Periodicals of Engineering and Natural Sciences ISSN 2303-4521
Vol. 8, No. 2, June 2020, pp.1083-1095

Modelling reinforced concrete beams for structural strengthening of buildings

Ali K. AL-Asadi[1], Majid Muttashar[2], Ahmad L. Almutairi[3]
[1,2] Civil Engineering Department, College of Engineering, University of Thi-Qar
[3] Public Authority for Applied Education and Training College of Technological Studies, Civil Engineering Department

ABSTRACT

Iraq has many damaged and vandalized building since it is located in the Middle East, in southwestern Asia. Reinforced concrete beams of normal weight and lightweight's beams were conducted. The study is also done on normal strength and high strength beams in each category. The reinforced concrete used were 0% and 0.75% in each category. The lengths of the concrete beams used were 35 mm and 60 mm in each category. The longitudinal reinforcement ratio in all the beams is kept at 1.46%. The effect of types of aggregates, length of concrete beams, and concrete compressive strength were studied and results were presented with regard to the shear and flexure strengths, beam load-deflection responses, mode of failure, stiffness, energy absorption, and ductility. Shear and flexural crack widths and cracking patterns of the beams were also presented. Reinforced concrete content of the beams was also discussed. The possibility of replacement of minimum concrete reinforcement for lightweight beams with reinforced concrete is discussed. The most efficient length of beams for this purpose was presented. The modeling of buildings was designed in *ANSYS* and the strengthening as well as reinforcement was being shown using the software tool for the buildings in Iraq.

Keywords: Beam, modelling, designing, reinforced concrete, structure, strengthen.

Corresponding Author:

Ali K. AL-Asad
Civil Engineering Department, College of Engineering
University of Thi-Qar, Iraq University
Iraq, Thi-Qar
E-mail: alazhareco.2005@yahoo.com

1. Introduction

In the last century the use of beams rose considerably. Its application extends from high-rise buildings to bridges in every form and from every type of material. Because some structures having transfer beams are past their serviceability time, and degradations have appeared, their retrofit is essential for continuous exploitation.Concrete is a brittle material with low tensile strength and strain capacity. This makes the concrete susceptible to cracking and shrinkage resulting in the deterioration of the concrete and eventual loss of durability [1]. To ensure durability of concrete, it is very essential to control the crack propagation process and be able to predict the cracking pattern (crack width, crack length, and crack spacing). Conventional reinforcement has used concrete bars in tension zones but this has been proven to be inadequate as it provides only one-dimensional reinforcement and not the three-dimensional reinforcement effect required in most structural members [2].

Figure 1. (a) Transfer beams being used in the buildings. (b) High depth/span ratio an under- construction building in Iraq [2]

The use of beams products is widespread in the Iraqian society. The country is estimated to generate about 2000 to 4000 tonnes of waste every month [3]. Few of the uses of reinforced concrete in Iraq Most of the reinforced concrete products are however non-biodegradable, non-compactible, and non-destroyable hence their disposal presents a huge challenge to the Waste Management Authorities and the nation as a whole. Some of the dangers posed by the indiscriminate disposal of the reinforced concrete products include flooding as a result of choking of drainage ways, pollution of water bodies including ground water resources, upsetting the food chain, and causing land and air pollution [4]. They are poisonous and therefore kill animals and cause ill-health in humans and impairment of soil nutrients for agricultural purposes as a result of over centuries of non-decay of buried plastics. There is therefore the need for re-cycling of reinforced concrete products in Iraq if the current level of usage of plastics in the country is to be sustained.
In baghdad and other parts of the country, concrete products are collected by human scavengers, deformed and recycled. There is the need for more recycling options.
This research is therefore geared towards addressing the strength and performance problems of conventionally reinforced concrete structural elements and at the same time providing an avenue for recycling thereby solving the menace of waste in the country.

- Compressive strength of concrete
- Flexural strength of concrete
- Post crack toughness of concrete
- Crack propagation, cracking pattern and crack distribution in concrete
- Water absorption of concrete and
- Surface abrasion resistance of concrete

Retrofitting bridge girders and cap beams can be of great importance due to their essential role in the infrastructure of a country. Many were built more than 60 years ago, thus several have serious degradations [5]. In this paper their retrofit using reinforced concrete and Ultra High Performance Reinforced Concrete layers will be analyzed and compared.

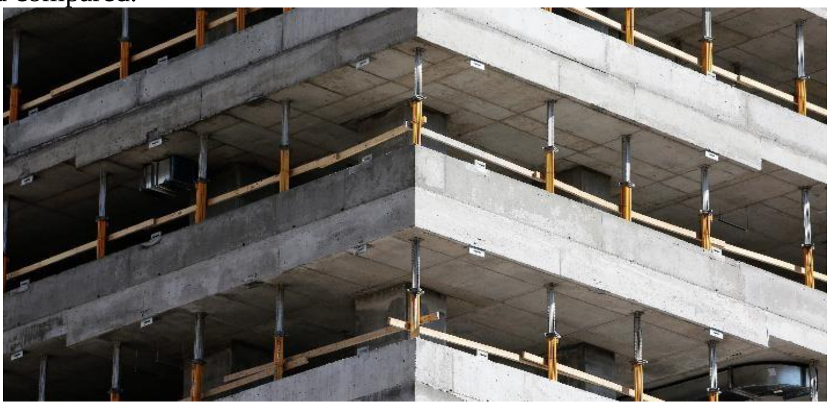

Figure 2. Reinforced concrete beams-based building under-construction in Basra Iraq [5]

1.1. Strengthening with reinforced concrete (RC)

In recent years, a lot of existing structures are past the service life. Due to this fact, their rehabilitation has been a major concern. The primary reasons for strengthening of structures include:

- Resistance upgrade to bear underestimated loads
- Changing the structural capacity to withstand higher loads
- Prevent premature failure
- Restoring corroded elements to former load carrying capacity
- Aging, creep and other types of degradations

One of the newer and highly promising materials for retrofitting purpose are the reinforced concrete (RC) composites. These can be mainly found in forms of thin unidirectional strips, or flexible sheets or fabrics, having one or at least two orientations of fibers.
Mainly when we are talking about RC strengthening systems, we have to look at the three main components, which are:

- Adhesives
- Matrices
- Fibers

Different types of RC products are presented in Figure 3.

