Composite reinforced concrete beam of embedded double skin steel plates

Fatima Sattar Jabbar¹ ², Sa’ad Fahad Resan¹
¹Civil Engineering Department, Engineering College, University of Misan, Amarah, Iraq
²Corresponding author; e-mail: eng.fatima1995@uomisan.edu.iq

Abstract: The study intends to develop double skin composite beams using smart utilizing of proper properties of concrete and steel by incorporating steel frame likewise ribbed I-Steel section within concrete. The adopted built-up steel frame consists of upper and lower mild steel flanges connected by ribs using deformed steel bars and equivalent to customary shear reinforcement in quantity and provided as ribs within target frame besides shear resistance. The study considered an experimental program to investigate the effectiveness of introduces mode upon ultimate strength and related issues such as flexural ductility, flexural stiffness, plastic hinge formation, and failure mechanism in addition to comparative analysis with traditional reinforced concrete beam in the scope of assigned structural characteristics. The experimental results exhibit that the incorporated double skin steel within concrete without flexural reinforcement exhibited 78% of RC model ultimate strength where the ratio of volume fraction in steel-concrete-steel to reinforcement ratio in reinforced concrete beam is (1.5064). The powerful observed enhancement of the proposed ribbed I-steel section could be related to fully skin friction provided by fully connected upper and lower steel plates that affect the concrete confinement positively.

Keywords: Skin composite beams, flexural strength, flexural ductility, Load-deflection response, flange steel section.

1. Introduction

The purpose of selecting or using any material in civil engineering construction is to make maximum use of its properties in order to obtain the best value for the structure produced. Durability, availability, structural strength, and workability, all these factors are needed for the construction material in all modern structural engineering applications [1]. The characteristics of each material vary from the characteristics of another material, because there is no material that can fulfill all the structural requirements. This is the reason why two or more materials are used and connected together in order to take full advantage of their properties by obtaining one structural feature that utilizes the materials desirable properties. The beneficial features of various materials are combined to create a member with a high carrying capacity. Then, the structural member of two or more materials is known as a composite member [2]. In any mixture, composite structures incorporate materials such as steel, concrete, timber, or masonry. Composite construction is usually taken to mean either steel and concrete construction or precast-concrete and in situ concrete bridges in common use today[3]. The composite structures have
the advantages of both steel and concrete structures, characteristics of high bearing capacity, best flexural ductility besides integrity, in addition to the excellent behavior in crack control, impact resistance, and leakage prevention [4].

Steel–concrete–steel (SCS) sandwich beams, which are known as double skin composite beams, consist of concrete sandwiched by outer two steel plates. Mechanical connections are used to achieve composite action between components. Steel–concrete–steel (SCS) could be used in large sized structures like bridges, tube tunnels, nuclear facilities, and core tubes of high-rise buildings, in which the seismic performance is of prime importance. Historically, the studies concerned with using the plate steel section in composite beam are so limited [5]. There are some interesting studies that deals with the investigation of the utilizing of double skin composite beams as both longitudinal reinforcement and permanent formwork, with promoting plastic deformation resistance [5-8]. Plastic deformation resistance upgrading considers an interesting subject for researchers and designers due to its importance in structural fields. Rotation capacity had the attention of many researchers to maximize concrete beam’s strength capacity of reduced section [9–18].

From previous studies, it is obvious there are various mechanisms to use plate sections.

2. Experimental Methodology

The current study is concerned with developing a double skin composite beam of concrete incorporated with embedded double skin steel plates. These concepts in addition to comparative comparisons in the scope of different parameters are considered in the current study. Incorporated likewise flange steel section is introduced using double connected steel plate (upper and lower parts) linked by ribs of (Ø10mm), the distance between ribs is 10 cm. Three specimens are developed which are reinforcement concrete beam of traditional reinforcement (RC), steel-reinforced concrete-steel beam of composite reinforcement, traditional longitudinal reinforcement with double skin steel plates (SRCS), and the steel-concrete-steel beam which have double skin steel plates without traditional reinforcement (SCS).

