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STRUCTURAL BEHAVIOR OF COMPOSITE REINFORCED CONCRETE DECKS WITH LIFE LINE STEEL TUBE SYSTEMS

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ABSTRACT: - This study focuses on benefits to be gained by using composite beams with concrete slab attached to a circular steel tube alternative IPE section in steel beam. The experimental research program was attitude to evaluate the flexural behavior of these composite beams with circular steel tube. A total of fourteen beams divided into seven test groups with different variable, were fabricated and testing under static loading conditions to determine the ultimate load and mode of failure of composite beam with circular steel tube. It was found, that the proposed structural system proved the qualification in flexural behavior, this mean; it can be used in building and construction as structural member resisting the bending. In addition, this composite beam can be used to pass through it the service work as electrical lines, mechanical heating, ventilating, etc. without need to increase floor height and web opening making that was cause increase building cost. Also the new proposed section can be used to transport water or oil.
Keywords: experimental, steel tube, shear connector, composite, concrete decks

INTRODUCTION

Composite steel structures have been introduced for a several years as one of the most economical construction systems. A composite member is defined as consisting of a rolled or a built-up structural steel shape that is filled with concrete, encased by reinforced concrete or structurally connected to a reinforced concrete slab. The perfect properties combination of the two most common building materials, i.e. steel and concrete, provides safe and economic structures. Composite beams offer many benefits more than non-composite sections. Since the load carried out by both the steel beam and the concrete slab, the steel section size is smaller than otherwise would be required. This reduces the total building height and the weight of steel required, thus reducing the direct cost. The typical structural framings compose of beams with solid webs; these backward the supplies of pipelines and air conditioning ducts necessary or satisfactory needing for which the construction is built. Production of beams with openings in web has become satisfactory engineering solution, and reduces the possibility of a service engineer making holes continuous in unsuitable positions. Introduction of openings in the web led to reduce beams stiffness resulting in more extensive deflections than the solid webs without opening. The bending moment capacity of the beam with web opening will be decreased at the opening because of the contribution of web to the moment capacity is reduced [1].

New structural sections of composite steel–concrete bridges were suggested and developed to be used in the last years. Such composite bridges types were adopted in Japan. Using steel section has high strength and ductility, such as concrete filled pipes or rolled H-girder, whereas filled concrete limits local buckling of steel plates [2]. Five composite bridges were suggested using steel pipes or cold –formed steel girders. The first project is a new railway bridge system that adopts steel tubes as the main beams. The steel pipe is filled with concrete close the mid supports. The bending capacity and behavior of concrete –filled steel pipes with concrete slabs were investigated using 6 m long specimens. The results showed that the concrete has a significant effect in limiting local buckling of the steel pipe and raising the bending capacity [3]. The second example is a cable stayed bridge that uses pipes of steel as the main girders. Because of the high compression in the girder, steel pipes have large resistance against axial compression, which would be useful for cable–stayed bridges [3].

Nakamura and Narita (2003) [4] experimentally studied the behaviour of steel tube filled with concrete bridge girder that consisted of composite with an overlying concrete slab. Mossahebi et al. (2005) [52] the concept of voided slab (hollow core slab) in conjunction with steel beam to form a type of composite beam or flooring system to be used in multistory buildings were established through a series of studies presented using finite element modeling, ABAQUS software, with experiments using precast hollow –core floor slabs, modeling the headed stud shear connectors. Saleem et al. (2010) [6] developed a steel free composite deck made of ultra high performance concrete (UHPC) and fiber reinforced polymer (FRP) tubes. A preliminary experimental testing program and an analytical evaluation were undertaken to investigate the strength and serviceability of the deck system. The findings indicate that the proposed system is a promising alternative to steel decks with opening from both strength and serviceability standpoints.

This study focuses on benefits to be gained by using composite beams with concrete slab attached to a circular steel tube as an alternative IPE section in steel beam. This type of composite beam able to track the new mechanical heating, ventilating, plumbing, and electrical lines through the steel tube, weight savings resulting reduces overall building costs. In addition, this type of beam, composite steel tube section, will show good behavior to resist the local buckling compared to I-section beam.

2. EXPERIMENTAL PROGRAM

This section will provide details related to fabrication procedure, test set-up, loading scheme, instrumentation, and test descriptions.

2.1 Test Specimens Details

Fourteen simply supported steel concrete composite beams were designed and tested under two points load in the one-third span. Typical composite beam was 2000 mm in length and it was a simply supported beam at a span of 1800 mm. Thickness of concrete slab was 130 mm and width 400 mm; it was connected to steel tube beam with studs as shear connectors in twelve of the specimens, while the other two were designed with angle and perfobond connectors. The typical geometry of test specimen is shown in Figure (1). The tested specimens were classified as seven groups depending on different parameters including; support length, where the steel beam was confined near the ends by concrete block around circular tube in different length 250, 450, and 650 mm, thickness and diameter of steel tube, spacing and type of shear connector, influence of one open and two open in mid span of beam, and for comparison of normally composite steel-concrete beam with I-section beam were tested. These were considered the main variable for the fourteen specimens.

The groups ID consists of two part; the first part denotes group number and the second part signifies the main variable, the first term, alphabetic term, of identification corresponded to a type of variable. ′S′ for supported length, ′Th′ for thickness of steel tube, ′Spa′ for spacing of studs, ′open′ for beam with opening, ′D′ for diameter of steel tube, angle and perfobond shear connector for the sixth group, and finally the steel beam with I-section was the seventh group. The second term, numerical term, used in the group from 1 to 5, represent the secondary variable. For group one, support length was 25, 45, and 65 cm; thickness of steel tube 3 mm, 4 mm, and 6 mm in second group, etc. Fabrication details of the test beams are presented in Table (1) and Figure (2). The concrete slab was reinforced with deformed steel rebar ϕ 4.75 at 60 mm in two layers in longitudinal and transverse direction.

2.2 Classification of Cross –Sections

All composite cross –sections should be classified according to the limiting values as recommended in some codes of practice as AISC 2005 [7], BS 5950-1 [8], and Eurocode 3 [9].In the present study, the cross section classification is carried out based on the limiting values provided in the previous codes. The circular steel tube beam used in this study varied in cross –section classification as class 1 (compact) for d/t ratio lower than 50, and class 2 (non compact) for d/t ratio larger than 50 based on limitation of AISC –LRFD [7]. In addition, steel I-section beam was classified as class 1 (compact) for web and flange according to AISC [7] and as class 1 (Plastic) according to BS 5950 -1[8] and Eurocode 3 [9].