Figure 3. Highly promising materials for retrofitting purpose are the reinforced concrete (RC) composites [5]

1.2. Strengthening with ultra high-performance reinforced concrete (UHPRC)

Even though the Reinforced concrete was invented and patented in 19th century, it was only in the beginning of the 20th century, that it was used in more and more constructions. Also, the development of high and ultra-high performance materials began 30 years ago, when a demand rose to retrofit existing concrete structures in order to extend their service lives [6]. Much research has been made in this direction, in order to create more efficient materials with high durability and strength.

Figure 4. Reinforced concrete beams placed at the construction site in Baghdad Iraq [6]

1.3. Literature review

One can define reinforced concrete as a cementitious composite material having compressive strength of over 170 MPa and tensile strength exceeding 8 MPa [7]. These high strengths can be obtained due to two major facts, namely preparation mode and fiber content. Under the term preparation mode one can understand the type of cement and size of aggregates used, but also the addition of silica fume or fly ash in some cases in order to reduce the volume of voids in the matrix [8]. Different natural environments require different mixtures in order to obtain the required durability and strength. The second component, namely fibers have an effect on the tensile strength of reinforced concrete [9]. These fibers come in different sizes, shapes and are made of different types of material as mentioned above. The way they work is by creating a miniature bridge across the micro-cracks, to transfer the tension.

An important characteristic of the reinforced concrete is its stress-elongation curve in tension [10]. The stress-elongation curve helps differentiate conventional reinforced concrete from high- performance one by analyzing its response in the post-cracked stage.

1.4. Advantages of reinforced concrete in strengthening

Reinforced concrete is considered a relatively new material in construction field. Thus many engineers are not yet familiar with its. In the following list are some of the advantages of reinforced concrete:

- Compared to normal concrete or even high-strength concrete, reinforced concrete exhibits far greater compressive strength, usually above 150 MPa. Thus cross-sections of elements can be reduced.
- Due to fiber content, reinforced concrete has considerable tensile strength, when compared to normal concrete.
- Reinforced concrete has a fast curing time. In the first two days it can reach up to 70% of its ultimate strength. Thus elements can be loaded after 48 hours.
- Due to the composition of reinforced concrete, its flowability is greater than of normal concrete. It can be used to fill small spaces without creating voids inside the concrete matrix. Thicknesses are mostly limited by the length of the fibers.
- Reinforced concrete can be considered an almost impermeable material. This makes the material a perfect protection for concrete against corrosion or chemical degradation. Thus structures using reinforced concrete become very durable and have longer service lives than normal concrete ones.

1.5. Drawbacks of reinforced concrete in strengthening

Having presented the advantages of reinforced concrete it is also important to highlight its drawbacks, such as:

- Initial costs of structures using reinforced concrete is much higher than the ones using normal of high-strength concrete. This can discourage investors in using the material.
- Even though a lot of research was conducted concerning reinforced concrete in the last decades, there is still no general design code for structure made out of this material, thus each project needs to be considered individually.
- For now, only a few producers of reinforced concrete exist on the market. Also special preparation method of the material is known by only a few specialists.
- Many current engineers do not have enough information about reinforced concrete to make them comfortable enough to apply retrofit designs based on the material. Simple and thorough presentations have to be made for them in order for the material to be more promoted in practical field also.

2. Material and methods

a. Concrete

Four types of concrete were produced based on the type of aggregates and concrete compressive strength and types of reinforced concrete. Normal weight and lightweight concrete were designed to target 35 MPa and 70 MPa to represent normal and high strength specimens, respectively. Ordinary Portland general use cement was blended with all kinds of aggregates. A substance called superplasticizer was added to those beams with reinforced concrete in order to improve the workability of the mix. The mix with 0.75% fibres of short reinforced concrete showed better workability than mixtures with long fibres while pouring the beams.

b. Reinforced bars in strengthening

Deformed concrete reinforcing bars of 15M and 20M were used against the flexural moment. Besides, 10M deformed concrete double-legged stirrups were placed to clamp the longitudinal bars within their detailed spacing. The 35M bars were cut and perpendicularly placed as spacers on the bottom reinforcing bars in order to hang the second reinforcing row and separate it from the first one. Testing both 20M and 15M concrete reinforcing bars showed yield strengths of 440 MPa and 420 MPa, respectively. Therefore, average yield strength was taken as 430 MPa for both reinforcing bars.

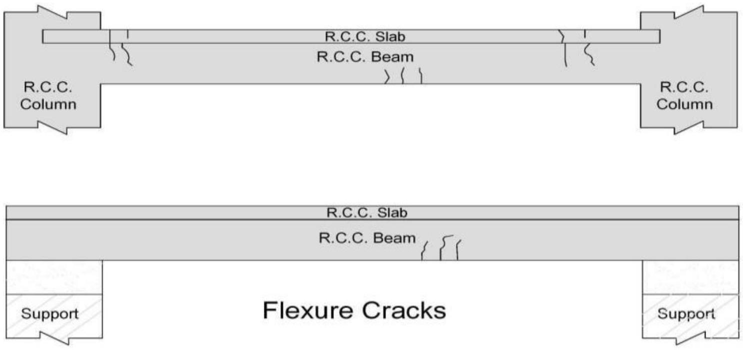

Figure 5: Flexure crackages in beams has high concrete compressive strength behaviour with high workability.

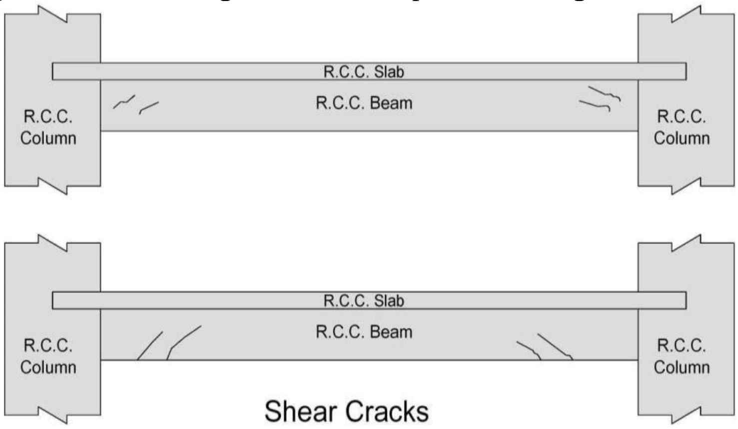

Figure 6: Shear crackages in beams has less concrete compressive strength behaviour with less workability.

