Steel Fiber Reinforced Self-Compact Concrete Beam under Static Loading Using Finite Elements Method

العتبات الخرسانية ذاتية الرص والمعززة بالياف حديدية تحت تاثير الاحمال الساكنة باستخدام طريقة العناصر المحددة

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ABSTRACT

Static resistance loading of reinforced concrete beams using normal and steel fiber self-compact concrete, with loading applied at the one – third of the beam (four points) was studied. The reinforced concrete beams have been designed under static load according to ACI-318R-2014 **[1]**. The static loading consists of dead load and residential live load based on ASCE-07-2010 **[2]**.as the beam a part from residential building that scaled down and modeled to not at full scale but as like the traditional experimental test. A three-dimensional finite element models by ANSYS15.0 software **[3]**, have been established to provide a numerical solution as an alternative approach to the experimental models, with some acceptable accuracy. Experimental tests for normal, self – compact and with and without steel fiber concrete to specify compressive strength, tensile strength, and modulus of elasticity presented. Modeling analysis as simply supported beams as approximate situation of beam that was performed to evaluate the performance of ordinary, self-compact and steel fiber self-compact concrete beams under static loading.

Keywords: Static loads, Finite element analysis, ANSYS, Self-compact, Steel fiber, normal concrete.

الخلاصه

تمت دراسة تحميل المقاومة الساكنة للعتبات الخرسانية المسلحة مستخدماً الخرسانة الاعتيادية وذات الالياف الحديدية ذاتية الرص , مع وبدون الالياف الحديدية تحت تأثير التحميل الساكن (أربع نقاط). صممت العتبات الخرسانية المسلحة تحت تأثير الحمل الساكن وفقا للمدونة الآمريكية ACI-318R-2014. الحمل الساكن يتضمن الحمل الميت والحمل الحي معتمداً المواصفة ASCE-07-2010 بأفتراض ان العتبة هي جزء من مبنى سكني تم تصغيره وليس أخذه بالقياسات الحقيقية بما يتلائم مع الفحوصات العملية التقليدية المماثلة.تم إنشاء نماذج العناصر المحدودة ثلاثية الأبعاد باستخدام برنامج ANSYS اصدار (15) كحل لتوفير حل عددي كنهج بديل للطرق التجريبية، مع بعض الدقة المقبولة. تم اجراء الاختبارات التجريبية للخرسانة الاعتيادية والخرسانة الذاتية الرص المعززة وغير المعززة بألياف الحديد لتحديد قوة الانضغاط، قوة الشد، ومعامل المرونة. تم إجراء تحليل النمذجة على شكل عتبات مدعمة باسناد بسيط وهذا تقريب للحالة الحقيقية لتقييم أداء العتبات الخرسانية الانفة الذكر.

1. INTRODUCTION:

Self-compacting concrete (SCC) is a flowing concrete mixture capable to make concrete physically stronger and more solid and easy to slip under its own weight. In case of placing concrete in difficult places that has conditions not allow easy work with ordinary concrete and in sections with congested reinforcement. Adopted of this type of concrete minimize hearing-related damages on the worksite because of vibration of concrete and reduced the time required to place large sections. This type of concrete is used to improve the durability properties of concrete structures.

The properties of self-compact concrete SCC mix which has value of yield stress less than normal concrete (little difference than normal concrete but enhanced in case of presence of steel fiber), high deformability, excellent refusal for segregation that prevents separation in the concrete mix content, and high viscosity placement without external compaction. Higher paste content and lower coarse aggregate fraction compared to conventional vibrated concrete, and uses super-plasticizer.

The behavior of SCC as a structural material can be improved in case of steel fiber reinforcement is added to SCC mix composition. The steel fiber reinforcement enhances the tensile strength of concrete and makes the concrete more ductile rather than brittle.

To improved concrete durability, strength and ductility with serviceability control largely carried out by using additives material to produce a concrete with special mechanical properties to resist various types of loading and reducible the dead load by reduced geometrical dimensions and increasing the strength **[4]**.

Many researches discussed the advantages of self-compact concrete as compared with the normal weight concrete because of gives better durability concrete compressive and tensile strength with lower permeability. To increase the compressive strength of concrete and resist tensile strength, mix design of steel fiber self-compact and self-compact alone. In 2011, A. R. Barros et al **[5]**, investigated the behavior of self-compact concrete SCC under bending. Deflection and strain at stirrups and main reinforcement were measured under four point loading. The results showed that increased in beam capacity due to increase in self-compact of concrete. In 2012, Kishor S. Sable and Madhuri K. Rathi [6], investigated and compared between normal and SCC beam with and without steel fiber against shear and torsion loading. The results showed that the presence of steel fiber gave better performance as compared with the normal concrete. In 2012, S.A. Bhalchandra and Pawase Amit **[7],** studied the performance of SCC with steel fiber of beams as flexural strength. The results showed that there was improvements in mechanical properties of concrete and increased strength capacity due to presence of self-compact additive and steel fiber in the concrete. In 2013, Youcef Fritih et al **[8]**, explored the effects of steel fibers on the SCC beams under the effect of flexural. The results showed that the fiber reinforcement allowed the control of cracking to be improved. In 2013, M. Paja˛k and T. Ponikiewski **[9]**, explored the flexural behavior of SCC with hooked end steel fiber concrete beam. The results indicated that the increased in beam capacity and reduced in deflection. In 2014, Ahmed S. Eisa and Khaled S. Ragab **[10],** investigated experimentally and analytically approached the behavior of SCC beams under the effects of torsion and bending. The steel fiber used as hook with different percentages. The total six beams were tested and the results showed that the presences of SCC with steel fiber enhanced the behavior of beams under combined loading. In 2015, R.Velumani **[11],** studied the properties of SCC and the behavior of SCC beams under seismic loading. Test results indicated that the SCC resistance better than normal concrete against applied loading. In 2016, R. Vengadesan et al **[12]**, investigated the behavior of SCC reinforced beams with steel fiber. Test results showed that the strength of concrete beams will increase with increase in amount of fiber content.

In present paper, the numerical performance of steel fibers SCC reinforced beams and the behavior of mechanical concrete properties in case of normal, SCC and steel fiber with SCC concrete were discussed.

2. MATERIALS AND TEST PROGRAM:

The following materials were used in the present investigation: Portland cement –type I- which was conformed the (IQS 5:1984) requirement **[13]**; fine aggregate with a maximum size 4.75 mm, specific gravity 2.65 and fineness modulus 2.61 and Coarse aggregate with a maximum size 12 mm and specific gravity 2.62. Both, the properties of fine and coarse aggregate were conformed the (IQS 45:1984) requirement **[14]**.

