Mechanical Performance of Construction Errors in Implementation of T-Reinforced Concrete Beams

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ABSTRACT

The objective of this study is to identify and evaluate the construction errors during the implementation of concrete T-beams. This research was borne out of the need to investigate some of the many factors responsible for the failure of structures, like the impact of misplacement of slab reinforcement, the effect of irregular arrangement of slab reinforcement and the effect of change in bar diameter of slab reinforcement on the structural behavior of T-beam sections. An experimental program was implemented on nine specimens, which were divided into eight specimens of T-beams, in addition to one specimen which was designed so that the section was a rectangular section without slab to identify the performance of slab in load resistance. Eight specimens of T-beams were designated to simulate the possible defects in the field. The results indicated that the faulty placement of slab reinforcement leads to a lower bending moment capacity of the slab and the steel strain of slab decreased as the height of slab reinforcement decreased. The irregularity of the reinforcing bars in the concrete slab affected the ultimate load of the slab and well-arranged distribution of reinforcement improves the ductile behavior of the slab and reduces the corresponding deflections. The minimum bar diameter for the reinforcement of the slab is 8mm, because the 6mm diameter reinforcement was found to be weak in terms of resistance to loads. It is suggested that a high level of quality assurance be maintained during the construction process to limit the occurrence and effects of construction errors. T-beams are more efficient than rectangular beams, where a part of the slab contributes to the resistance of the loads.

KEYWORDS: T-beams, Human errors, Faulty placement, Irregularity, Bar diameter.

INTRODUCTION

The fast growth in the construction sector had not come without a price. Rarely does a month pass without reading in an official newspaper about the collapse of buildings in Egypt and other parts of the world that led to fatalities and injuries due to human errors. It becomes necessary to find an approach that efficiently measures the effects of human errors in concrete slab and beam implementation on structural reliability in Egypt, as well as to assist in providing guidelines to control and improve the safety of structural elements during and after construction. In Egypt, Housing and Building National Research Center (HBNRC) has conducted a statistical study on the causes of deterioration in concrete structures in different periods. This statistical study illustrated that about 83% of the causes of damage

Received on 17/3/2018.
Accepted for Publication on 17/10/2018.

were referred to bad execution practices starting from the eighties of the past century. Thus, there is an increasing demand for developing a better understanding of the effect of bad execution practices on the performance of concrete structures, especially on cracking, to determine the proper method of repairing these defects (Elrakib and Arafa, 2012).

Most of the concrete structures can be sub-divided into concrete beams and concrete slabs subjected primarily to flexure (bending) stresses. The concrete slabs and beams act together in resisting the applied loads. As a result, the beam will have an extension concrete part at the top called the flange and the portion of the beam below the slab is called the web. To consider a slab and a beam as a T-section, it is necessary to ensure interaction between these elements by a solid connection. Connection in the contact between the slab and the beam must be capable of ensuring a proper resistance to longitudinal and transverse shear forces (Ciesielczyk et al., 2017; ECCS203, 2007).

Few investigations have been concerned with the elevation of the shortcomings which frequently existed in the execution of reinforced concrete structures and cracking in RC structures. Defects can be classified into two main sections; the first section focuses on the defects that occur in the reinforcing steel detailing and cracking in RC elements, while the other section focuses on the strength of concrete. Cracks occur because of the low tensile strength of concrete. These cracks, however, have a significant influence on the structural performance of concrete elements, including tensile and bending stiffness, energy absorption capacity, ductility and corrosion resistance of reinforcement (Watstein and Parson, 1943; Byung and Kang, 1987). ACI Committee (1993), Nurul and Mydin (2014) and Duinkherjav and Bayar (2014) have discussed the causes of cracking in reinforced concrete structures. These can be classified into three groups: structural group, non-structural group and fire load group. There are many reasons for the development of non-structural cracking in the plastic stage of freshly cast concrete. However, structural cracking influences load carrying capacity of the structure, significanttly decreasing structural stability and safety factors. These cracks may even lead to possible failure of structures and accident condition in construction. Some possible causes of structural cracking are: design failure, change of serviceability, increase of design load, poor quality of materials used, mistakes in construction technology and impact loads. Cracks due to fire load can be considered as both structural and non-structural cracks.