2.3 Materials

The materials used in this investigated are locally available except the stud shear connector. All beams in the test program were cast using normal concrete. The structural steel I-beam of section 160 mm x 16 kg/m, and circular steel tube section with five type was used, three with diameter of 168 mm (6 inch) and thickness 3 mm, 4 mm, 6mm; the other two with diameter of 100 mm (3.8 inch), 215 mm (8.5 inch) and thickness 4 mm. The material properties of the steel were determined by cutting and testing several tension coupons according to ASTM A370-10[10]. Material properties obtained from the coupon tests, yield stress, ultimate strength and elongation, are presented in Table (2).

Each of the beams group was cast on the same day, together with six cylinders, three cubes, and three prisms to determine the concrete mechanical properties. After the beams and control specimens were casted and compacted, these were leveled by using a steel trowel. The beams were cured one day after the form was removed by using dump blanket (cover) for 28 days. Then they were left under the laboratory condition.

2.4 Instrumentation

In given period of the beams test, the main structural behavior characteristics were recorded at each loading stage. Dial gauges (reading to 0.01 mm) with magnetic base were used to measure the mid span deflection, as well as the slip (relative movement) of both ends of the beam between the steel beam and concrete at each load increment. Seven strain gauges with 30 mm long were used to measure the strain on concrete surface and steel beam. Three of these strain gauges were installed on the top concrete surface of the mid span (one on center of slab, two at 50 mm from the slab edge at mid -span). Four strain gauges were attached directly to the steel surface, including three attached to steel beam from bottom, one in mid span and two under the loading point (one third –span), while the fourth one was attached to top of steel beam at mid span (embedded in concrete) as shown in Figure (2). The flexural testing machine with 3000 kN capacity was used as shown in Figure (3).

3. EXPERIMENTAL RESULTS AND DISCUSSION

The test results of the experimental program described in previous section to study the structural behavior of composite concrete structural steel tube beams presents in this section. G1S45 specimen selected as comparison specimen between seven groups, where it's designate based on group name that related to, as follows: G1S45, G2Th.4, G3Spac.60, G4NoOpen, G5D.6″, and G6Stud Conn.

3.1 Experimental Observations and Failure Modes

The load on beams was applied in increments. The beam specimens under this load failed by crushing of concrete flange in compression zone and the load recorded by the test machine dropped suddenly with increased in deflection. The maximum load recorded by the machine was considered as the ultimate load. The initial behavior of the specimens was elastic without any evident change. When the load reached between 40-90 kN, first crack at the bottom surface of the concrete slab was first observed. At the load of 220 kN to 240 kN for specimens with steel tube diameter of 6″ (168 mm) with stud connector, the ends slip was observed, and at load 100 kN to 180 kN the initial slip was read for specimens G5D3.8″, G6Angle Conn., G6Perfobond Conn, and G7I-Sec.. After the load exceeded 280 kN, the deflection at mid-span increased rapidly and the number of crack began to increase.

The cracks near top and bottom of steel tube at the end of specimens were observed at the load increased to 280 kN. When the load larger than 300 kN, the longitudinal cracks, started at the support of beams, appeared from the inner towards end of beam until reached to the steel tube at load exceeded 340 kN, as shown in Figure (4). As loading procedure progressed, the crack width began to increase after load 350 kN.

The composite steel–concrete beam is failed because of the cracks are appeared in the concrete slab, yield of the steel beam and due to the crushing of concrete slab. Figure (5.a) illustrates a typical failure mechanism of one specimen; this failure mode was observed for all specimens except G7I-Sec., where, the failure was initiated by the local flexural buckling of web at support as shown in Figure (5.b).

3.2 Load –Deflection Behavior

The estimation of the composite steel tube beams deflection at mid-span according to the applied load have been recorded by dial gauge as shown in Figure (6). Two regions of the curves were shown from these curves: elastic and plastic zones. It is found that specimens in group G1Support, G2Thickness, G3Spacing, G4Opening, and G6Connector loads–deflection curves to be identical in the initial elastic region up to about 250 kN. This demonstrates that up to load value of about 50% of ultimate load, no degradation occurred in stiffness of composite concrete with circular steel tube beams and that is no effect appeared when support length, thickness of steel tube, spacing of connector, tube with or without opening, and type of connector were change.

3.3 Behavior of Interface Slip

The interface slip, which is the relative movement between the concrete slab and the steel tube beam, was measured by using dial gauges at the ends of beams. For each test beam in the experiments, two dial gauges have been used to measure the slip, as shown in Figure (2). The experimentally measured values of the end slip are presented in Figure (7). In these results, the mean value of two readings was used. It can be noticed that during the early stage of loading no interface slip was recorded for all composite beams and this state continued until the applied loading approached 200 kN, after which the curve becomes nonlinear. From these curves and load–mid span deflection curves presented earlier, it can be shown that for any composite beam, as the load increases a comparable increase in slip and deflection is recorded. As the slip has increased, loss of interaction is resulted which allows for extra deflection, where as the slip is a function of degree of connection and the properties of materials.

Figures show for beam G1S65 it is obvious that the values of end slip in this beam are less than those in beams G1S25 and G1S45 because there is a confinement for shear span in G1S65 beam larger than other beams. It can be seen that the slip value had decreased as the tube thickness was increased to 6 mm. It can be concluded that when the degree of shear connection increased, the measured end slip considerably decreases. Similar behavior of end slip was observed for G4NoOpen, G4Open1, and G4Open2 and approximately linear up to 70% of the ultimate load, after which the curve becomes nonlinear. The opening effect on the strength and the behavior of the member may be small, because a hole is located to avoid regions of high shear.

It can be concluded that beams with small diameter exhibit higher slip values at the end of beam. In the G5D3.8″, comparable to the slip value at maximum load of it (245 kN) with other beams of group 5 at this load, the increase in slip is 85%, while for the G5D6″, the increase in slip value is 79% comparable to the slip value at beam G5D8.5″ in load value of 400 kN, after that the slip value was increase rapidly at maximum load for the last two beams to approximately equals.