A total of nine cubes with dimensions classified as six (150x150x150 mm) was adopt to check out the compressive strength of cylinder tests by compared the results with the approximate value of cylinder compressive strength that rounded (0.78-0.82) from cube strength. Three of (100x100x100 mm) with six cylinder (300 mm) height and (150 mm) in diameter have been tested under compression machine to specify the compressive strength of concrete and the same quantity have been tested for tensile strength and modulus of elasticity. The mix design adopted for normal and SCC with and without steel fiber with water / cement ratio as (0.5 and 0.45) respectively that resulted compressive strength (30.53, 39.1 and 32.3 MPa) respectively, as listed in Table (1). In SCC, the lime stone for one cubic mold was (0.4 kg) and the superplasticizer was (0.017 liter). Plate (1) shows the compression machine used for compressive strength tests for cylinder and cube specimens and specimens after tests.

(a)

(b)

(c)

(d)

Plate (1): (a) Compression machine, (b) Cylinder specimen (150x300 mm), (c) Cube specimen (150x150x150 mm), (d) Cube specimen (100x100x100 mm).

Table (1) lists the compressive strength, modulus of elasticity, tensile strength of concrete and the modulus of elasticity by ACI-318-2014 **[1],**

$$E_c = 4700\sqrt{fc'} \qquad \text{.......... (1)}$$

Where:

E_c = Modules elasticity of concrete, and fc' = Compressive strength of cylinder specimen.

Table (1): Compressive strength and modulus of elasticity for different mix type.

Mix type	Compressive strength fc' – Experimental results (MPa)	Modulus of elasticity Experimental results (GPa)	Tensile strength Experimental results (MPa)	Modulus of elasticity (GPa) Equation (1)
Normal concrete	30.53	26.35	3.62	25.97
Self-compact concrete	32.30	27.74	3.84	26.72
Self-compact concrete with steel fiber	39.10	34.58	4.43	29.39

3. BEAM SCALE DOWN:

A one – fourth scale model is scaled from prototype beam to model beam using dimensional analysis that deals with homogeneous equations. The geometry of the reinforced beam plays important rule for scale and then simulation. The model and the prototype material are same so that the scaled factor for materials becomes unity. A linear scale factor was adopted to model the dimensions from prototype and the gradation of the materials was not scaled.

4. FINITE ELEMENT MODLING:

Three-dimensional linear and non-linear finite element models of simply supported reinforced concrete beam subjected four points loading have been built using the finite element approach by ANSYS software. Eight node solid element SOLID65 was adopting to simulate the concrete beams because of cracking and crushing capabilities. The element is defined by eight nodes having three degrees of freedom at each node (translation in the nodal directions x, y, and z). Element SOLID65 in case of normal concrete there was no real constant ratio while in case of presence steel fiber another material will add to the concrete as a function of percentages from total volume. SOLID181 was used for modeling the steel plates under the applied loading and simulation the supports. This element is defined with eight nodes having three degrees of freedom at each node and eight translations in the nodal directions x, y, and z. The interface between concrete and steel plate that represents supports and under points loading are assumed as one node (merge), and having the same coordinates. The full structural analysis is performing to predict the load-deflection and load-strain performance of the reinforced concrete in case of linear and nonlinear material analysis. The criteria for convergence based on the equivalent displacement, so that the loads were applied incrementally up to convergence in small steps. Concentrated loads were applied at one-third of span from both the ends and the load step increments with total sub-steps (200). The rotational degrees of freedom were released to allow rotation at each support where one is pin and other is roller to satisfy the simply supported boundary conditions at each end. Figure (1) shows the simply supported beam, loading locations, boundary condition and geometry. The beam was designed based into ACI-318-2014 **[1]** and the loading according to ASCE-07-2010 **[2],** with superimposed dead load act on the top of slab is (4 kN/m^2) and live load (2 kN/m^2). The beam dimensions (200x300x1500 mm) with effective depth (275 mm) and reinforced by two (16 mm) bar diameter with yielding strength (400 MPa), modulus of elasticity (200 GPa), Poisson's ratio (0.3) and density of the steel was (7850 kg/m^3). The main reinforced bars were φ16 mm and the stirrups were φ10@200 mm center to center.

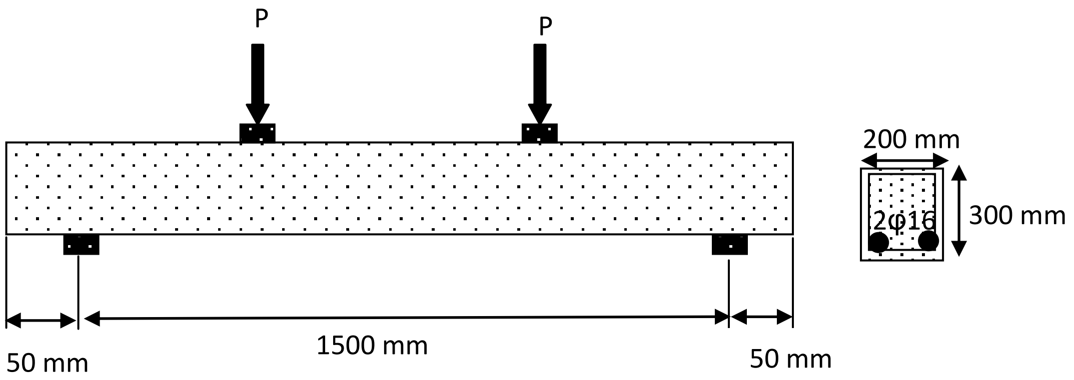

Figure (1): Reinforced concrete beam model.

4.1 Concrete Modeling:

The compressive strength, tensile strength and modulus of elasticity in three different cases as normal, self-compacted, and self-compacted with steel fiber concrete were founded by experimental tests and listed in Table (1). Figure (2) show the stress-strain behavior of concrete in three cases (fitted) from the scatter points from the experimental tests that used in nonlinear analysis because of in linear the modulus of elasticity assumed constant.

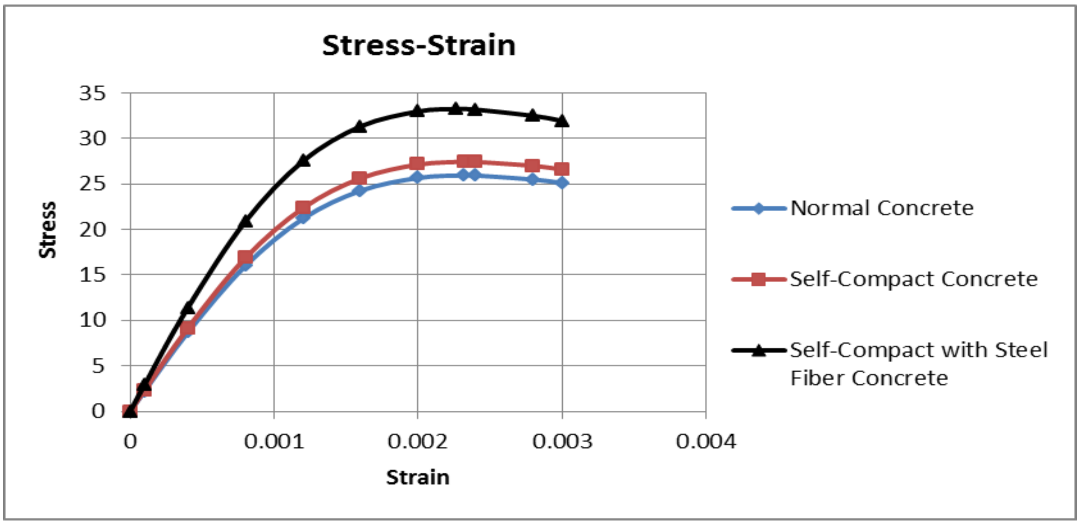

Figure (2): Uniaxial stress-strain (fitted) behavior for different types of concrete.