Commercially available materials were used in this investigation which includes cement, water, crushed gravel diameter is about (9-10) mm, fine aggregate, superplasticizer denoted as silica fume(Mega Add MS(D)), steel bar (longitudinal reinforcement 2Ø16mm) and (shear reinforcement Ø10mm), steel plate. The three beams are prepared and casting in the Concrete Laboratory in Maysan, using the central mixer. The compressive strength of concrete which is based on the average values of 150×150mm of cubic was calculated according to (ASTM C39-86) [19] and (BS.1881: Paw 116:1989) [20]. As well as prisms with dimensions (100×100×500) mm which are tested according to (ASTM C78-2002) [21] procedure and Splitting tensile test is computed according to the procedure in (ASTM C496-2004) specification [22]. Table .1 depicts the mixing proportion of used concrete. Table .2 depicts the mechanical properties of hardened concrete. Table .3 illustrates the mechanical properties of the adopted Ø 10mm and Ø 16mm bars according to ASTM A615 [23] while Plate .1 shows the tensile test of steel bars and coupon. Figure (1) shows the stress- strain curve for average test of three coupons at length 60cm. Table .4 summarizes the mechanical properties of flanged steel section with has length of 60cm that tested according to the ASTM (8E)[24]; Figure (2). The Geometrical properties of the considered steel section are listed in Table .5.

| Table .1 Mixing Proportions of concrete |
|----------------------------------------|
| No. | Max agg Size, mm | Cement, kg/m³ | Silica Fume, % | Sand, kg/m³ | Gravel, kg/m³ | Superplastizer, % | Water/Binder, % |
|-----|------------------|----------------|---------------|-------------|---------------|----------------|----------------|
| 1   | 10               | 500            | 7             | 625         | 875           | 2              | 10             | 26.5           |
Table 2. Mechanical properties of concrete

| Specimen | \( f_{y}(\text{MPa}) \) | \( f_{u}(\text{MPa}) \) | \( f_{t}(\text{MPa}) \) |
|----------|----------------|----------------|----------------|
| 1        | 55.8           | 9.0686         | 3.8            |
| 2        | 61.3           | 8.585          | 3.339          |
| 3        | 62.8           | 8.724          | 3.386          |
| Average  | 59.9667        | 8.7925         | 3.508          |

Table 3. Mechanical properties of Reinforcement

| Nominal Diameter | Yield stress (MPa) | Ultimate strength (MPa) |
|-----------------|-------------------|-------------------------|
| \( \varphi, \text{mm} \) | \( f_{y} \) | \( f_{u} \) |
| 10              | 416.34           | 618.567                |
| 16              | 484.253          | 689                    |

Table 4. Mechanical properties of flanged steel plates

| Specimen | Yield stress (MPa) | Ultimate strength (MPa) |
|----------|-------------------|-------------------------|
| Average  | 270.24            | 445.76                  |

Figure 1. Stress-strain curve for coupon

Figure 2. Steel coupon details

Table 5. Geometrical properties of considered steel section

| Type of steel beam | Geometrical Properties |
|--------------------|------------------------|
| \( A(\text{cm}^{2}) \) | \( S_{x}(\text{cm}^{3}) \) | \( S_{y}(\text{cm}^{3}) \) |
| 3.65               | 0.304167               |
| \( I_{x}(\text{cm}^{4}) \) | \( I_{y}(\text{cm}^{4}) \) | \( Z_{x} \) | \( Z_{y} \) |
| 0.0760417          | 16.2090                | 0.45625               |
| \( r_{x}(\text{cm}) \) | \( r_{y}(\text{cm}) \) | \( J(\text{cm}^{4}) \) |
| 0.1443             | 2.1073                 | 16.285                |
| \( b/2t_{f} \) | \( r_{z}(\text{cm}^{3}) \) |
| 7.3                | 2.112                  |
2.2 Specimens Description

The experimental work program included manufacturing and tests three beams which are Steel-Concrete-Steel beam (SCS) and Steel-Reinforced Concrete-Steel beam (SRCS) besides the traditional Reinforced Concrete beam (RC) as shown in Figure .3. The three beams have a length of 225 cm, width 15 cm, and high 35 cm as shown in Plate.2. Table 6 shows the dimensions and details of tested specimens while Table 7 shows reading the specimens designation.