It can be seen that nearly the same overall behavior of all beams when the type of shear connectors is angle, stud and perfobond. The results of G6Perfobond Conn. show this low slip value because the concrete dowel is passing inside the connectors opening and the influence of the transversal reinforcement passing inside the connectors' holes. While for beam G6Angle Conn., width of angle and the profile of it provide high shear area in front of angle and marked it capable to resist the bearing stress on a shank is concentrated near the base, that cause bending of stud connector, because concrete bearing on the connector is confined laterally by the steel element.

In group 7 as shown in Figure (7), the slip behavior cannot be compared because the beam was failed by local web buckling at support at early stage of loading and the slip value is very small or negligible. In Eurocode 4 [11], the ductile behavior of composite beams can be defined, if the ultimate load higher than the loading causing the recorded slip of 0.1 mm by more than 10% (Hyeong- Yeol-Kim, et. al.) [12]. Therefore, in this study the behavior of the composite steel tube beams tested is considered ductile where ultimate load larger than the load value causing end slip 0.1 mm is about average value 57 %.

3.4 Strain Profile along the Beam Depth

The strain profile of the cross –section were obtained by taking the strain values at different loading stages and plotted with the depth of the beam section, as shown in Figure (8). Figures presents the strain distribution of some specimens measured by the strain gauges attached to the top surface of the concrete, top surface of steel tube (embedded in concrete), and the steel beam bottom surface at mid –span of composite steel tube beam. Very small strains were recorded at the first stage of loading up to onset of cracks in concrete when a sudden –increase in the strains were took place, thereafter the strains increased almost linearly with increasing the load. The maximum concrete strain in compression were measured at top most fibers of concrete slab, while the gauge located on top surface of steel tube and embedded in concrete may be recorded either compression or tension strain, based on the neutral axis movement. Also strains at bottom most fibers of steel beam exceed the yield strain of steel as shown in figures of strain profile.

3.5 Neutral Axis of Composite Section at mid -span

Figure (9) illustrate the movement of the neutral axis position for the seventh groups respectively. The plastic neutral axis is located within 100 mm above the steel tube (in concrete slab) for all beams except for G5D8.5″ until the load 280 kN, where the neutral axis position in between 100 mm and 120 mm from top, i.e. at embedded area of steel beam in concrete slab.

In addition, it's clear that the movement of neutral axis of composite beam may be illustrated in three stages. Firstly, when the load is smaller than the yield load (yield of steel beam) close to 220 kN, the position of neutral axis is fixed until that load. While for the beams of groups (G2Thickness and G5Diameter) the behavior is different. The first stage of test results can be called elastic neutral axis. The composite neutral axis moved towards the upper with the load increase, which might be plastic neutral axis. This is presumably because the developments of the end slip and yield of steel beam and may be considered the second stage. In the final stage, when the load is larger than 350 kN, the cracks in the concrete at supports, top and bottom of steel tube will developed and the crack width will increased rapidly. The composite neutral axis began to remain constant at around 60 mm and 40 mm from top fiber.

3.6 Moment – Curvature Results

The moment –curvature relationships for all tested composite beams are given in Figure (10). A linear branch was observed before the yielding moment is achieved, after that the curve became nonlinear. The curvature increases with load until failure. Large cross section lead to stiffer response as shown in specimens G2Th.6, G5D8.5″, G5D6″ and when no open in steel beam. This behavior was because the curvature value was calculated based on N.A depth, where it is increased with cross –section area increased and that cause decreased in curvature. There is no effect of other parameters such as support length, spacing and type of shear connector on curvature value.

4. CONCLUSIONS

Experimental investigations on the behavior and strength of composite circular steel tube, with concrete slab, have been presented. The following conclusions can be drawn from this investigation:

1- The load –deflection curve of group with support dimensions (G1Support), tube thickness (G2Thickness), spacing of connectors (G3Spacing), opening in tube (G4Opening), and connectors type (G6Connectors) show no degradation occurred in stiffness of composite steel tube beams up to 50 % of ultimate load value.

2- The thickness of steel tube is important factor, where the strength of beam with 6 mm steel tube thickness is 39% larger than beam with 3 mm thickness. It's appeared that, increase the cross section area of steel tube, increases the ultimate strength of composite steel tube beam.

3- Suddenly failure by web buckling was observed for beam G7I-sec at support, because no stiffeners were used in the middle and end of I-section steel beam. A heavy load or reaction concentrated on a short span produces a large portion of the steel web under high compressive stresses either under the load or at the support. This makes the steel section more susceptible to web failures phenomena such as web crippling, web buckling, or web crushing.

4- Failure mode of I-section beam (G7I-Sec.) is web buckling, while this phenomenon was not observed in circular steel tube. Where, section dimensions were selected based on the same beam weight and depth of I-section the same as diameter of steel tube.

5- It is clear, that though even the beam is designed as a full composite section, a perfect interaction without any slip cannot be obtained because of the bearing stress of shear studs, which are consider as ductile connectors.

6- Finally from previous conclusions, it can be said, the tube section is the best alternative to I-section in composite beam. It has better response in bending and resistance to buckling failure without stiffeners need at mid span and support near. The proposed structural system proved the qualification in flexural behavior, this means: it can be used in building and construction as structural member resisting the bending. In addition, this composite beam can be used to pass through it the service work as electrical lines, mechanical heating, ventilating, etc. without need to increase floor height and web opening making that causes increase in building cost. Also, the new proposed section can be benefit to transport water or oil through it.