4.2 Reinforcement modeling:

The reinforcing deformed bar that representing the main reinforcement and stirrups were modeled as linear and nonlinear. The modulus of elasticity is kept constant as (200000 MPa), for linear analysis, while in nonlinear analysis, the steel reinforcement assumed behaves as elastic-full plastic as shown in Figure (3).

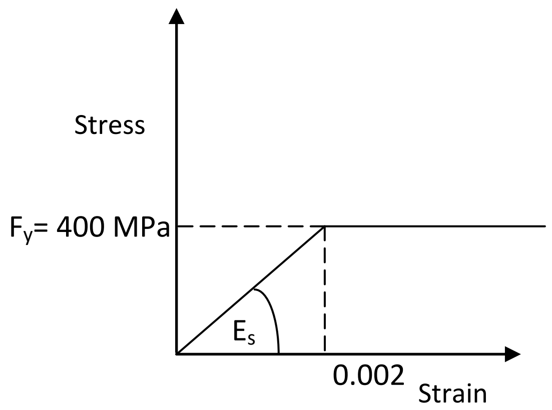

Figure (3): Stress-strain curve for steel reinforcement

4.3 Steel Fiber:

The common hooked-end straight steel fibers with length (30 mm) and (0.6 mm) in diameter with tensile stress (1100 MPa), was adopted. The steel fiber ratio was (1.5%) that distributed uniformly through concrete mix by stirring the total mix many times until all components become as unity.

5. ANALYSIS:

The reinforced concrete beam was modeled by finite elements approached by ANSYS with suitable selected elements that represented the real behavior of beam components in actual conditions. Linear analysis was run by applied the calculated plastic load capacity incrementally up to (200) steps. The convergence criterion is displacement control with tolerance not greater than (5%) by Newton - Raphson numerical iteration method. Modulus of elasticity for concrete, reinforcements and steel fiber kept constant through analysis with constant Poisson's ration because of the material were assumed isotropic. In nonlinear analysis, the stress-strain curves shown in Figures (2) and (3) are used for concrete (each type with separate analysis) and reinforcement with constant Poisson's ration. The parameters such as close shear coefficient (0.2), open shear coefficient (0.7), and other parameters that mentioned in Table (1) were input data while others become zero. The main and stirrups nodes are same nodes for concrete that is mean the full interaction between reinforcement and concrete (no shear friction). Figure (4), show the finite elements of simulated reinforced concrete beam, Figure (5), represent the side view of the reinforcements of simulated reinforced concrete beam and Figure (6), show the three dimensional wire frame of the full layout reinforcements of simulated reinforced concrete beam.

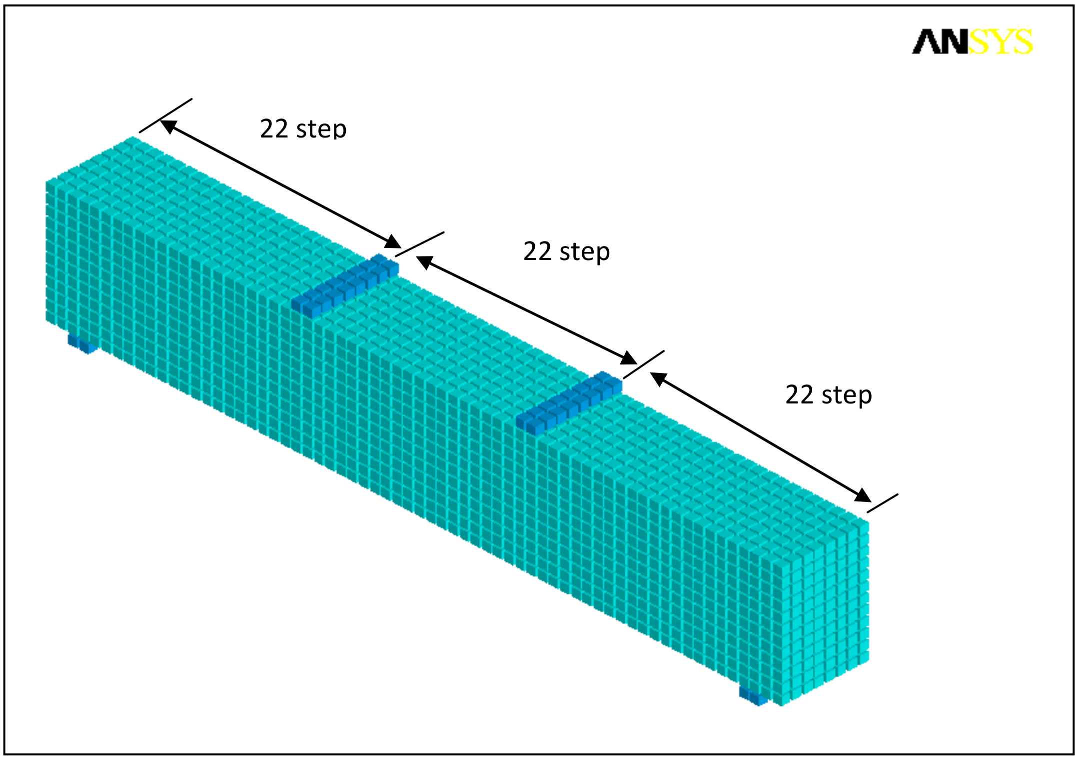

Figure (4): Finite elements of simulated reinforced concrete beam.

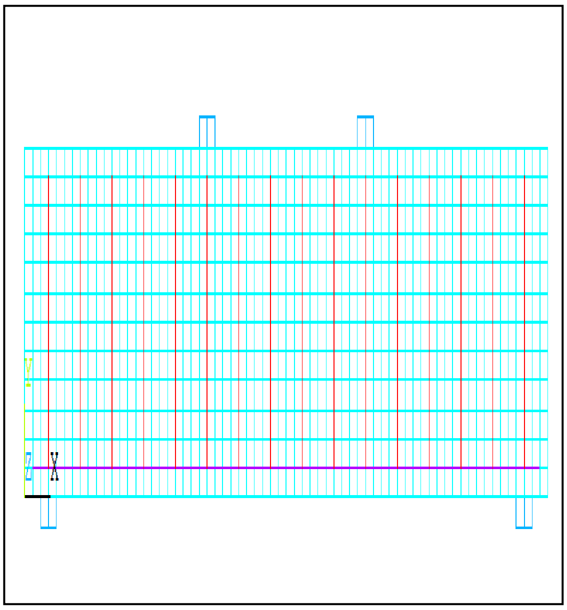

Figure (5): Side view show the reinforcements of simulated reinforced concrete beam.