3.1 Types of concrete mixtures in beam strengthening

Four types of concrete mixtures were produced based on the database of a chain of trials conducted in this research. These types of mixtures were classified based on the type of aggregates and the type of reinforced concrete. The type of aggregates and length of reinforced concrete played a main role in the mixtures.

3.1.1 Normal strength of lightweight and normal weight mixture

Six mixtures of the twelve specimens in this experiment were designed to conform to the specified normal strength concrete of 35 MPa. Half of these six beams were poured using 10 mm normal aggregate size with (0.50 water to cement ratio and 1.20 course to fine aggregate ratio). The other half of the beams contained the same aggregate size and quantities mentioned previously, but with lightweight aggregates and about 8% more retarders. The quantities in kilograms per cubic meter for normal strength concrete of both lightweight and normal weight aggregates. Some plain and fibre reinforced concrete trial mixtures, either with (0.40 or 0.45 water to cement ratios), showed high concrete compressive strength behaviour with less workability. Therefore, the main objective of using such a high water to cement ratio was to increase the workability and maintain the targeted range of specified normal strength. Although some studies claim that using high water to cement ratio might affect the durability of the concrete beam, this choice was fixed after executing many concrete trial mixtures. Four out of six normal strength beams contained a fixed amount of 0.75% of reinforced concrete, either short or long ones.

3.1.2 High strength of lightweight and normal weight mixture

Workability was negatively affected by the selected water to cement ratio of 0.35. Therefore, high rate water reducers "superplasticizer" liquid was used in the mixture to increase its viscosity by breaking the bonds among the components and enhancing the hydration between cement and water. Water to cement ratios of 0.30 and 0.28 were accomplished in a series of concrete trial batches to reach the specified high strength concrete. However, bad workability was observed at the end of those concrete mixture trials. Some researchers have stated that when less water to cement ratio is added to the concrete mixture, less hydration is achieved. A water to cement ratio of 0.35 was precisely chosen after conducting many concrete trial mixtures. Four specimens out of six high strength ones were reinforced with a fixed amount of 0.75% of short and long reinforced concrete.

3.2 Fresh concrete beams in strengthening

Strength of fresh concrete against segregation was inspected by personal experience and it was obviously noticeable to the naked eye. This test was repeated with each single batch before pouring the whole amount of fresh concrete in the formwork of the specimens. All batches with a slump within the range from 19 mm to 22 mm were approved, whereas the other rejected batches were associated with either lesser or higher than specified slump. Reinforced concrete content did not play a negative role in concrete workability in this study. Low levels of slumps mostly occurred in concrete batches with reinforced concrete. Although two different types of aggregates were used in this research, the workability was not markedly affected owing to the use of the same aggregate size. Since different water contents were used, normal strength concrete batches seemed more workable than those batches with high strength concrete before the use of the superplastisizers admixture. Higher concrete slumps were observed in plain concrete batches without reinforced concrete. Although short reinforced concrete seemed more workable than long fibres during pouring, the effect of types and length of reinforced concrete on workability was almost negligible due to the use of almost similar aspect ratios.

3.3 Modeling the buidlings

Concrete hardened beams were cured and monitored under the same conditions as the cylindrical samples and they were both tested in the same day the beams were examined. Simple small-scaled beams (100 mm x 100 mm x 400 mm) with third-point loading setup were tested in order to measure the modulus of rupture according to standards. Table 1 shows the reinforcement ratio for flexures, fibre volume fraction, shear span-to-depth ratio, average values of concrete compressive, tensile strengths, and modulus of rupture in given units.

Table 1. Proportions of the normal strength mixtures being used for modelling the beams

Material	Beams of Normal strength normal weight (properties)		Beams of Normal strength lightweight (properties)	
	SG	(kg/m3)	SG	(kg/m3)
Cement (GU)	3.15	350	3.15	350
Coarse aggregates	2.60	985	-	-
Expanded slate	-	-	1.53	580
Fine aggregates	2.60	821	2.60	821
Water	1.00	175	1.00	175
Reinforced concrete (0.75%)	7.85	59	7.85	59
Retarders	-	600 (ml/m3)	-	650 (ml/m3)

Table 2. Proportions of the used high strength mixtures being used for modelling the beams

Material	Beams of Normal strength normal weight (properties)		Beams of Normal strength lightweight (properties)	
	SG	(kg/m^3)	SG	(kg/m^3)
Cement (GU)	3.15	530	3.15	530
Silica fume	2.20	42	2.20	42
Coarse aggregates	2.60	946	-	-
Expanded slate	-	-	1.53	556
Fine aggregates	2.60	630	2.60	630
Water	1.00	200	1.00	200
Reinforced concrete (0.75%)	7.85	59	7.85	59
Retarders	-	600 (ml/m^3)	-	650 (ml/m^3)
Superplastisizers	-	3200 (ml/m^3)	-	3500 (ml/m^3)