### Table 6 Dimensions and Details of Tested Specimens

| No | Designation     | Description                              | H, cm | B, cm | Flexural reinforcement | Steel plate Volume Fraction *, Vf | ρ | Shear reinforcement (mm) | Spacing of shear reinforcement (cm) | L, cm |
|----|-----------------|------------------------------------------|-------|------|------------------------|----------------------------------|---|-------------------------|-------------------------------------|------|
| 1  | RC-35-10        | Control specimen                         | 35    | 15   | Ø16                    | 0.0087                           | 0.001235 | Ø10                     | 10                                  | 225  |
| 2  | SCS-P-35-10     | Specimen without traditional             | 35    | 15   | Ø16                    | 0.0081                           | Ø10                     | 10                                  | 225  |
| 3  | SRCS-P-35-10    | Specimen with traditional                 | 35    | 15   | Ø16                    | 0.0081                           | Ø10                     | 10                                  | 225  |

* Volume fraction (Vf) is the ratio of the volume of used double skin steel plate to the entire volume of concrete beam (Vf/Vc).

### Table 7 The Specimens Designation.

| Designation   | Reading of the Designation                                                                 |
|---------------|-------------------------------------------------------------------------------------------|
| RC-35-10      | Reinforced concrete beam has high equal 35 cm and distribution of stirrups each 10 cm    |
| SCS-P-35-10   | Steel-concrete-steel plate beam, high equal 35 cm and distribution of ribs each 10 cm    |
| SRCS-P-35-10  | Steel-reinforced concrete-steel plate beam, high equal 35 cm and distribution of ribs each 10 cm |
Figure 3. Geometrical definition of proposed ribbed I steel section incorporated within concrete

Plate 2. Incorporated steel frames
2.1 Test setup
All beam specimens are tested using flexural testing machine as shown in Figure (4), with a maximum capacity of 600 kN. The simply supported setting is considered. The specimens are subjected to a central concentrated two point loads (distance between the two load is 0.7m). The beams are tested under static loads, which loaded in successive increments, up to failure. For each increment, the load is kept constant until the required readings are recorded. LVDT (10 cm) and (5 cm) were used to detect the deflection of the beams at every loading stage. During each load step the corresponding central deflection and one concrete strains at central beams of top face beam and three steel strains (two at central beams one of the top of the beam and the other at the bottom of the beam) and the third strain on the distance \( d \) from the bottom of the beam. The first crack load and the failure load are recorded. The tests were continued up to failure and the ultimate load was recorded. Testing mechanism and treatment of beam specimens are shown in Plate (3).

![Figure 4. Test Setting](image)

![Plate 3. Test Arrangement](image)

3. Results and Discussion
Table 8 summarizes the measured test data besides comparative analysis of tested developed specimens (SCS) and (SRCS) regards control specimens (RC). The analysis included flexural strength, flexural ductility, Load-deflection response, flexural stiffness, strain distribution and plastic hinge formation.

3.1 Flexural Strength
After examining the RC, SCS, and SRCS beams it turns out that the double skin composite beam mode which is enhanced by reinforcement (SRCS) has higher ultimate load than RC (control specimen) the increment rating is 1.673 and higher than SCS beam. While the SCS beam has ultimate load less than the RC (control specimen) in the rate of 0.7829 and less than the SRCS beam in the rate of 0.4679 as shown in Table (8) and Figure (5).
Hence, the incorporation of double skin steel in the fashion of ribbed I steel section of volume fraction, \( V_t =0.01235 \) (which is 1.50646 of flexural reinforcement ratio \( \rho=0.008198 \)), within reinforced concrete beam RC of \( \rho=0.008732 \) had been upgraded the ultimate strength from 258 to 431.7 kN where the incremental ratio is 1.67, in other hand incorporated double skin steel of volume fraction 0.01235 within
concrete without flexural reinforcement present in SCS mode, resists ultimate load of 202 kN which is corresponding to 78% of that of RC model. The powerful observed enhancement of proposed ribbed I-steel section could be related to fully skin friction provided by fully connected upper and lower steel plates that affects the concrete confinement positively.