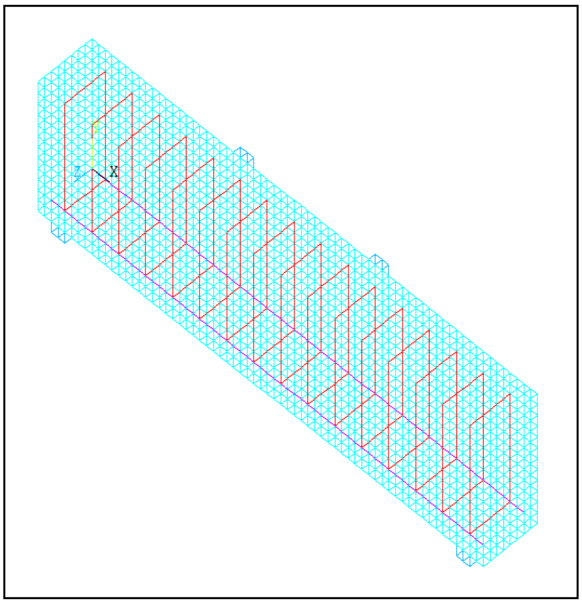

Figure (6): Three dimensional wire frame view show the full layout reinforcements of simulated reinforced concrete beam.

The model was simulated using also finite elements analysis by SAP2000 **[15]** to check out the results of ANSYS. The model was build and applied the same loading that applied in ANSYS, the same mechanical properties, and element size.

The axial stresses in x, y, and z direction as S11, S22 and S33 over all stress points at that station are shown in Figure (7), Figure (8), and Figure (9), respectively.

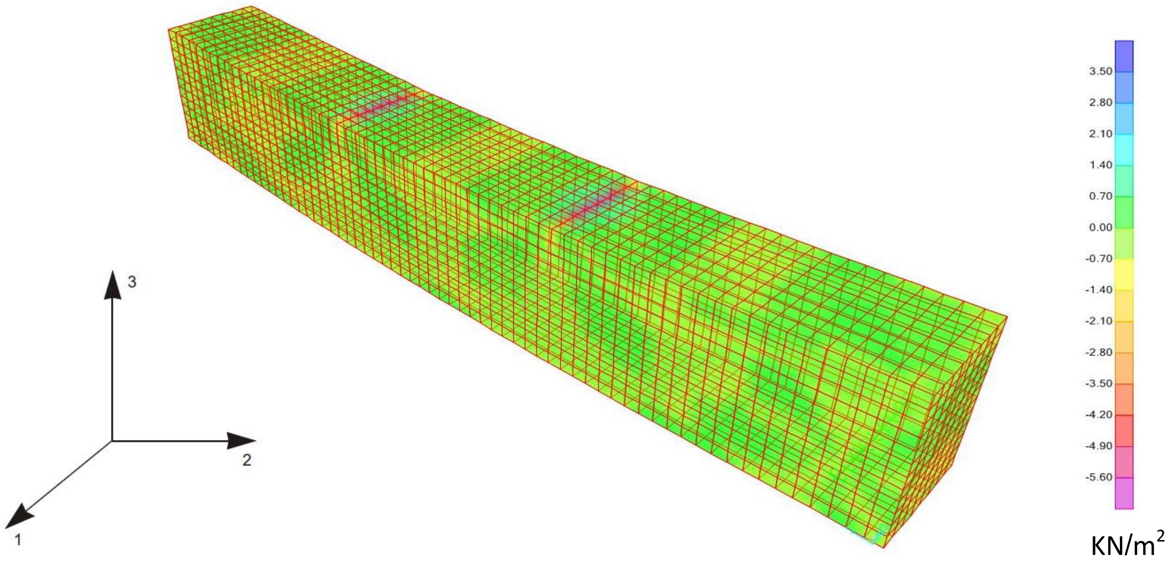

Figure (7): S_{11} stress of the simulated beam by SAP2000.

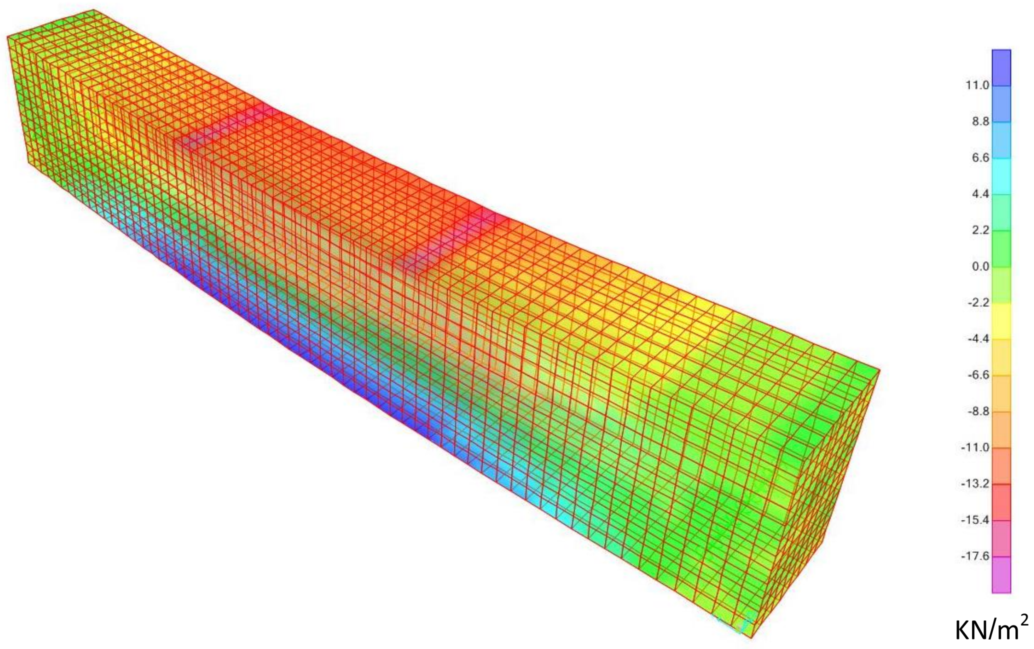

Figure (8): S_{22} stress of the simulated beam by SAP2000.

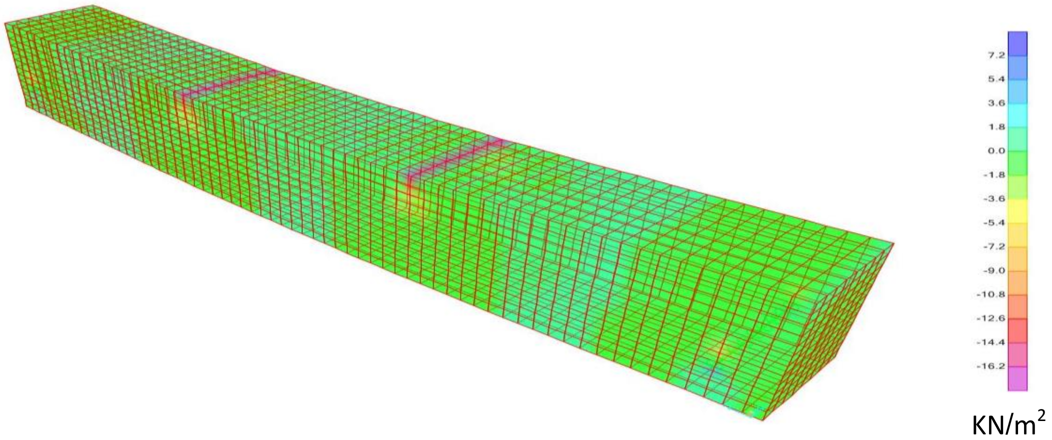

Figure (9): S_{33} stress of the simulated beam by SAP2000.