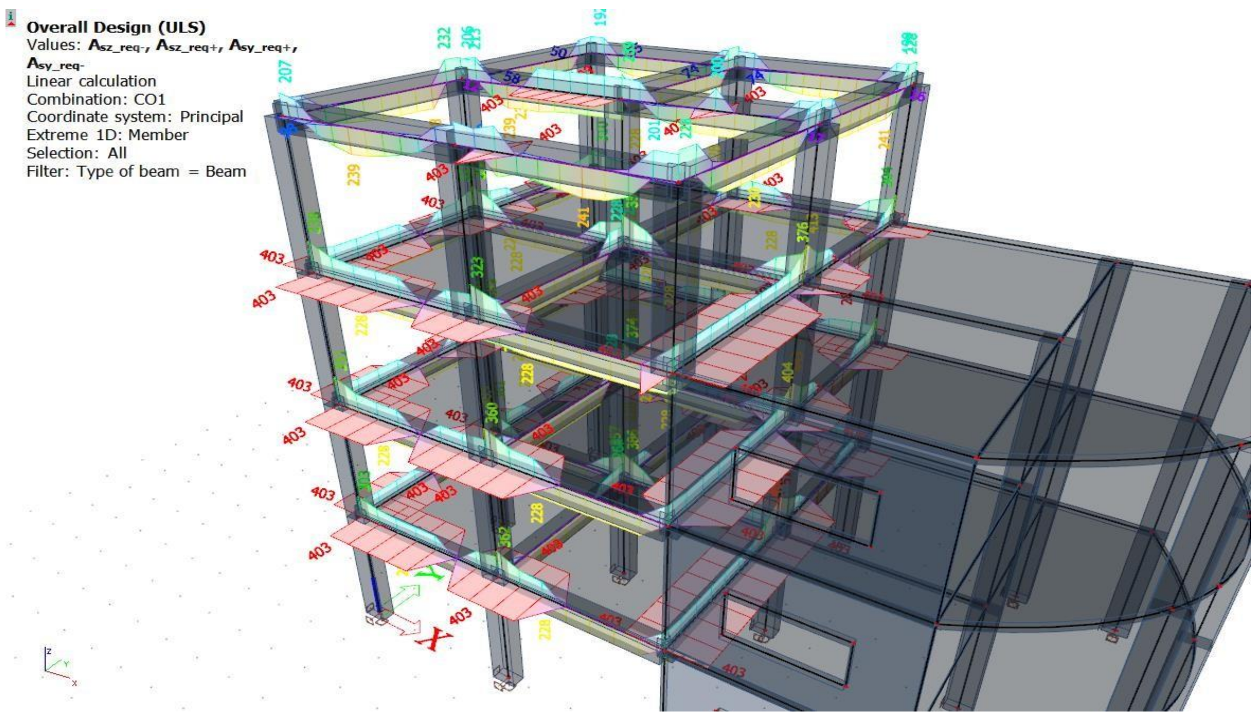

Figure 7. The modelling of building with beams

3.4 Proportioning and mixing of concrete in modeling buidlings

A beam constructed using concrete mixer with an unmixed capacity of 0.150 m^3 was used to produce the whole quantity of the required materials for all specimens in this study. A quantity of

0.256 m^3 of concrete was required for each specimen. Although two batches of 0.150 m^3 could have satisfied the amount of concrete required per beam, four batches had to be produced in order to maintain the efficiency rate of the mixer. That is, the low rate of mixer revolution of about 30 rpm played a major role in choosing a small mixing quantity. Therefore, a specific short period of time had to be set and monitored for each batch to maintain the consistency of mixture and to construct homogenous concrete in order to preserve uniform compressive concrete strengths. All concrete construction materials were proportioned by using scoops and loaded in separate buckets. Each bucket filled with a concrete portion had to be manually lifted and unloaded into the mixer just before blending them together. Coarse aggregates had to be first mixed with reinforced concrete in order to disperse and disband them uniformly before adding the remaining binder proportions.

Volumes of chemical admixtures such as retarders and superplastisizers were measured by using a glass-measuring jug and then added to the bucket with water.

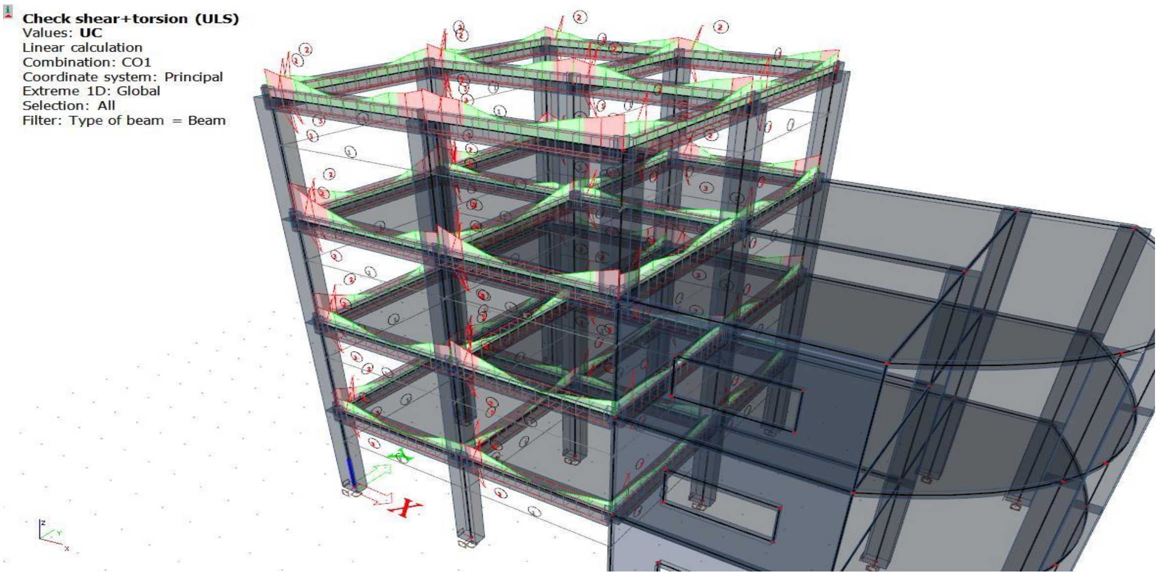

Figure 8. Proportioning and Mixing of Concrete in Modeling Buildings with Beams for strengthening

3.5 Pouring and curing of concrete in modeling buidlings

Pouring stage started with the casting and curing of normal and high strength reference beams specimens with normal weight aggregates. Buckets and trays were directly filled and used to transport and pour concrete mixtures into the beams' formworks. Concrete mixtures were uniformly cast, distributed, compacted and tapped layer by layer using an electrical-powered vibrator with a diameter head of 35 mm to avoid undesirable concrete honeycombs and segregations especially in the presence of reinforced concrete and low water content. Finishing concrete trowels were used to polish and level the top surfaces of the beams to make them smooth for gluing concrete strain and crack concrete gages. After casting, plastic rolls were placed to cover the specimens and the sampling cylinders for 28 days for curing purpose in order to maintain the water content. The other four normal weight concrete beams were cast right after testing and analyzing the reference normal weight concrete beams. Same casting procedures were repeated with the entire remaining lightweight concrete beams except that wet burlap rolls were used for curing normal weight concrete beams. All specimens were demolded after 7 days in their formworks and kept for curing for about a month.

