concrete compressive strength has an apparent influence on the beams load capacities and deflections.
2- The initial cracks developed at a higher applied load with increasing of compressive strength, so that the increase in compressive strength provide a better restraint to growth of cracks.
3- Although high strength concrete (\( f'c \geq 60\)MPa) show a sudden failure in compression test, high strength reinforced concrete beams exhibit a higher ductility when compared with normal strength concrete beams for same amount of steel reinforcement.
4- The flexural strength capacity of the tested beams increases as the increasing in concrete compressive strength due to reduction in compression part of the beam and this means increase in their curvature ductility that lead to increase in moment capacity or in another word increase in load capacity of the concrete section.
5- High strength reinforced concrete beams generally have no softening part. Therefore, softening may not contribute to additional ductility in high strength concrete beams.

References

[1] Revanth J.; and Kumar, G. V. (2017). High Strength Concrete. International Journal of Engineering Sciences & Research Technology, 6(2), 394-407.

[2] Preethi, M.; Ashveen, P. K.; and Hamraj, M., (2019). Strength Characteristics of High Strength Concrete (HSC) with and without Coarse Aggregate. Journal of International Journal of Engineering and Advanced Technology (IJET), 9(2), 4701-4704.

[3] Carrasquillo, P. M., & Carrasquillo, R. L. (1988). Evaluation of the use of current concrete practice in the production of high strength concrete. Materials Journal, 85(1), 49-54.

[4] Paulson, K. A., Nilson, A. H., & Hover, K. C. (1991). Long-term deflection of high-strength concrete beams. Materials Journal, 88(2), 197-206

[5] Ahlam, S. Mohammed, (2018). Flexural Behavior of Spliced Ultra High Strength Concrete Beams using Finite Element Analysis. ARPN Journal of Engineering and Applied Sciences, 13(16), 4598-4609.

[6] Al-Quraishy, Q. A., (2018). Behavior of Normal, High and Ultrahigh Strength Concrete in Direct shear. International Journal of Civil Engineering and Technology (IJCIET), 99(2), pp.349-359.

[7] Chong, W.; Changhui, Y.; Fang, L., Chaojun, W.; and Xincheng, P, (2012). Preparation of Ultra-High-Performance Concrete with common technology and materials. Cement and Concrete Composites, 34(4), 538–544.

[8] Qais F. Hasan, Maan A. Al-Bayati and Dlear A. Al-Amamany. (2019). Flexural Behavior of High Strength Reinforced Concrete Beams Strengthened with Hybrid Fibers. International Journal of Civil Engineering and Technology 10(1):1147-1158

[9] Fiorato, A. E. (1994) PCA Research on High- Strength Concrete. ACI Compilation, High-Strength Concrete, Compilation 17, 4-10.

[10] Mansor A. Ahmed, (2001). Flexural cracks in high strength reinforced concrete beams. M.Sc. thesis, University of AL-Mustansriya, 1-3.

[11] Cook, J. E. (1989). 10000 psi Concrete. Concrete International: Design & Construction V.11, No.10, 67-75.

[12] ACI Committee 363. (1984) State-of-the-Art Report on High-Strength Concrete. ACI Journal, V. 81, No. 4, July-August, 1984, 364 - 411.

[13] ASTM C150/C150M-16e1. (2016). Standard Specifications for Portland Cement. Developed by ASTM Subcommittee C01.10 on Concrete and Concrete Aggregates, Vol. 04.01, West Conshohocken, PA, USA, 10pp.

[14] ASTM C33/C33M-11. (2011). Standard Specifications for Concrete Aggregate. Developed by ASTM Subcommittee C09-20 on Concrete and Concrete Aggregates, Vol.04.02, West Conshohocken, PA, USA, 11pp.

[15] ASTM C494/C494M-15a. (2015). Standard Specifications for Chemical Admixtures for Concrete. Developed by ASTM Subcommittee C09.23, Vol. 04.02, West Conshohocken, PA, USA, 10.
[16] BS 5328 Part 2. (1991). Method for Specifying Concrete Mixes.

[17] ACI 211, Part 1. (1991). Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete. American Concrete Institute. Detroit, 38pp. Also, Structural Journal, Vol.93, No.1, January – February 1996, 30 – 35.

[18] ACI Committee 318. (2019). Building Code Requirements for Structural Concrete (ACI 318M-19) and Commentary on Building Code Requirements for Structural Concrete (ACI 318R-19). American Concrete Institute, Farmington Hill, MI, 2019, 628.

[19] ASTM C 39/C 39M-16a. (2016) Standard Test Method for Compressive Strength of Cylindrical Concrete specimens. Developed by ASTM Subcommittee C09.61 on Concrete and Concrete Aggregates, Vol. 04.02, West Conshohocken, PA, USA, 7pp.

[20] Amer M. Ibrahim., Mansor A. Ahmed, and Muthafer Hameed (2017). Structural Behavior of Strengthened RC Beams in Shear using CFRP Strips. The Open Civil Engineering Journal, 11, pp.205-215. DOI: 10.2174/1874149501711010205

[21] Mansor A. Ahmed, Salman, W.D., Abbas, A.L., and Khalifa, H.J. (2018). Additional Steel Reinforcement Surrounded Opening as Strengthening in Reinforced Concrete One-Way Slabs. International Journal of Civil Engineering and Technology (IJCIET), 9,11, 1662-1671.

[22] Salman, W. D., Mansor A. Ahmed, and Mohammed, M. (2018). Behavior of Reinforced Concrete One-Way Slabs Strengthened by CFRP Sheets in Flexural Zone. International Journal of Civil Engineering and Technology (IJCIET), 9, (10), 1872–1881.

[23] Amer M. Ibrahim, Mansor A. Ahmed, Salman, W.D., and Hamood, M.J. (2018). Strength and Ductility of Bubbled Wide Reinforced Concrete Beams with Diverse Types of Shear Steel Plates. International Journal of Engineering & Technology, 7(4.20), 502-506.

[24] Shin S.W., Ghosh S. K., and Mereno J. (1989). Flexural Ductility of Ultra High Strength Concrete Members. ACI Structural Journal, 86(4), 340-400.

[25] Budynas, R. G. (2015). Shigley's Mechanical Engineering Design. 10th ed. McGraw Hill. p. 233, ISBN 978-0-07-339820-4.

[26] Salman, W. D., Safie Mahdi Oleiwi, and Mansor A. Ahmed, (2019). Flexural Behavior and Mechanical Properties of Steel Fibers Ferro geopolymer One Way Slabs Mortar. Journal of Engineering and Applied Sciences, 14(15), 1267-1281.

[27] Hussain N. Laith, Mohammed S. Ahlam and Mansor A. Ahmed, (2020). Finite Element Analysis of Large-Scale Reinforced Concrete Shell of Domes. Journal of Engineering Science and Technology (JESTEC), 15(4), 782-791.