3.1 Flexural ductility
It is critical to assess the flexural ductility of reinforced concrete beams in order to prevent a structure's sudden collapse by ensuring adequate plastic deformation at ultimate load. Both flexural strength and flexural ductility must be considered when designing reinforcing concrete beams. Flexural ductility is at least as important as strength from the standpoint of overall safety. If ductility is better attended to, the reinforced concrete beam may have a better chance of surviving if it is overloaded, subjected to an accidental impact, or attacked by a serious earthquake. The flexural ductility can be measured in terms of a ductility index, which is defined as the ratio of the maximum deflection corresponding to the ultimate strength to the deflection corresponding to elastic limit, and given by:

$$\Psi = \frac{\Delta u}{\Delta y}$$

where:
- $\Psi$ ductility index, dimensionless
- $\Delta u$ Maximum deflection corresponding to the ultimate strength, mm
- $\Delta y$ Deflection corresponding to elastic limit, mm

Table (8) exhibits the assigned deformation data related to tested beams. As shown in Figure (6), the ductility index in the SCS beam is higher than the conventional RC beam (control specimen) by increment rating of 15.8737 As well as higher than SRCS beam by increment rating of 21.4956. But the ductility index for SRCS beam less than the RC (control specimen) in the rate of 0.7384 and less than the SCS beam in the rate of 0.0465. It could be concluded that the significant ductility enhancement using I ribbed steel section in the top with of reinforcement and higher than the RC thus, this beam could be in structural that are exposed to earthquakes this gives us time to take safety measures before the constructor collapses.

Figure 5. Ultimate strength variation

Figure 6. Flexural ductility variation

The comparative analysis between Figures 5 and Figure 6 clearly indicated that, In scope of strength (Figure .5), specimen of composite reinforcement (bars and double skin steel plates) is better than the corresponding specimen without composite reinforcement while in scope of ductility (Figure .6), the providing of double skin plate without longitudinal reinforcement enhanced the ductility much more than that of composite reinforcement.
## Table 8. Result Analysis

| NO | Specimen designation | Description | (Pu) \(\text{(kN)}\) | (Pw) \(\text{(kN)}\) | Pw/Pu | (Δu)u \(\text{(cm)}\) | (Δy) \(\text{(cm)}\) | (Δψ) \(\text{(cm)}\) | (Δw) \(\text{(cm)}\) | \((Δw)/Δu\) | \(\psi_u\) | Lp (cm) | Moment capacity \(\text{(kN.cm)}\) | Failure mode |
|----|----------------------|-------------|----------------|----------------|-------|----------------|----------------|----------------|----------------|---------------|---------|---------|----------------|---------------|
| 1  | RC-35-10             | Control specimen | 258            | 82.2           | 0.3186 | 1              | 3.675          | 0.955          | 0.26           | ----            | 1       | 3.848   | 105.681 8       | Primary tension failure |
| 2  | SCS-P-35-10          | Specimen without traditional reinforcement Specimen with traditional reinforcement | 202            | 86             | 0.4257 | 0.7829         | 19.6256        | 8              | 0.3213         | 9.565         | 0.370        | 2       | 5.3403 61.082 136.666 7 | Primary tension failure |
| 3  | SCRS-P-35-10         |                           | 431.7          | 60             | 0.1389 | 1.6732         | 2.8561         | 1.0051         | 2.4520         | 0.0546         | 0.002        | 85      | 0.777 2.8416 121.666 7 14030.25 | Primary tension failure |
3.2 Load-deflection response

Figure (7) shows the load–deflection curves at mid span for three tested specimens which shows that specimen behavior is divided into three parts. The first part is the straight line and represents the elastic region. Where the SRCS beam have higher stiffness than RC (control beam), and SCS beam result as shown in Table (8). The second portion begins after the initiation of the first cracks whereas the first crack in the RC beam begins at load 82.2 kN and it began in the SCS beam at load 86 kN and it began in the SRCS beam at load 60 kN and depicts the steel yielding level. This portion is characterized by a slight variation in the progression of load–deformation increment. The final section is the plastic response, which refers to strain hardening of the given steel reinforcement and extension to ultimate strength. Figure (7) shows the SCS specimen have deflection higher than RC (control specimen) in the rate of 5.34 and higher than SRCS specimen in the rate of 6.871 while as low load than RC and SRCS specimens and the SRCS beam has deflection less than the RC (control specimen) in the rate of 0.777 and less than the SCS beam in the rate of 0.1455 while as high load than RC and SCS beams. Figure (7) shows the SRCS specimen have higher stiffness than SCS specimen since that it doesn’t show plastic region or the SRCS specimen have higher plastic deformation.