The Von Misses stress for the simulated beam shown in Figure (10).

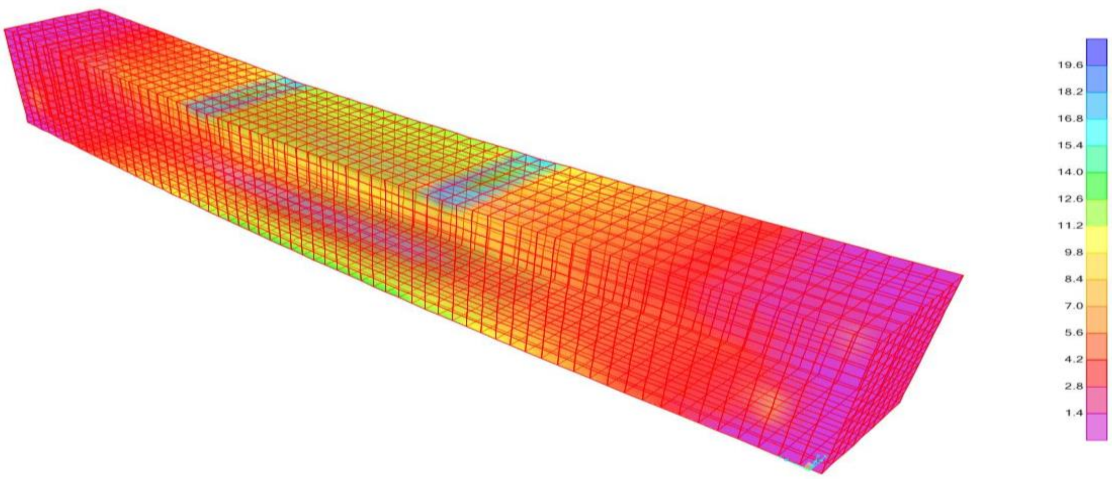

Figure (10): Von Misses stress of the simulated beam by SAP2000.

The Von Misses stress represented the maximum distortion energy. Von Misses formulated as equivalent tensile stress and compared with that reach the stress in tension zone the tensile strength or not in concrete and the tensile strength of yield so that the failure occur first in reinforcement or concrete. The axial stress, bending stress and normal stress that shown in Figures (7, 8 and 9) within the elastic stresses of the beam.

The handout calculation of maximum deflection in linear elastic analysis by adopted the formula below for four point's formula **[16]:**

$$\Delta_{max} = \frac{P\,a}{24\,EI}(3l^2 - 4a^2) \qquad ...(2)$$

Where, a: is the distance from support to the applied point load. The elastic deflection is (2.36 mm).

6. RESULTS AND DISCUSIONS:

Analysis results as linear and nonlinear such as central deflection at ultimate load capacity is listed in Table (2). The central deflection decreases in presence of steel fiber and self-compact additives materials. The full performance of three types of concrete is drawn as shown in Figures (11) to (15). Figures (16) to (20) represents that the performance of applied loading on concrete beams classified according to concrete type with the longitudinal strain at top. Figures (21) to (26) appear the cracks propagations at the final stage of applied loading (ultimate) for all concrete types and in case of linear and nonlinear analysis.

The maximum elastic deflection by ANSYS for normal concrete is (2.76 mm) and by SAP2000 is (2.81 mm). Deflection for self-compact concrete is (2.68 mm) and by SAP2000 (2.73 mm). Deflection for self-compact concrete with steel fiber is (2.44 mm) and by SAP2000 (2.57 mm), so the results are close.

Experimental tests as cubes and cylinders are adopted to investigate the mechanical properties of normal, self-compact and self-compact with steel fiber. The mechanical properties such as compressive strength, tensile strength and modulus of elasticity were investigated.

Table (1) listed the mechanical properties of three type of concrete, there was enhancement in the mechanical properties as compressive strength increased in case of self-compact and self-compact with steel fiber compare with the normal concrete respectively. In presence of SCC and SCC with steel fiber there was improvement in tensile strength and modulus of elasticity.

Figures (11) to (15) showed the performance of incremental applied loading verse central bottom deflections. The performance up to (17%) from ultimate loading behaved as linear and there is inflection point and the line become toward x-axis at a point around (26%) from ultimate loading, but in case of presence steel fiber, this point become (39%) from ultimate loading.

Figures (16) to (20) showed the performance of incremental applied loading verse longitudinal strain at the top. The performance up to (80%) from ultimate loading behaved as linear and there is inflection point and the line become toward x-axis at this point, but in case of presence steel fiber, this point become (91%) from ultimate loading.

Figures (21) to (26) showed the cracks and crushed at ultimate stage. The cracks at tension zone but limited and the crush at compression zone but still less than the compressive strength because of there is no crushed point's intensity at that zone. The normal concrete deflection as maximum in mid span of the beam closed results compare the results of analytical solution using equation (2) with SAP2000 and ANSYS results as numerical solutions. All results by ANSYS are checked by SAP2000 to ensure and confirmed the work.

Table (2): Central deflection for all concrete beam and compared with the normal beam as reference.

Analysis type	Normal concrete	Self-compact concrete (%decreed in deflection with normal)	Self-compact concrete with steel fiber (%decreed in deflection with normal)
Linear	2.708 mm	2.682 mm (1)	2.449 mm (9.57)
Nonlinear	2.954 mm	2.842 mm (3.8)	2.708 mm (8.33)

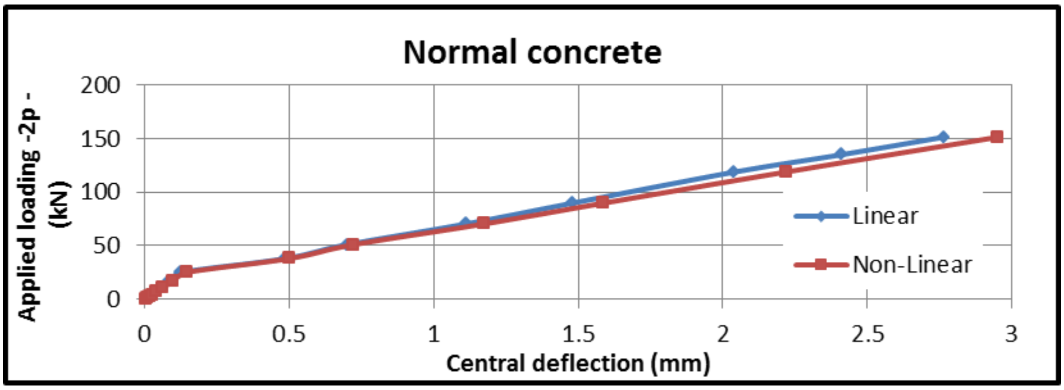

Figure (11): Applied loading with central deflection of simulated normal concrete beam as linear and nonlinear analysis.