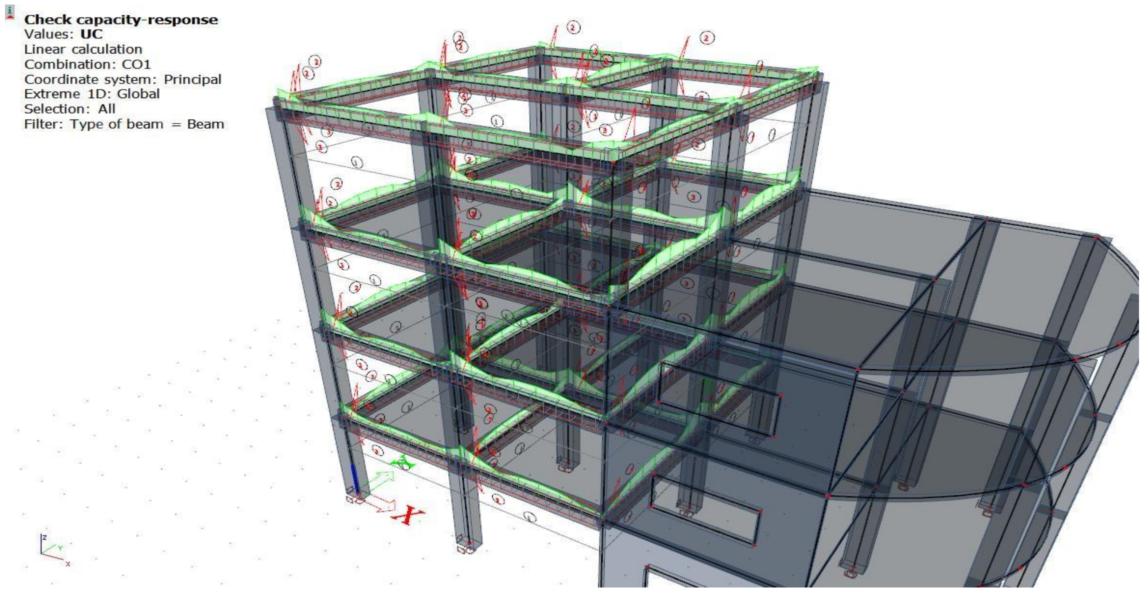

Figure 9. Pouring and Curing of Concrete in Modeling Buildings with Beams for strengthening

3. Results

4.1 2D-Reinforcement strengthening of buildings

As a result concrete strength increased the load capacity for reference concrete beams by an average rate of 70%, higher concrete strength achieves, greater load capacity gains regardless of the type of aggregates. Besides, both the higher strength normal weight and lightweight reference concrete beams showed an improvement rate of 38%, approximately, in term of deflection at a given peak load. Ultimate load resistance increased by an approximate rate of 16% for all types of concrete beams with reinforced concrete. Beam deflection increased by about 10% compared to sample, while beams dramatically showed an increase by 58% in its deflection in contrary with beam specimen. Furthermore, in lightweight beams with either length of reinforced concrete was used, deflection developed by about 20% in average compared to the same beams with lower concrete grade. Thus, it was obviously detected that the concrete compressive strength highly improved the load capacity and increased deflections of specimens.