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Table (1) Details of Test Specimens

Beam Group*	Specimen Designation	Steel Sec. Type**	Support*** Length x Depth x Width	Shear Connector		Opening
				Type	No. & Spa. mm	
G1	G1S25	Tube 168 (6″)x 4	250x240x300	Stud	33@60	No Open
	G1S45	Tube 168 (6″)x 4	450x240x300	Stud	33@60	No Open
	G1S65	Tube 168 (6″)x 4	650x240x300	Stud	33@60	No Open
G2	G2Th.3	Tube 168 (6″)x 3	450x240x300	Stud	33@60	No Open
	G2Th.6	Tube 168 (6″)x 6	450x240x300	Stud	33@60	No Open
G3	G3Spa.80	Tube 168 (6″)x 4	450x240x300	Stud	24@80	No Open
	G3Spa.100	Tube 168 (6″)x 4	450x240x300	Stud	20@100	No Open
G4	G4Open1	Tube 168 (6″)x 4	450x240x300	Stud	33@60	1 open
	G4Open2	Tube 168 (6″)x 4	450x240x300	Stud	33@60	2 open
G5	G5D.3.8″	Tube 100(3.8″)x 4	450x170x235	Stud	33@60	No Open
	G5D.8.5″	Tube 215(8.5″)x 4	450x290x355	Stud	33@60	No Open
G6	G6Angle	Tube 168 (6″)x 4	450x240x300	Angle	17@120	No Open
	G6Perfobond	Tube 168 (6″)x 4	450x240x300	Perfobond	Plate with holes along beam	No Open
G7	I-section	I-sec. 160x80	_	Stud	33@60	No Open

* G1: Support, G2: Thickness, G3: Spacing, G4: Opening, G5: Diameter, G6: Type of connector, G7: I-section.
** Section type [Dia. of tube (mm), (inch)] x thickness (mm).*** All dimensions in mm.

Table (2) Material properties of structural steel beam

Materials		Yield Strength MPa	Tensile Strength MPa	Max. Elongation % (50mm)
Steel I-section beam	Web (4mm)	307	421	31
	Flange (7 mm)	311	428	22
Circular Steel Tube beam	Tube (168(6″)* 3mm)	346	427	36
	Tube (168(6″)* 4mm)	345	435	44
	Tube (168(6″)* 6mm)	345	417	50
	Tube (100(3.8″)*4mm)	385	450	34
	Tube (215(8.5″)*4mm)	337	438	54