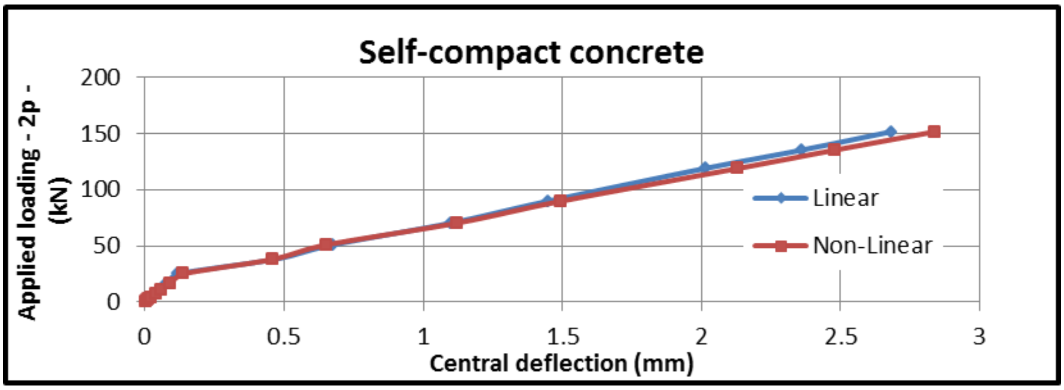

Figure (12): Applied loading with central deflection of simulated SC concrete beam as linear and nonlinear analysis.

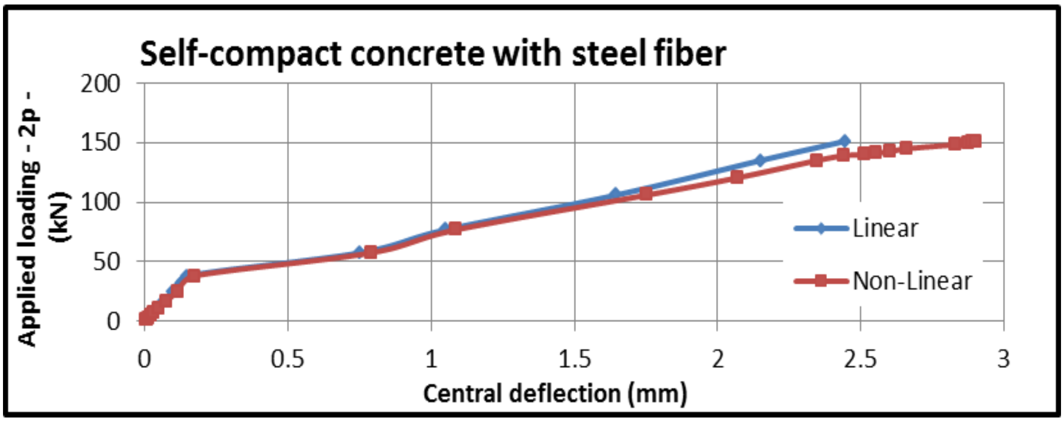

Figure (13): Applied loading with central deflection of simulated SC with steel fiber concrete beam as linear and nonlinear analysis.

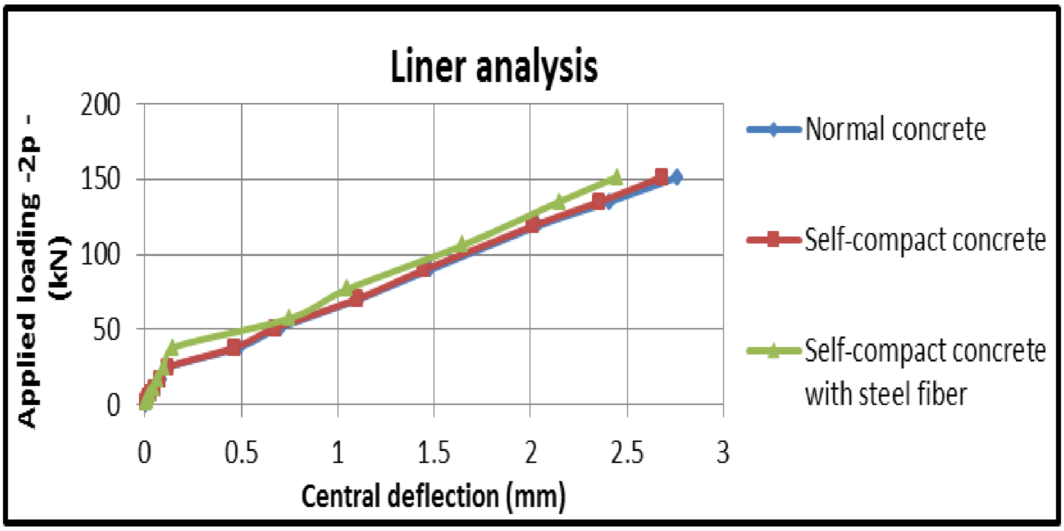

Figure (14): Applied loading with central deflection of all simulated concrete beam as linear analysis.

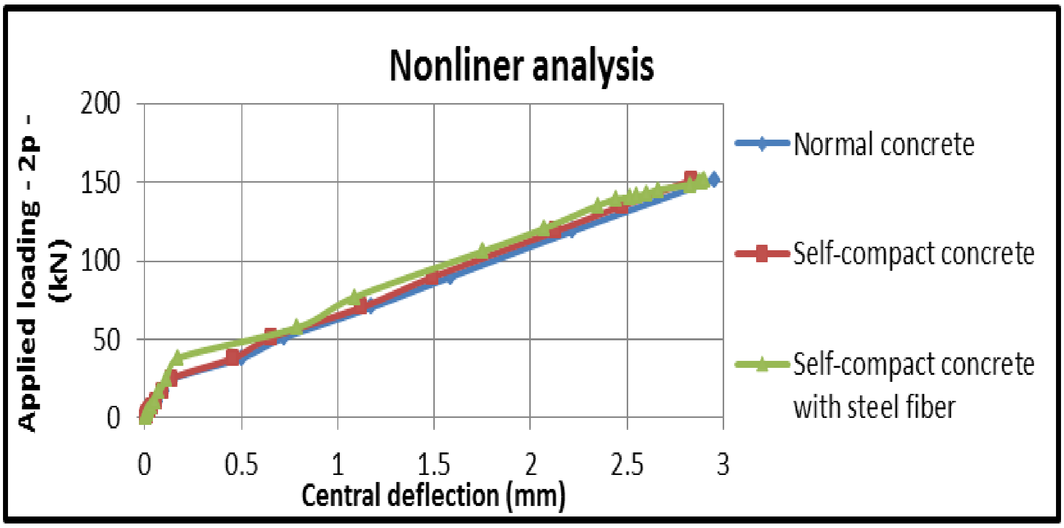

Figure (15): Applied loading with central deflection of all simulated concrete beam as nonlinear analysis.