There are several parameters which affect cracking in reinforced concrete structures, including properties of concrete constituents, concrete cover, diameter of main steel and its ratio, distribution of reinforcement and characteristics of applied loads. Furthermore, cracking may appear as a result of a wide variety of poor construction practices. Cogurcu (2015) and Peansupapa and Rothmony (2015) investigated the construction and design defects in residential buildings. There are three causes for failure of residential buildings which can be identified in design mistakes, construction stage mistakes (poor workmanship, low strength of materials, inadequate transverse reinforcement–stirrup usage, defective and inadequate interlocking length and lack of control) and mistakes in usage. An experimental investigation was performed to investigate the behavior of reinforced concrete T-beams with different types of concrete in web and flange and the effect of flange geometry was investigated by Ghailan (2010), Al-Mahaidi et al. (2011) and Zaher et al. (2015). T-beams have full importance in roof simply supported slabs on load bearing walls or girders. This technique of construction is widely used and suitable for residential, commercial, prefabrication and industrial buildings, especially for large spans. A web-reinforced shear critical reinforced concrete T-beam subjected to a concentrated point load will fail by one of two mechanisms. The first is a beam shear mechanism, in which a diagonal tension crack continues from the web and penetrates into the flange. The second is a punching shear mechanism, whereby the applied load punches through the flange. An increase in the ratio of flange width to web width is shown to produce an accompanying increase in the ultimate strength of a reinforced concrete T-beam, provided that the ratio of flange depth to effective depth is above a particular minimum value. This increase in shear resistance with an increase in the ratio of flange width to web width continues until the flange is wide enough to allow the formation of a failure mechanism, whereby the load point punches through the flange. The existence of slab contributed to the increase of shear resistance in the T-beam, where shear failure loads increased by 42% of the rectangular section in the T-beam without stirrups, up to 43% in the T-beam with ordinary web stirrups and up to 54% in the T-beam with flange stirrups. The shear resistance increases with the increase of slab thickness. When the ratio of slab thickness to beam thickness increases from 13% to 27%, the shear failure loads increase by 45%.

Human errors are predominant and are among the many factors responsible for the failure of structures (Kaminetzky, 1991; Stewart, 1993; Hong and He, 2015). Human errors arise in the form of lapses and shortcomings that remain unnoticed during the design and construction of structures. It is obvious that there are very few research studies that investigated the human errors and implementation defects that occur during the execution of concrete structures. These defects are due to the displacement of the reinforcing steel from the appropriate position, the distribution of reinforcing bars irregularly in the concrete slabs or beams, casting method and increase in water/cement ratio in the concrete mix. These defects occur in many countries of the world, especially Egypt. These defects are needed to be investigated more deeply to determine precisely the effect of these parameters on the structural behavior of concrete slabs and connected beams.

This paper investigated an experimental work to study the structural behavior due to change in position and ratio of negative reinforcement in the concrete slabs and attached beams. The experimental investigation involved three parameters; the first parameter deals with the effect of misplacement of slab reinforcement on the efficiency of T-beam sections, while the second examines the effect of irregular arrangement of slab reinforcement on the behavior of T- beam sections. Effect of change in bar diameter of slab reinforcement was displayed in the third parameter.

EXPERIMENTAL PROGRAM

An experimental program was planned through which seven reinforced concrete slabs fabricated with defects in erecting practices were studied, in addition to the control specimen and the other specimen without slab (flange) (rectangular beam) to compare with control specimen to identify the importance of slab in resisting loads. The shape of the specimen consisted of a beam and a slab that was monolithically cast on the shape of character T-section. Thus, slab and beam act together in resisting the applied loads. Dimensions of slab are 950 mm (width), 100mm (thickness) and 2000mm (length), while the dimensions of projected beam are 150mm (width), 200mm (drop depth) and 2000mm (length). The dimensions and geometry of the experimental specimens are shown in Figure (1), while the dimensions of the rectangular beam are shown in Figure (2).

Reinforcement of the slab and the stirrups of the beam were normal-grade bars 24/37, while high-tensile steel 36/52 was used in main and secondary steel of the projected beams. For a beam in all specimens, the amount of main longitudinal bottom and top reinforcement was kept constant. The vertical stirrups were also constant. The main longitudinal bottom reinforcement or the secondary reinforcement comprises three bars with 10mm diameter high tensile steel. The vertical stirrups' reinforcement was 8mm diameter mild steel bar spaced at 200mm acting as transverse reinforcement. The reinforcement of the slab was changed from specimen to specimen according to the type of parameter. All specimens are loaded by a uniformly distributed load (line load) at the end of the slab from the two sides. After the failure of the slab, the beam of control specimen was re-tested under the effect of two-point loads to see whether the concrete slab is still resisting new applied loads or not and to find out whether the concrete section was still a T-section or changed to an R-section. In addition, the rectangular beam was compared with the control specimen.