Figure (10) illustrates deflection curve at ultimate strength at mid span and at d from mid span of tested beams along the length of specimens. The figure indicated that the curves tend to be more smooth and gradual along beam span that produce the increase of flexural ductility in SCS beam more than SRCS and RC beams.

![Load-deflection relationships at mid span of the beams](image.png)

3.3 Tensile strain distribution

The readings have been taken by Data Acquisition System using electrical strain gauges. It was used to measure surface steel strain at points located in mid span of beams in compression top fiber and tension bottom fiber (as well as along span at d and 2d from mid span. For comparative investigation, the concrete strains distribution was measured and the process of measuring was continued up to the failure. Figure. 8 shows tensile strain distribution verse applied loading at mid span and at d from mid span. The sustainability of plastic deformation and flexural ductility enhancement in present of skin steel plates are clearly depicted in comparative of load strain response of SCS and SRCS specimens. The determined elastic strain distribution dominated by obtained modulus of elasticity which is compatible with stress strain linear portion slope and adopted it as a specific limit state condition. The comparison of measured tensile strains with limit values indicated that; the skin double steel initiates plastic behavior, while the measured compressive strain in concrete still less than crushing limit (0.003) as shown in Figure 9, hence the responses were steady, whilst tensile strain at d from mid span, reached to the limited value in tension and the flexural bending maintained with gradually spreading of cracks companied with plastic behavior till failure.

3.4 Plastic Hinge formation

For all beams of different reinforcement modes, the deformations were initially within the elastic ranges, and then the applied load was increased until the first crack became visible which was observed in the maximum moment region under applied load. As the load was increased further, several flexural cracks initiated in the
tension face at intervals throughout the beam, gradually increased in number, became wider and moved upwards reaching the compression face of the beam. Figure 10 exhibits deflected curve lines of tested specimens, the SCS mode indicates the significant plastic hinge developing abroad $L_p$ of extended plastic strain corresponding to range of proportional plastic moments, the SRCS specimens exhibits no significant formation of plastic hinge and show response likewise that of traditional RC mode, Photo 2 clearly depicts SCS trend upon plastic hinge formation.

![Figure 8. Steel tensile strain variation of the beams.](image)

![Figure 9. Concrete - steel comparative tensile strain analysis](image)

![Figure 10. Deflected curve lines](image)

### 3.5 Crack pattern and failure modes
In all tests the load recorded by test machine dropped with increasing deflection when the specimens reach failure. The maximum load recorded by the machine was considered as the ultimate load. The failure modes for the tested composite beams are shown in Table (8). The deformations were originally within the elastic ranges (linear) during the early stages of loading, and then the applied load was increased until the first crack appeared, which was observed. As the load was increased further, several flexural cracks appeared at random intervals in the tension face of the beam, grew in number, widened, and moved upwards, eventually reaching the compression face of the beam and this observation modes could be relates to provide continues connection.
mode of upper and lower skin steel plates. Plate (4) shows the failure modes and corresponding crack pattern of tested beams.