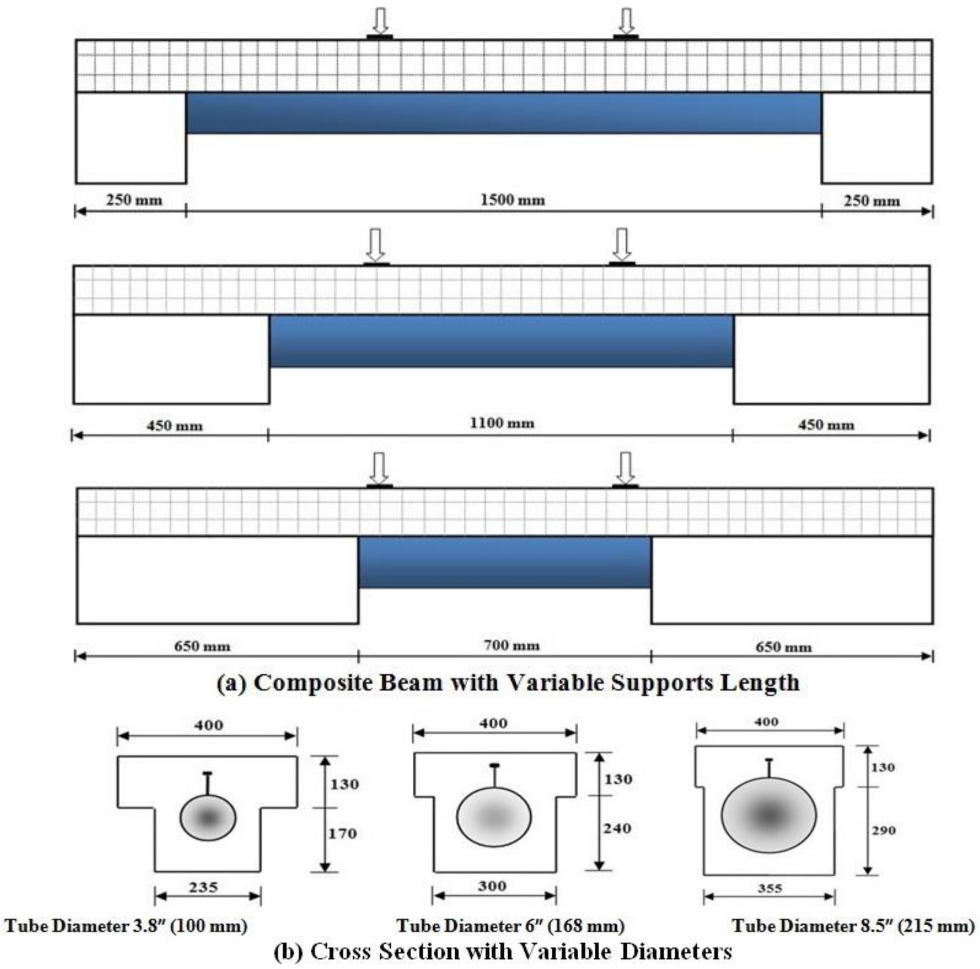


Figure (1) Typical Geometry of Test Specimen

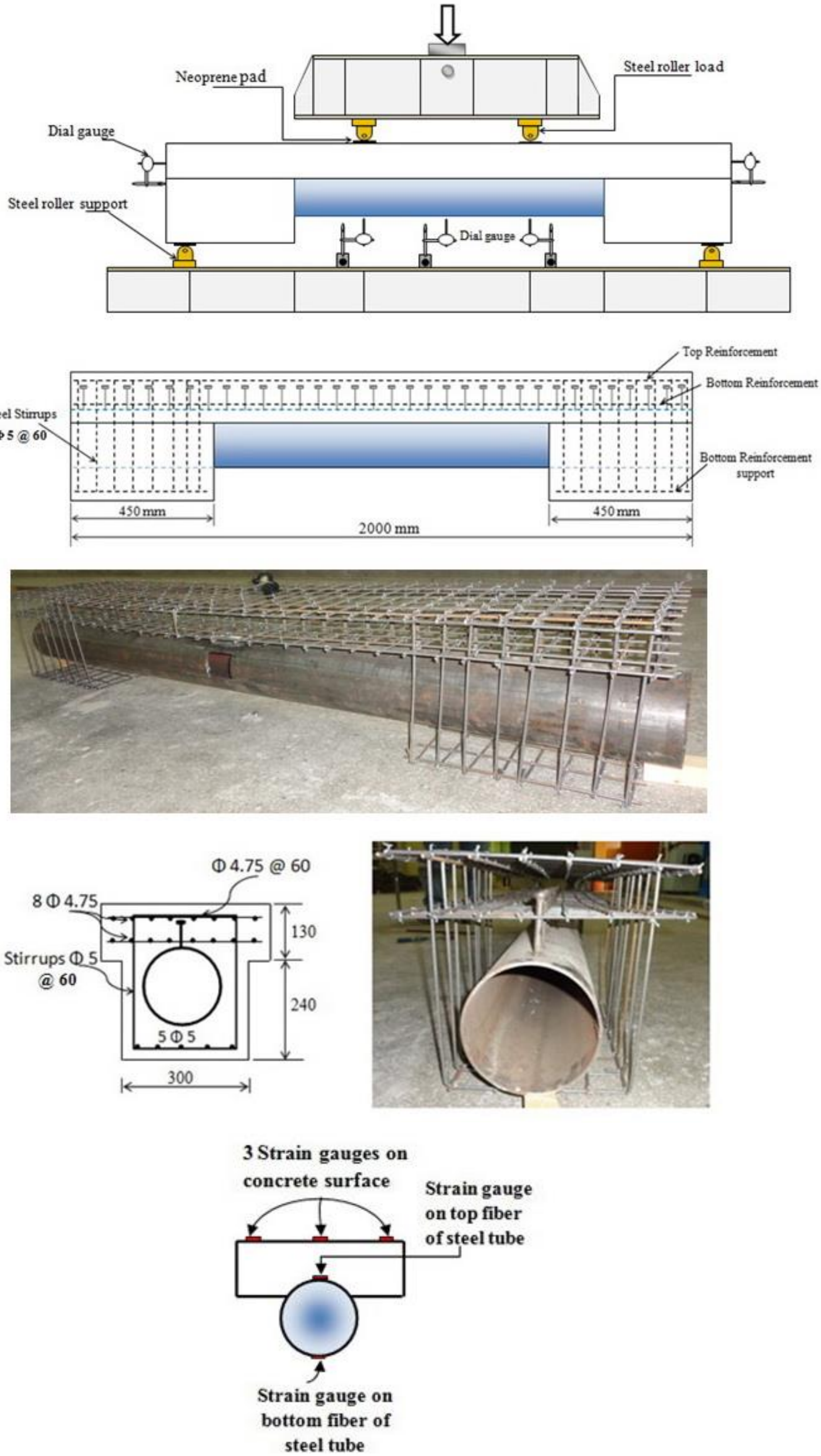
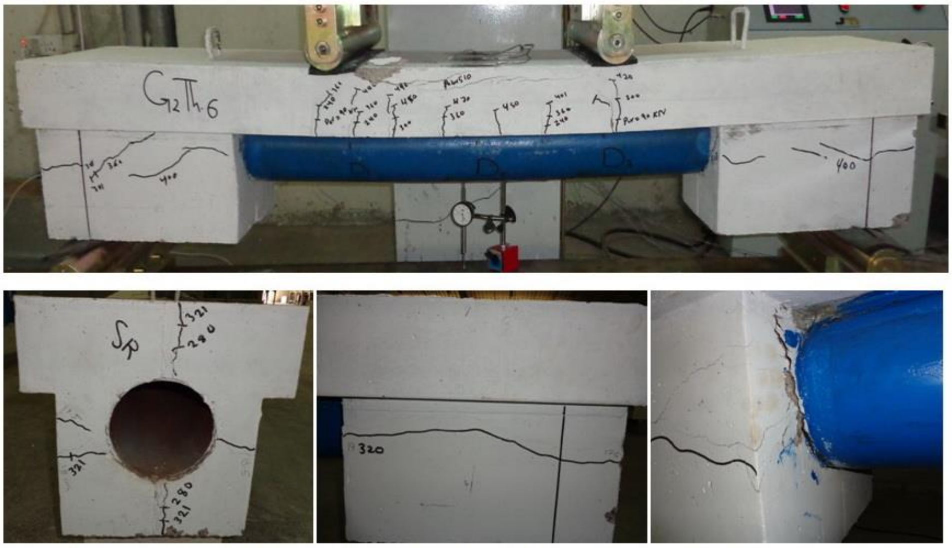


Figure (2) Test Specimen Beam

Figure (3) Testing Machine



Crack around steel tube | Longitudinal crack at support | Crack from inner to outer