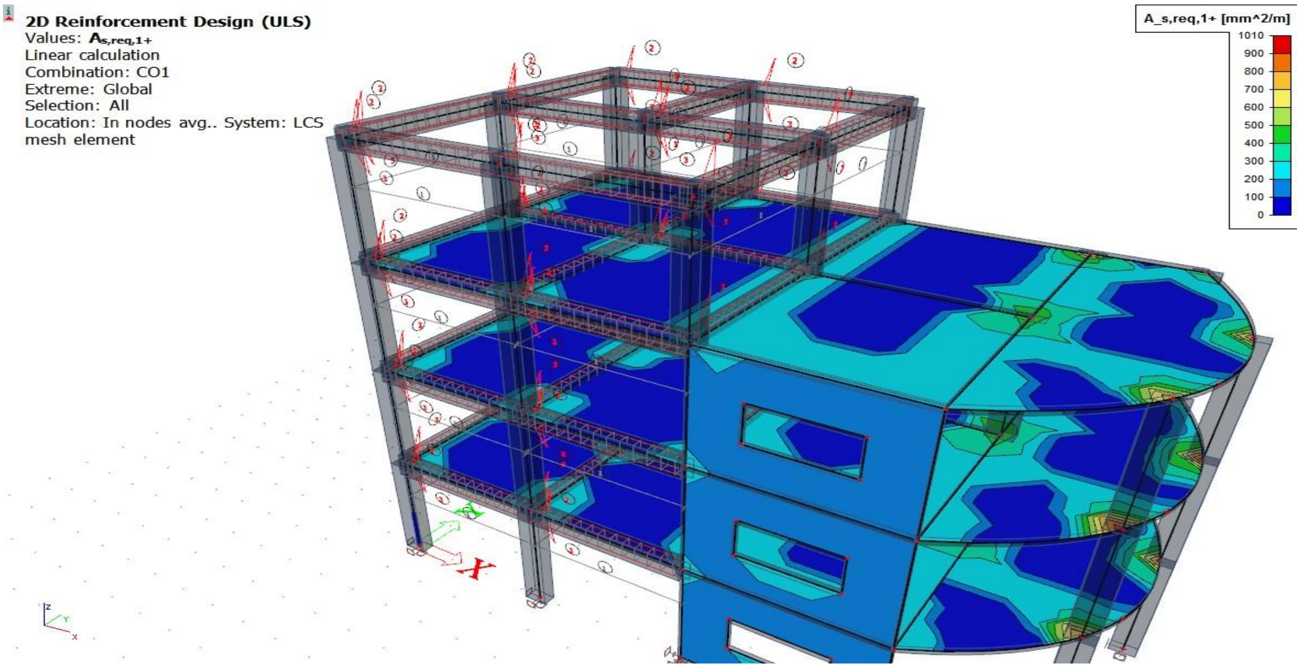

Figure 10. The 2D-Reinforcement strengthening design of buildings

4.2 Beam load-strain behaviour

Typical curves of the subjected load versus reinforcement concrete and concrete strains for the two beams that failed in ductile shear and the beams failed in flexure are shown in Figure 10. Linearity and elasticity of both concrete and concrete strains were expected to appear as the specimens were under loading until first cracks were occurred. However, concrete strains developed faster than concrete strains and this might be attributed to the high tensile stresses in the extreme extension fibre against the small compressive stresses on the extreme compression fibre. To be more specific, concrete strains were inconsiderable at that first linear stage. As the load was gradually increased and after beams were cracked, mid-span strains of reinforcing rebar rapidly increased as the cracks were opened and expanded within the constant moment zone while strains at mid-shear span were slightly lower. This particularly happened in reference concrete beams when cracks initially developed rapidly within the constant moment zone while there was almost no considerable cracks within shear span zones. On the other hand in beams with reinforced concrete, strains either in the east or west mid-shear span showed similar trends as the mid-span in beams without reinforced concrete. Although it was expected that the mid-shear span strains would increase faster than the mid-span strain as what happened in reference concrete beams, they kept developing approximately similar values and this might be attributed to the addition of reinforced concrete that led to a uniform propagation of cracks and symmetric flexural mode of failure. Loads went down as the cracks grew and highly opened in a short period of time and this was an obvious indication for beams failed in shear.

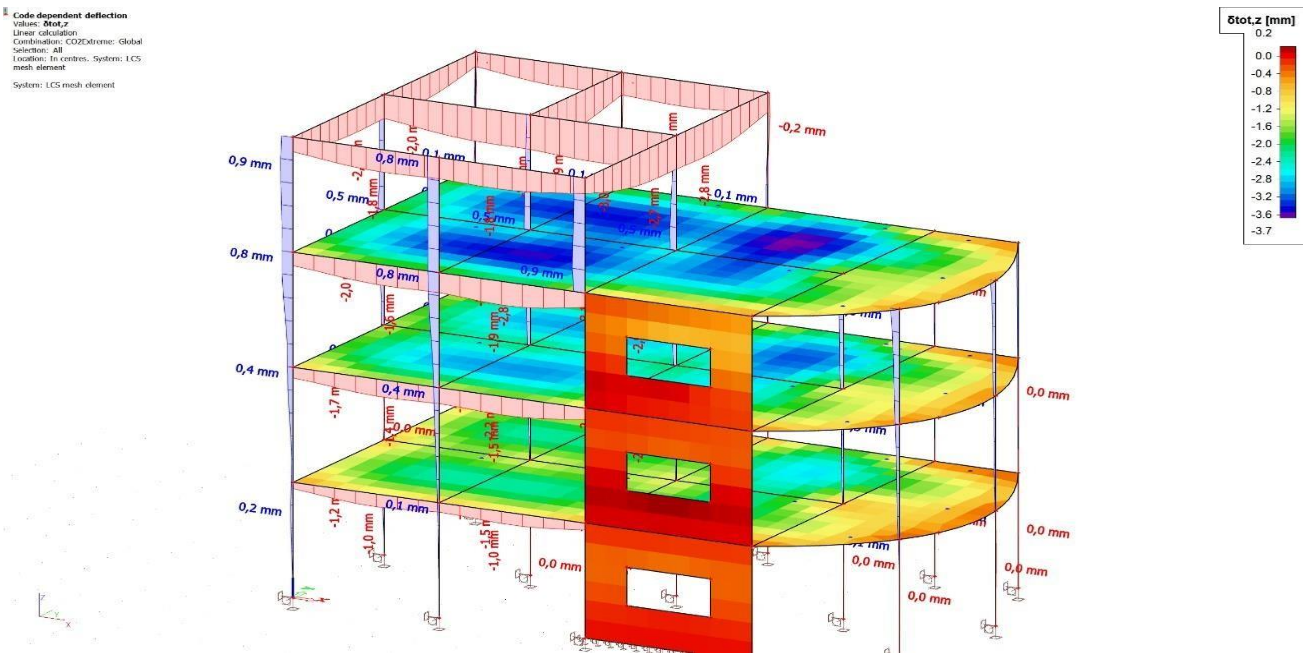

Figure 11. Beam load-strain behaviour in the modelled building from bottom-to-top

4.3 Evaluation of beam load deflection

The stiffness of beams in un-cracked section stage (1) and cracked section stage (2) generally increased as the concrete was used. To be more specific, the long reinforced concrete mostly increased the stiffness by more than 50% in the first stage and by more than 30% in the second stage. The highest ratio was with beam when the stiffness showed an enhancement by 91% compared to the reference beam. Besides, beam showed the lowest enhancement due to the addition of long reinforced concrete by about 26% in contrast with the other specimens contained long reinforced concrete. The enhancement of the stiffness due to the addition of short reinforced concrete also ranged from 5% to 31%. For example, the lowest improvement rate happened with beam compared to member while the greatest was in beam in contrast with specimen. The long fibres generally seemed more efficient in enhancing the stiffness in either stage. The higher loading capacity produced when long reinforced concrete were used, the bigger slope could be generated. Therefore, stiffness of long fibrous reinforced beams usually showed greater stiffness. On the other hand, the type of aggregates plays an important role of the stiffness of beams. For example, stiffness of beam was lower than the stiffness of specimen by about 42% on average in both stages. Although stiffness of beam was lower than member in stage (1) and higher than specimen in stage (2) by 4% in both cases, this minor influence could be negligible. Thus, aggregates mostly reduced stiffness of normal strength beams. Although concrete compressive strength was not a significant factor affecting stiffness, high concrete strength may mitigate the negative affect of presence of lightweight aggregates on stiffness.