![Plate 4. Failure mode and cracks pattern of tested beams](image)

**Plate 4.** Failure mode and cracks pattern of tested beams

**Notations**

RC: Reinforced concrete beam  
SCS: Steel concrete steel beam  
SRCS: Steel reinforced concrete steel beam  
P: Steel plate  
H: high of specimen, cm  
B: width of specimen, cm  
L: length of specimen, cm  
A: Area of cross section  
$V_r$: Steel plate Volume Fraction = $(V_s/V_c)$  
$b/f$: The ratio of the width of flange to the flange thickness  
$I_x$: Moment of inertia about x-axis, cm$^4$  
$I_y$: Moment of inertia about y-axis, cm$^4$  
$J$: Polar moment of inertia about z-axis = $I_x+I_y$, cm$^4$  
$r_x$: Radius of gyration about x-axis = $\sqrt{I_x/A}$, cm  
$r_y$: Radius of gyration about y-axis = $\sqrt{I_y/A}$, cm  
$r_z$: Radius of gyration about z-axis = $\sqrt{r_x^2 + r_y^2}$, cm  
$Z_x$: Plastic section modulus about the x-axis = $t_w h_w^2/4 + b h t_d/2 - b t^2 r^2/4 t_w$  
$t_r \leq A/2b$  
$Z_y$: Plastic section modulus about the y-axis = $t_b h^2/4 + h t_d/2 - b t^2 r^2/4 t_w$  
$t_r > A/2b$  
$S_x$: Elastic section modulus about x-axis = $I_x/C$, cm$^3$  
$S_y$: Elastic section modulus about y-axis = $2I_y/b$, cm$^3$  
$P_u$: Ultimate load, kN  
P$\sigma$: Cracking load, kN  
$(\Delta u)_m$: Deflection at mid span correspond to ultimate load, cm  
$\Delta y$: Ultimate deflection at elastic level, cm  
$(\Delta u)_d$: Deflection at d from mid span correspond to ultimate load, cm


\[ (\Delta_{cr})_{m}: \text{Deflection corresponding to cracking load at mid span, cm} \]
\[ (\Delta_{cr})_{d}: \text{Deflection correspond to cracking load at } d \text{ from mid span, cm} \]
\[ \psi_{m}: \text{Ductility index}= \frac{\Delta u}{\Delta y}, \text{dimensionless} \]
\[ L_{p}: \text{Plastic hinge length, cm} \]

4. Conclusion

1. The incorporation of double skin steel in the fashion of ribbed I steel section of volume fraction, \( V_f = 0.01235 \) (which is 1.50646 of flexural reinforcement ratio \( \rho = 0.008198 \)), within reinforced concrete beam RC of \( \rho = 0.008732 \) had been upgraded the ultimate strength from 258 to 431.7 kN where the incremental ratio is 1.67, in other hand incorporated double skin steel of volume fraction 0.0014 within concrete without flexural reinforcement present in SCS mode, resists ultimate strength of 202 kN which is corresponding to 78% of that of RC model.

2. The powerful observed enhancement of the proposed ribbed I-steel section could be related to fully skin friction provided by fully connected upper and lower steel plates that affects the concrete confinement positively.

3. The significant flexural ductility enhancement is corresponding to Steel-Concrete-Steel mode, the ductility index in the SCS beam is higher than the conventional RC beam (control specimen) by increment rating of 15.8737 As well as higher than SRCS beam by increment rating of 21.4956. But the ductility index for SRCS beam less than the RC (control specimen) at the rate of 0.7384 and less than the SCS beam at the rate of 0.0465.

4. The SCS mode indicates the significant plastic hinge developing abroad \( L_{p} \) of extended plastic strain corresponding to range of proportional plastic moments, the SRCS specimens exhibits no significant formation of plastic hinge and show response likewise that of traditional RC mode.

5. The comparison of measured tensile strain of double skin steel with plastic limit values indicated that; the skin double steel initiates plastic behavior, while the measured compressive strain in concrete still less than crushing limit (0.003), hence the responses were steady, whilst tensile strain at \( d \) from mid span, reached to the limited value in tension and the flexural bending maintained with gradually spreading of cracks accompanied with plastic behavior till failure.