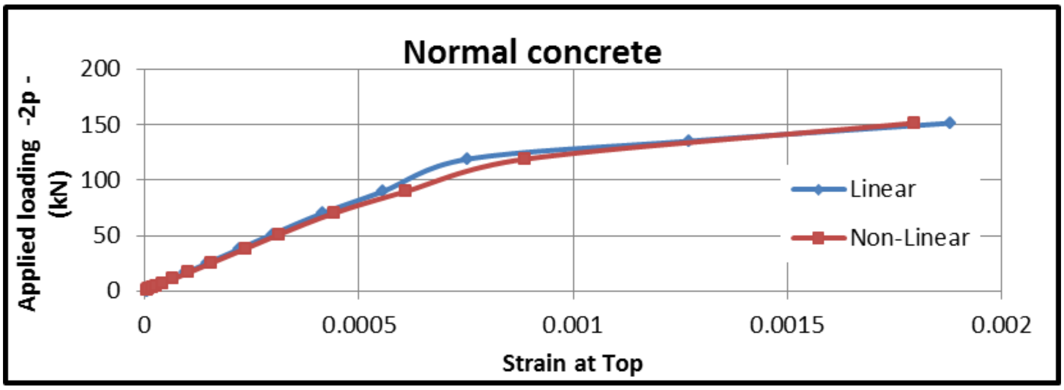

Figure (16): Applied loading with longitudinal strain of simulated normal concrete beam as linear and nonlinear analysis.

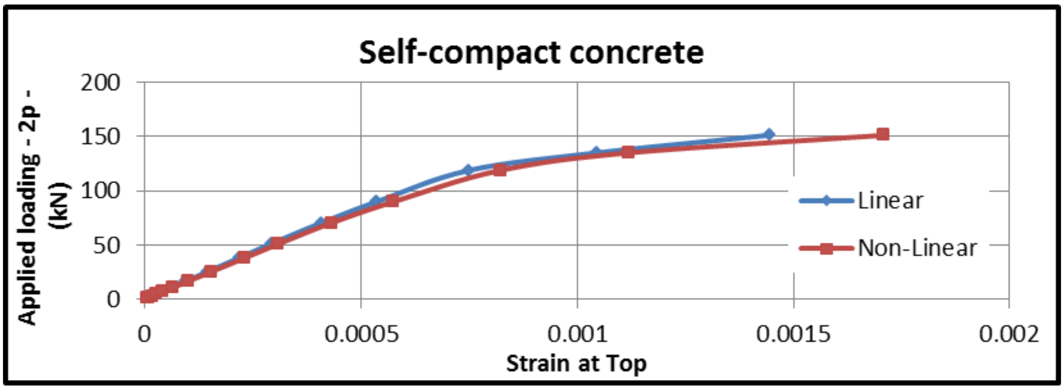

Figure (17): Applied loading with longitudinal strain of simulated SC concrete beam as linear and nonlinear analysis.

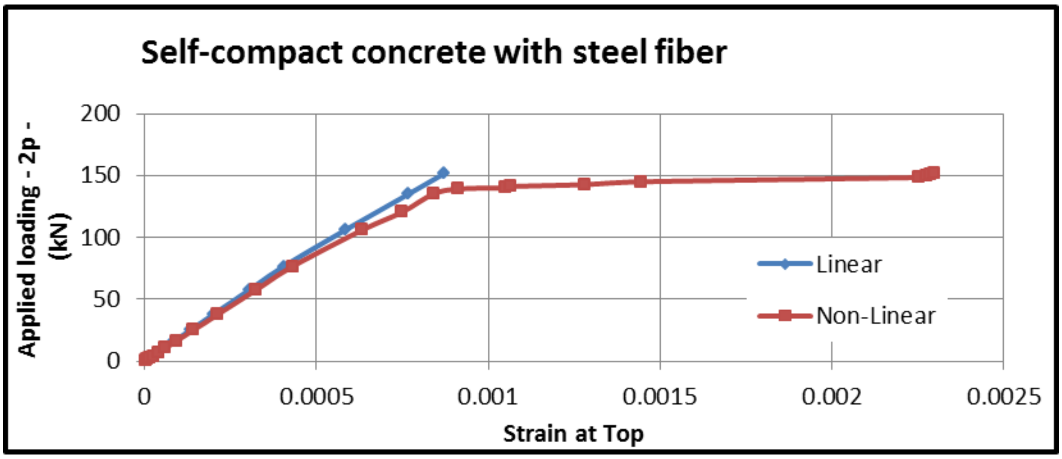

Figure (18): Applied loading with longitudinal strain of simulated SC with steel fiber concrete beam as linear and nonlinear analysis.

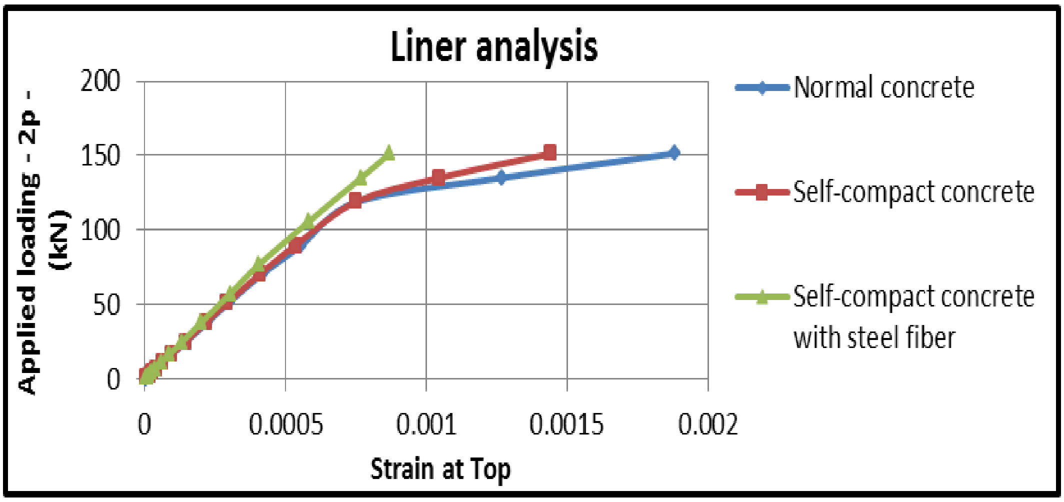

Figure (19): Applied loading with longitudinal strain of all simulated concrete beam as linear analysis.