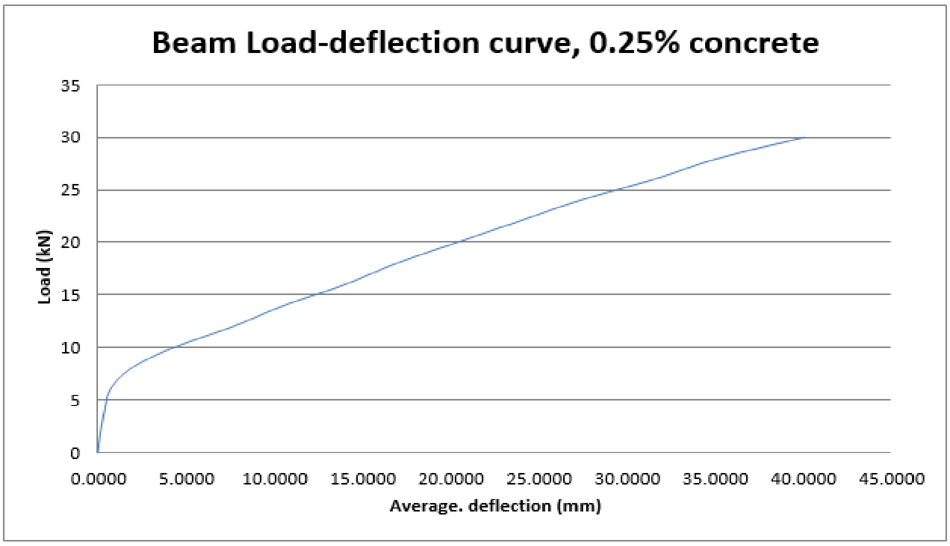

Figure 12. Beam load deflection curve with 0.25% reinforced concrete

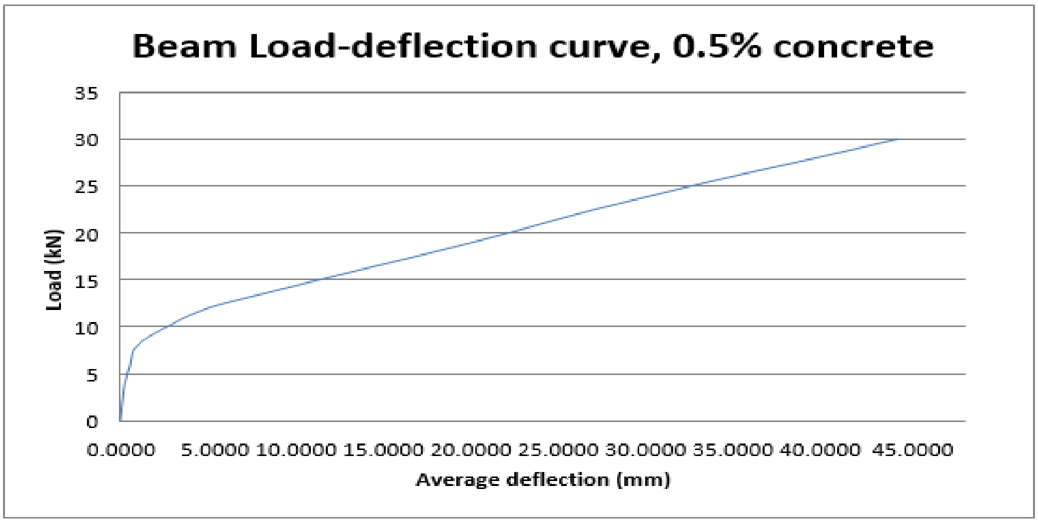

Figure 13. Beam load deflection curve with 0.5% reinforced concrete

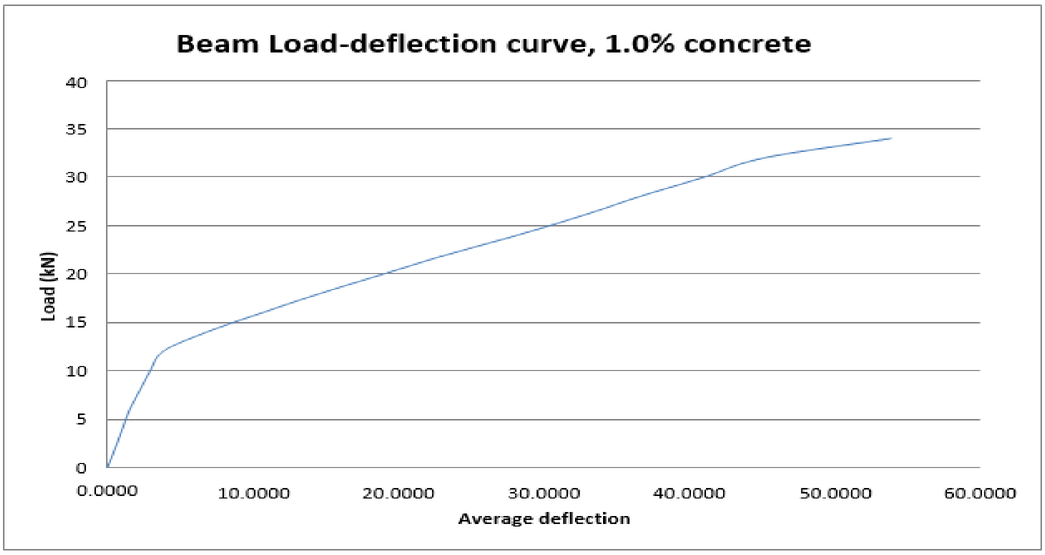

Figure 14. Beam load deflection curve with 0.1% reinforced concrete

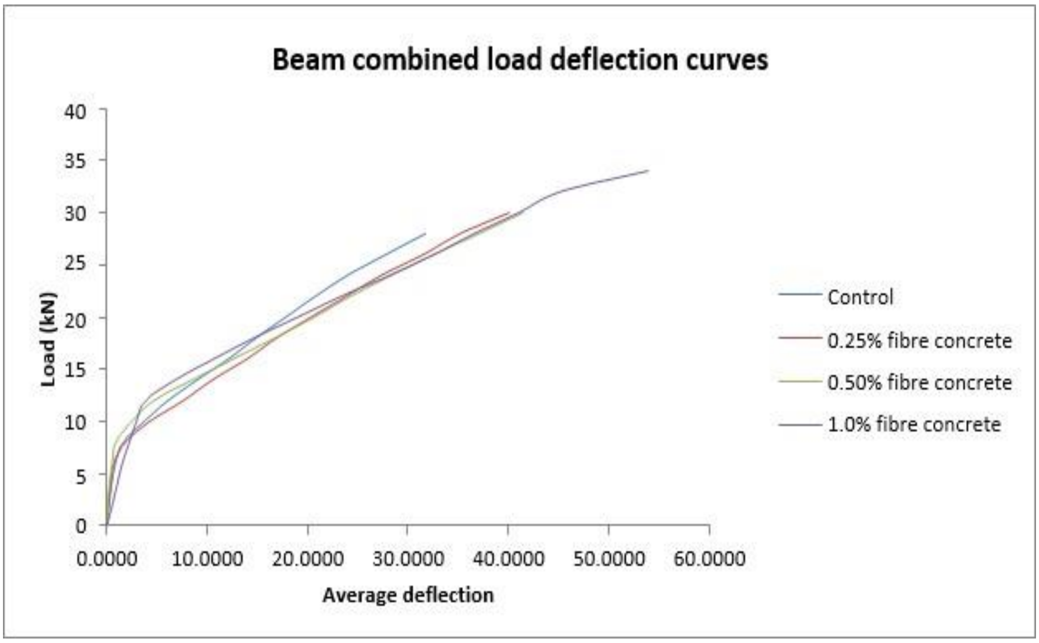

Figure 15. Comparison of amount of reinforced concrete being used for the strengthening