References

[1] Oehlers, D.J. and Bradford, M.A. First published, 1999, p.259, "Elementary Behavior of Composite Steel and Concrete Structural Members", Butterworth-Heinemann.
[2] Ridha, T.A. April 2012, "Structural Behaviour Of Composite Beams With Web Opening Under Repeated Loading", M. Sc. Thesis, Civil Engineering, College of Engineering, Al-Mustansiriya University.
[3] David Collings, ., 2005 “Steel-Concrete Composite Bridges “, Thomas Telford, London.
[4] Sohel KMA, Liew JYR, Yan JB, et al. (2012) Behavior of steel-concrete-steel sandwich structures with lightweight cement composite and novel shear connectors. Composite Structures 94(12): 3500–3509.
[5] Yubing Leng, Xiaobing Song, 2018, Application of steel-concrete-steel sandwich deep beams into coupled shear walls, Advances in Structural Engineering 90(0), DOI: 10.1177/1369433218783297
[6] Yubing Leng and Xiaobing Song, 2018, Shear strength of steel–concrete–steel sandwich deep beams: A simplified approach, Advances in Structural Engineering 90(0), DOI: 10.1177/1369433218777522
[7] Leng YB, Song XB and Wang HL (2015a) Failure mechanism and shear strength of steel-concrete-steel sandwich deep beams. Journal of Constructional Steel Research 106: 89–98.
[8] Leng YB, Song XB, Chu M, et al. (2015b) Experimental study and theoretical analysis on resistance of steel-concrete–steel sandwich beams. Journal of Structural Engineering 141(2): 04014113.
[9] Sa’ad Fahad Resana,, Jassim Kadhem Zamel, 2021, Rotation capacity assessment in developed non prismatic flanged reinforced concrete Tee beams, Case Studies in Construction Materials 14 (2021) e00517, https://doi.org/10.1016/j.cscm.2021.e00517.
[10] R. Park, T. Panley, 1975, Reinforced Concrete Structures, JohnWiley & Sons.
[11] M.-Y. Ko, S.-W. Kim, J.-K. Kim, 34 (June) (2001) 302–311,Experimental study on the plastic rotation capacity of reinforced high strength concrete beams, Mater. Struct.
[12] Alberto Carpinteri, Mauro Corrado, 77 (2010) 1091–1100, Dimensional analysis approach to the plastic rotation capacity of over-reinforced concrete beams, Eng. Fract. Mech., doi:http://dx.doi.org/10.1016/j.engfracmech.2010.02.021.
[13] E.O. Pfrang, C.P. Siess, M.A. Sozen, Load-moment-curvature characteristic of reinforced concrete cross sections, ACI J. 61 (7) (1964) 763–778.
[14] A. Placas, P.E. Regan, A.L.L. Baker, Shear failure of reinforced concrete beams, ACI J. 68 (1971) 763–773.
[15] B.V. Rangan, R.F. Warner, Large Concrete Buildings, Longman Group Limited, 1996, pp. 158–182. [16] R.H. Scott, Behavior of high strength concrete beams, Proceedings of Third CANMET/ACI International Conference, Malaysia, 1997, pp. 119–133.
[17] R.N. Swamy, S.A. Al-Ta’an, Deformation and ultimate strength in flexure of reinforced concrete beams made with steel fiber concrete, ACI J. (1981) 395–405.
[18] CEB Task Group 2.2, Ductility of Reinforced Concrete Structures, CEB, 1998.

Majid Jafar Sada ⤵, Sa’ad Fahad Resan, December 28-30, 2020, Structural behavior of hybrid reinforced concrete beams of trapezoidal Section Materials Today: Proceedings, 3rd International Conference on Materials Engineering and Science (IConMEAS 2020), Kuala Lumpur – Malaysia.

[19] ASTM C39/C 39M-05; “Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens,” Annual Book of ASTM Standards, American Society for Testing and Materials, pp.1-7.
[20] BS 1881: Part 116; “Method for Determination of Compressive Strength of Concrete Cubes,” British Standards Institution, 1989.
[21] ASTM C78-02; “Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading).” Annual Book of ASTM Standards, American Society for Testing and Materials.
[22] Iraqi specification No. 45; “Natural Sources for Gravel that is Used in Concrete and Construction,” Baghdad, 1984.
[23] ASTM Designation A615; “Standard specification for testing method and definitions for mechanical testing of steel products”, Annual Book of ASTM Standards, American Society for Testing and Material, Philadelphia, Pennsylvania, Section 1, Vol. 1.01, 2005, pp. 248-287.
[24] E8/E8M – 13a, Standard Test Methods for Tension Testing of Metallic Materials.