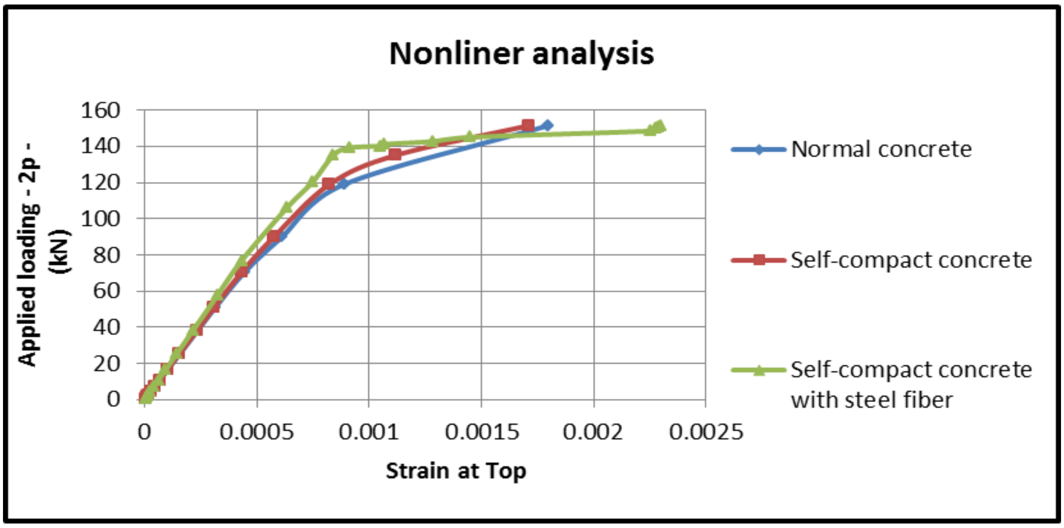

Figure (20): Applied loading with longitudinal strain of all simulated concrete beam as nonlinear analysis

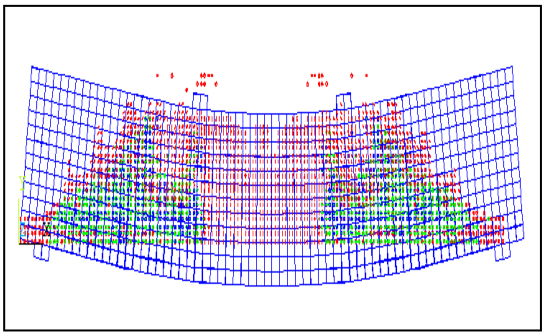

Figure (21): Cracks propagations in three direction of normal concrete beam at ultimate stage as linear analysis.

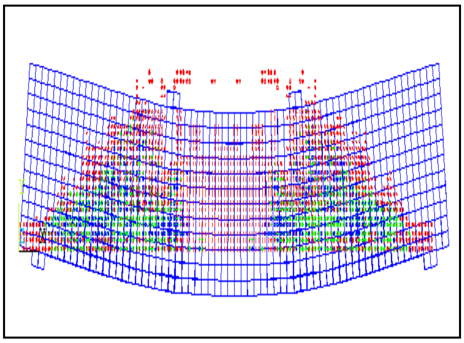

Figure (22): Cracks propagations in three direction of normal concrete beam at ultimate stage as nonlinear analysis.

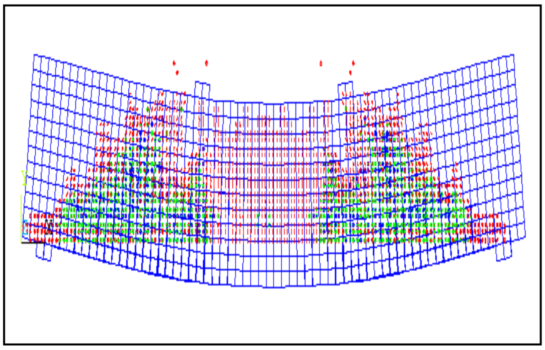

Figure (23): Cracks propagations in three direction of SC concrete beam at ultimate stage as linear analysis.

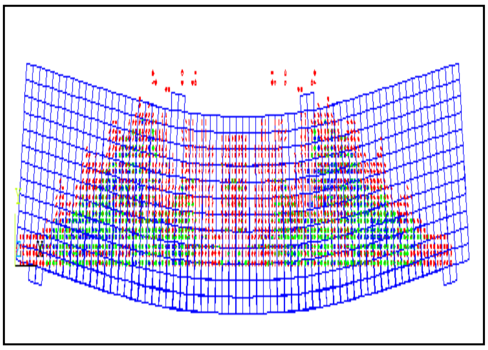

Figure (24): Cracks propagations in three direction of SC concrete beam at ultimate stage as nonlinear analysis.

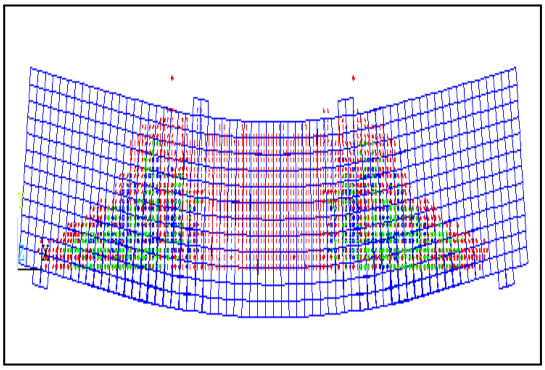

Figure (25): Cracks propagations in three direction of SC concrete beam with steel fiber at ultimate stage as linear analysis.

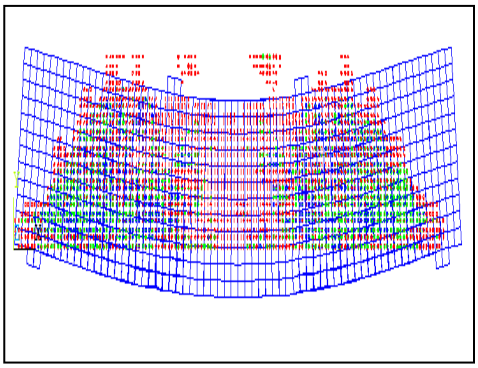

Figure (26): Cracks propagations in three direction of SC concrete beam with steel fiber at ultimate stage as nonlinear analysis.

7. CONCLUSION:

Based on the analysis results, the following points are concluded:

1. Increased in strength capacity in case of self-compacted and self-compacted with steel fibers because of increased in compressive strength.
2. Decreased in deflection in case of self-compacted and self-compacted as compared with the normal concrete because of increased in compressive strength and modulus of elasticity.
3. Increased in longitudinal strain in case of self-compact as compared with the normal concrete because of enhancement of tensile strength at tension zone so that the concrete strain become more and then after make the concrete more ductile.
4. Nonlinear analysis gave more reliable results because of the real behavior of experimental test is nonlinear, also there are different in results between linear and nonlinear analysis.
5. The intensity and concentration of cracks are less in case of presence of steel fiber because of the steel fiber increased the load caused first crack and enhance the tensile resistance of concrete in tension zone (see above Figures (21) to (26)).
6. Based on the analysis results by SAP2000 that compared with the ANSYS results showed around close.

References

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