4. Discussion

Normal strength beams with reinforced concrete irrespective of type of aggregates showed less shear capacity compared to high strength beams with the same properties. The greater bond produced between longer double-hooked fibres was attributed to the higher aspect ratio generated by the longer length and concrete matrix. Regarding length of reinforced concrete, beam puts the requirements as: the ratio of length and diameter should be more than 50 and less than 100 [11]. The length of the beam satisfying this requirement are the most efficient to replace minimum shear reinforcement of flexural members.

The workability of lightweight concrete would be negatively affected by the addition of minimum recommended amount of reinforced concrete before adding the sufficient quantity of workability admixtures.

Although some specimens showed that the onset of first flexural and shear cracks occurred earlier in members with long double-hooked reinforced concrete than in beams with short fibres, these specimens with long double hooked reinforced concrete showed higher capacity and greater deflection at failure [12]. This was attributed to the larger number of short reinforced concrete exist within the section to resist the opening of first cracks, while long reinforced concrete would be in less quantity to resist initial cracks.

5. Conclusions

This study was carried for the modelling of reinforced concrete beams for structural strengthening of buildings in Iraq. All types of reinforced concrete transformed the brittle mode of failure to more ductile collapse. However, ductile concrete fibrous beams should not always fail in flexural mode of failure especially with short reinforced concrete. Long reinforced concrete beams (doublehooked end with 60 mm long) always replaced the shear mode of failure by a flexural manner. Flexural mode of failure governed all specimens with long double hooked reinforced concrete. Both short and long reinforced concrete maintained a maximum crack width at serviceability limit state of less than 0.18 mm. However, short reinforced concrete seemed better than long fibres in term of reducing and controlling crack widths. Reinforced concrete with 35 mm long reduced crack width by about 55% on average while crack widths of those beams with long reinforced concrete were reduced only by 45% approximately. This was attributed to the larger o of shrt reinforced concrete can be within to resist the expansion of the crack, while long reinforced concrete would be in less number to resist enlargement of crack thicknesses. Adding 0.75% of long or short reinforced concrete reduced spacing. Therefore, number of cracks was increased in all beams with concrete beams either short or long ones.

References

[1] M. Imam, L. Vandewalle, F. Moretelmans, and D. Van Gemert. Shear Capacity and Flexural Ductility of Reinforced High- and Normal-Strength Concrete Beams. Engineering Structures. Doi: 10.5353/th_b3121444, vol. 12, pp 132-137, 2015.

[2] M. Imam, L. Vandewalle. Role of Fibres in Controlling Failure Modes of High-Stregth Concrete Beams. Repair, Rehabilitation, and Maintenance of Concrete Structures. vol. 13, pp 232-237, 2015.

[3] K. Jain, and B. Singh. Deformed Steel Fibres as Minimum Shear Reinforcement - An investigation. Structures, 7, 126–137. https://doi.org/10.1016/j.istruc.2016.06.003, vol. 14, pp 32-43, 2016.

[4] P. Jongvivatsakul, K. Matsumoto, and J. Niwa. Shear Capacity of Fibre Reinforced Concrete Beams with Various Types and Combinations of Fibres. Journal of JSCE, vol. 04, pp 2-7, 2017.

[5] T. Kang, H. K. Kim, W. Kwak, Y. K, and S. G. Hong, S.-G. Shear Testing of Steel Fibre-Reinforced Lightweight Concrete Beams without Web Reinforcement. ACI Structural Journal, vol. 6, pp 12-17, 2015.

[6] C. G. Kim, H. Lee, H. G. Park, G. H. Hong, and S. M. Kang. Effect of Steel Fibres on Minimum Shear Reinforcement of High-Strength Concrete Beams. ACI Structural Journal, vol. 08, pp 43-46, 2015.

[7] K. S. Kim, D. H. Lee, J. H. Hwang, and D. A. Kuchma. Shear Behaviour Model for Steel Fibre-Reinforced Concrete Members without Transverse Reinforcements. Composites Part B: Engineering, 43(5), 2324–2334. https://doi.org/10.1016/j.compositesb. vol. 1, pp 12-17, 2018.

[8] Y. Kwak, M. Eberhard, W. Kim, and J. Kim. Shear Strength of Steel Fibre-Reinforced Concrete Beams without Stirrups. ACI Structural Journal, vol. 09, pp 22-23, 2016.

[9] S. J. Lee, and J. P. Won. Flexural Behaviour of Precast Reinforced Concrete Composite Members Reinforced With Structural Nano-Synthetic and Steel Fibres. Composite Structures, 118(1), 571–579. https://doi.org/10.1016/j.compstruct. vol. 22, pp 45-47, 2018.

[10] F. Minelli, A. Conforti, E. Cuenca, and G. Plizzari. Are Steel Fibres Able to Mitigate or Eliminate Size Effect in Shear? Materials and Structures/Materiaux et Constructions, 1–15. https://doi.org/10.1617/s11527-013-0072-y, vol. 21, pp 46-47, 2014.

[11] Md. Shah Alam. "Influence of Different Parameters on Shear Strength of FRP Reinforced Concrete Beams." PhD. Thesis, Department of Civil Engineering, Memorial University of Newfoundland, Canada. vol. 07, pp 77-79, 2016.

[12] M. Hamrat, B. Boulekbache, M. Chemrouk, and S. Amziane. Flexural Cracking Behaviour of Normal Strength, High Strength and High Strength Fibre Concrete Beams, Using Digital Image Correlation technique. Construction and Building Materials, vol. 12, pp 432-438, 2015.