Figure (4) Types of Cracks and Position

a. Circular Steel Tube beam | b. I-Section Steel beam

Figure (5) Typical Failure Modes of Test Specimens

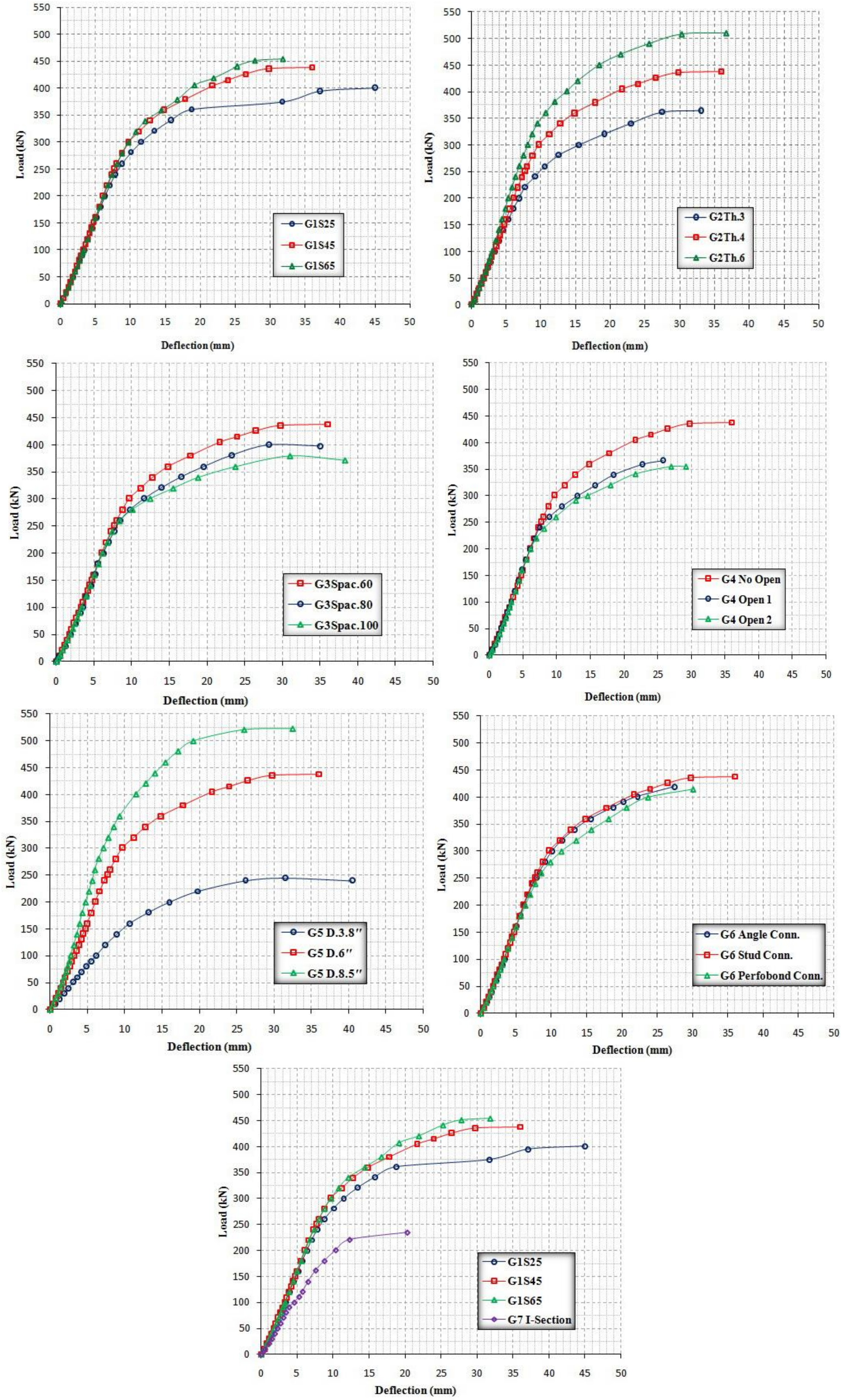


Figure (6) Load –Deflection of Groups

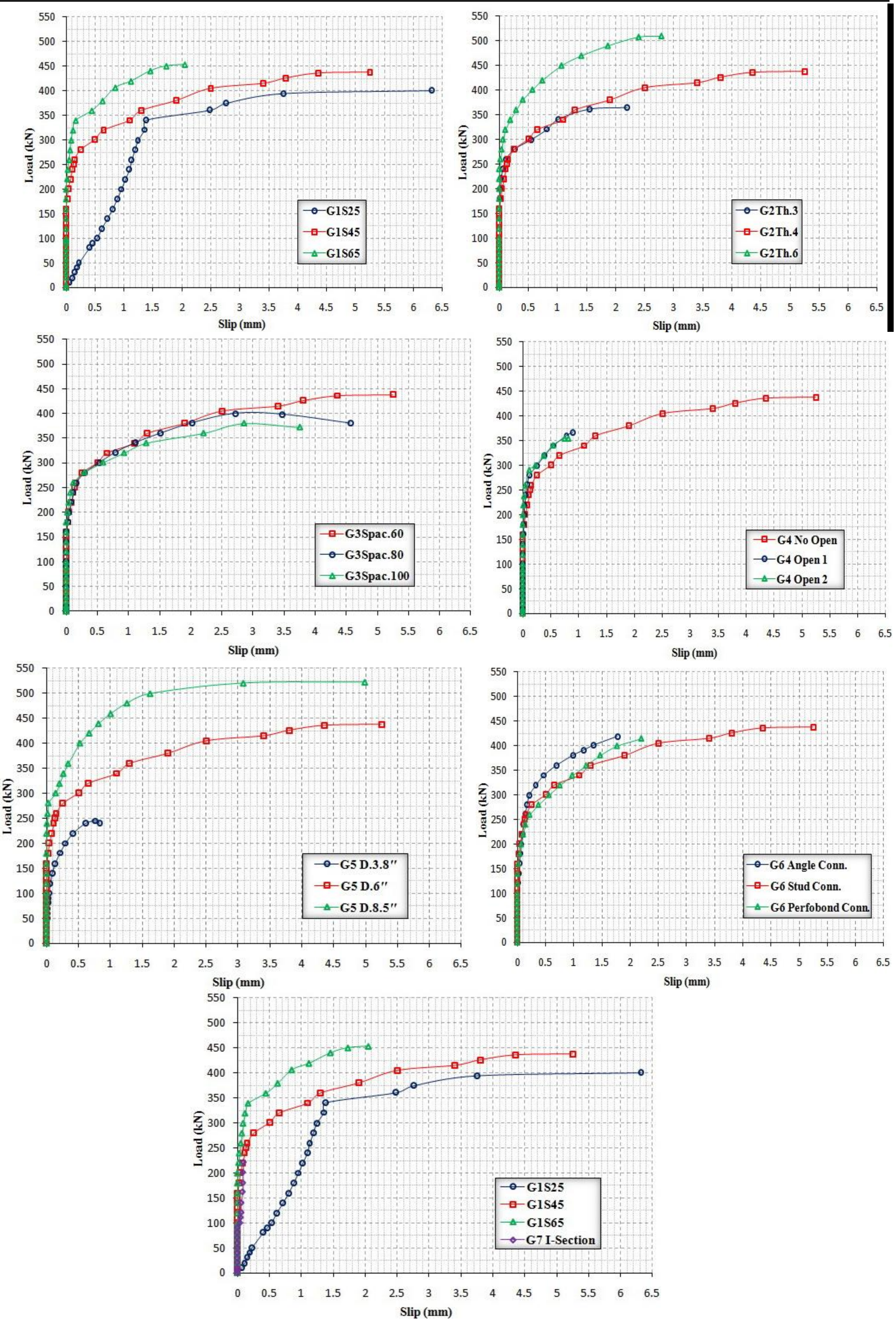


Figure (7) Load –Slip Curves of Groups

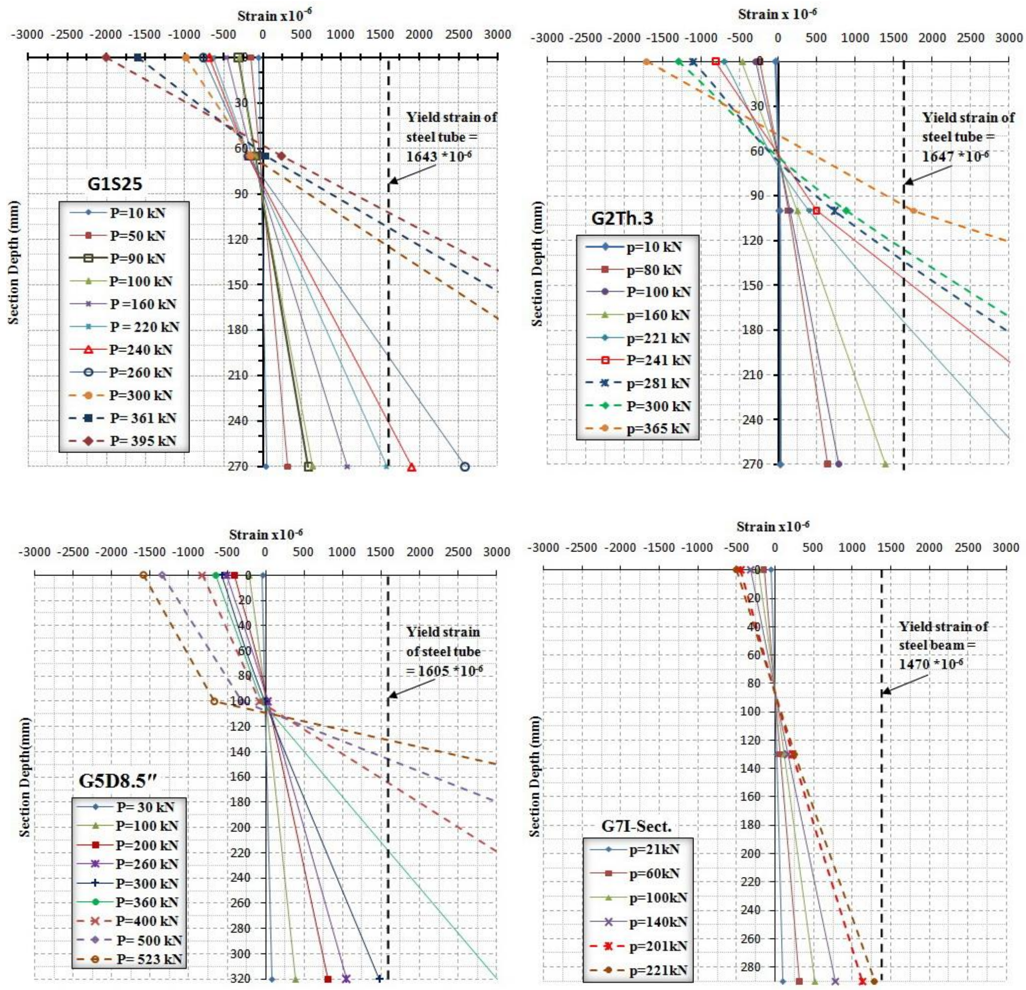


Figure (8) Strain profiles of Specimens

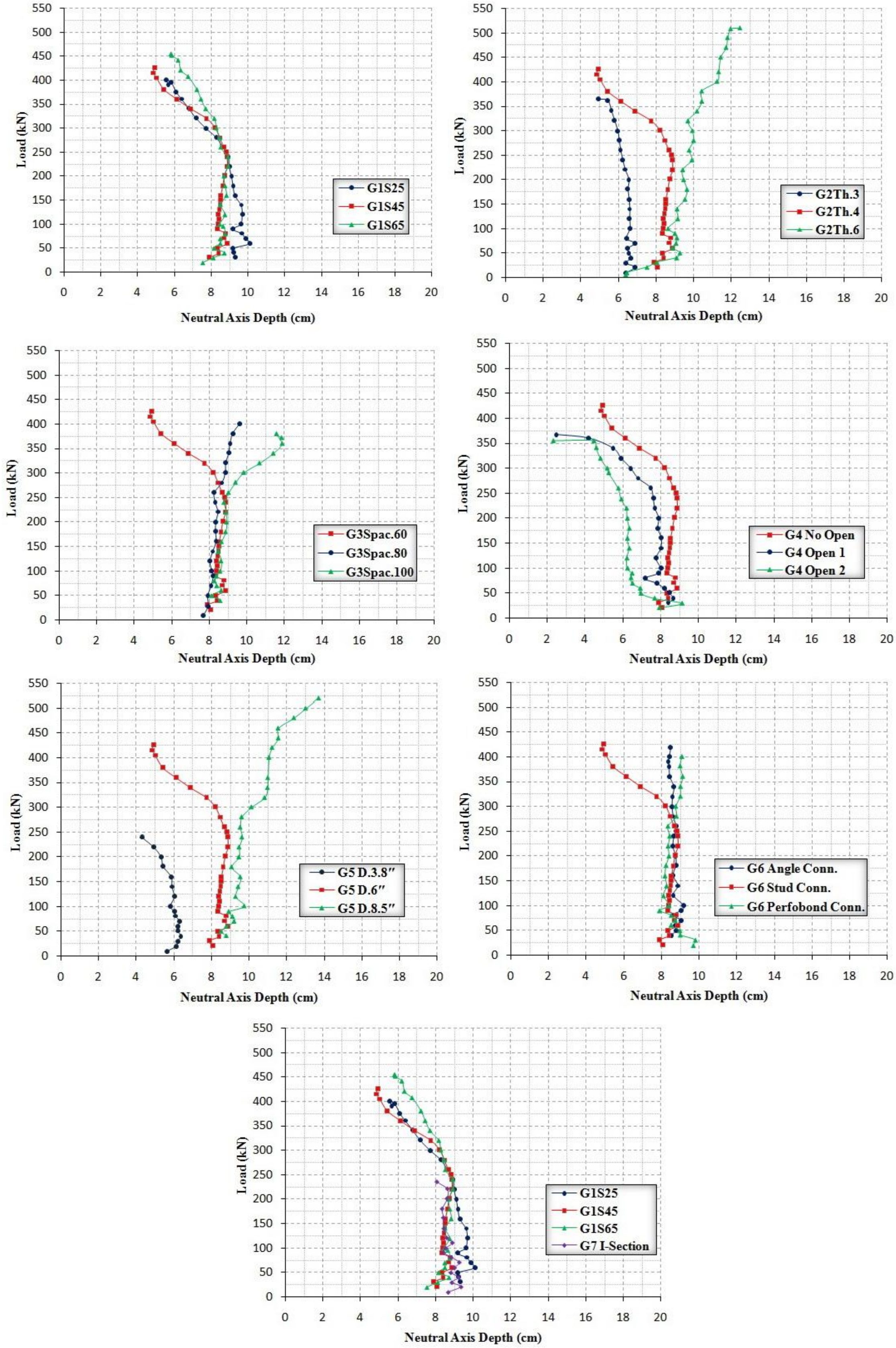


Figure (9) Neutral Axis Depth of Groups

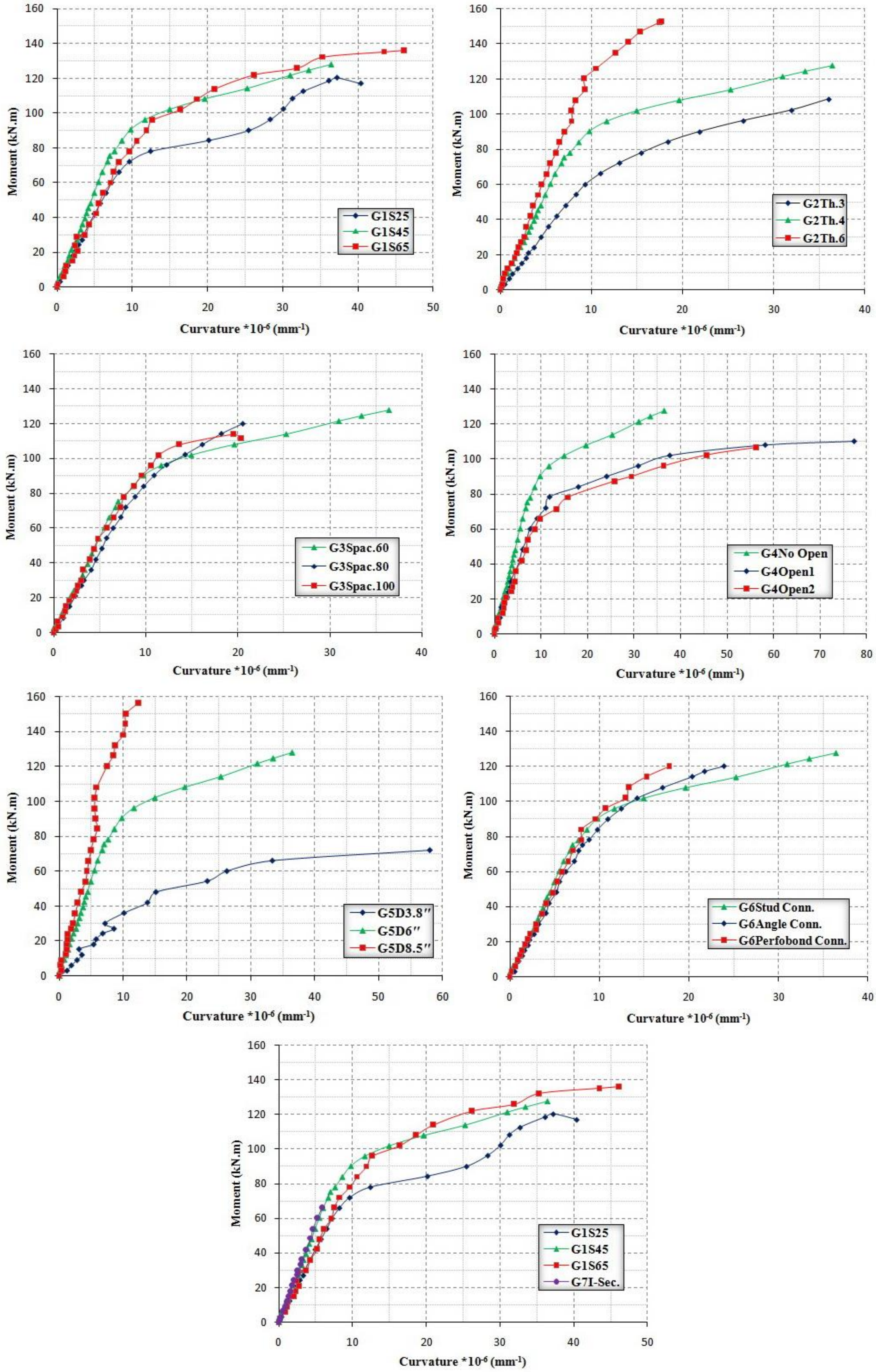


Figure (10) Moment –Curvature of Groups

التصرف الانشائي لعتبات خرسانية مسلحة مركبة مع انظمة انابيب حديدكخطوط حياة

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الخلاصة

هذه الدراسة تركز على المميزات التي يمكن ان تكتسب باستعمال العتبات المركبة مع بلاطة خرسانية تثبت الى انبوب حديد دائري كبديل للمقطع (I) في عتبة الحديد. برنامج البحث العملي أعد لتقييم سلوك الانثناء للعتبات المركبة من عتبة خرسانية مثبتة الى انبوب حديد دائري. الاربعة عشر عتبة الكلية قسمت الى سبعة مجاميع مع متغيرات مختلفة تم تصنيعها وفحصها تحت ضروف تحميل ساكنة لتحديد السلوك الانشائي لعتبة مركبة مع انبوب حديد دائري. وقد وجد ان النظام الانشائي المقترح اثبت كفائته بسلوك الانثناء، هذا يعني؛ انه ممكن استعماله في الابنية والمنشأت كعضو انشائي يقاوم الانحناء. بالاضافة الى ان هذه العتبة المركبة يمكن ان تستعمل لتمرير الخدمات منها مثل خطوط الكهرباء، اعمال التدفئة والتبريد، الخ بدون الحاجة الى زيادة ارتفاع الطابق وعمل فتحات في العتبة وهذا يسبب زيادة كلفة البناية. المقطع الجديد المقترح ممكن الاستفادة منه لنقل الماء والنفط من خلاله.