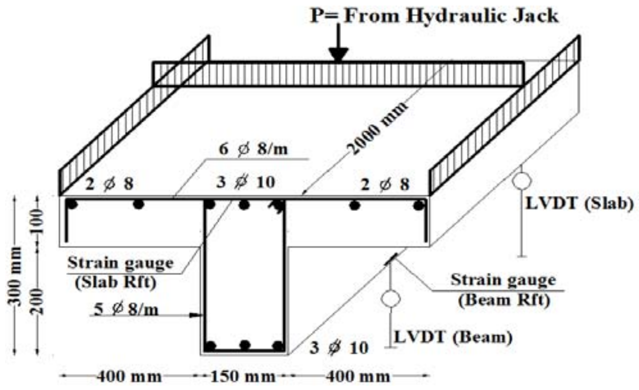

Figure (1): Details of control specimen

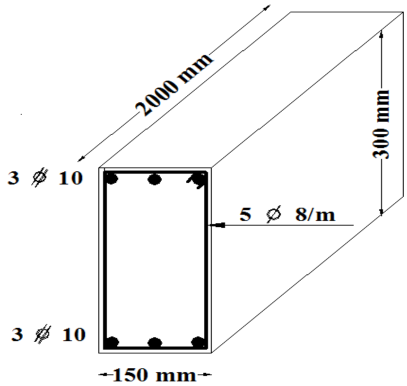

Figure (2): Details of rectangular beam

The first parameter consists of five specimens, GIM-1 (control specimen), GIM-2, GIM-3, GIM-4 and GIM-5. The variable of all specimens was the depth of slab reinforcement. The misplacement of slab reinforcement ($t_{mis.}/t_s$) varied as 0.2, 0.4, 0.6 and 0.8 percent for specimens GIM-1, GIM-2, GIM-3 and GIM-4, respectively, while the last specimen GIM-5 was without slab to identify the importance of slab in resisting loads. Control specimen (GIM-1) was made with standard requirements of good compaction using a mechanical vibrator, enough concrete cover and well-arranged reinforcement. No splices in the reinforcement of slab or beam were used in this control specimen. All specimens were constructed in the laboratory in the Faculty of Engineering at Al-Azhar University. The second parameter contains two specimens, in addition to the control specimen. In these specimens, the eccentricity of the main steel in the slab was the major parameter. The area of steel for the slab was not changed (13Ø8mm on the length of the slab), but the distribution of steel was varied for two specimens (unequal distribution of slab reinforcement). In the first specimen (GIIA-1), irregular arrangement of slab reinforcement was used by means of three reinforcement bars at the mid-span of the slab at 50mm, while two bars were placed at a distance of 260mm from the two sides from the previous three bars, keeping the distance between these bars at 50mm. Moreover, there are two bars from two sides at a distance of 260mm from the end of the slab. At the ends of the specimen, one bar was erected. Figure (3) illustrates the plan of reinforcement distribution of slab specimen (GIIA-1). In another specimen (GIIA-2), the eccentricity of slab reinforcement was in the three groups, where every group comprises three bars with two distances between the three bars. This distance was 100mm, while the distance between groups was 290mm. At the end of the specimen, two bars were erected from the two sides and the distance was 100mm. The plan of slab reinforcement distribution for specimen (GIIA-2) is shown in Figure (4). The last parameter comprises three specimens (GIIID-1), (GIIID-2) and control specimen (GIM-1) and identifies the change in bar diameter of slab reinforcement. The ratio of steel was not changed, but the diameter was changed. The first specimen was of a diameter of 6mm, whereas a diameter of 10mm was used in the second specimen. In the first specimen (GIIID-1), the area of steel was fulfilled by 11Ø6/m, while the second specimen (GIIID-2) comprises 4Ø10/m. Details of all tested specimens are shown in Table (1).

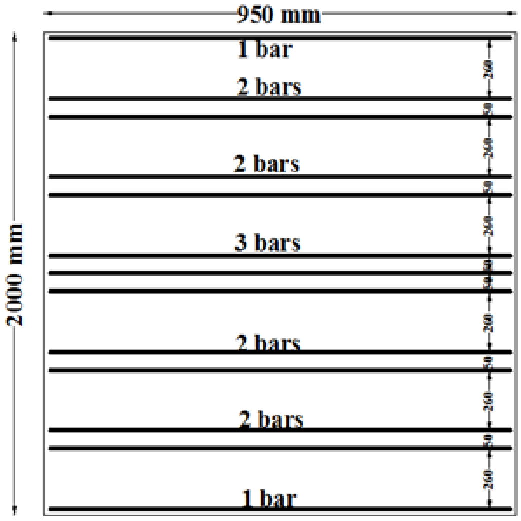

Figure (3): Plan of slab reinforcement distribution for specimen (GIIA-1)

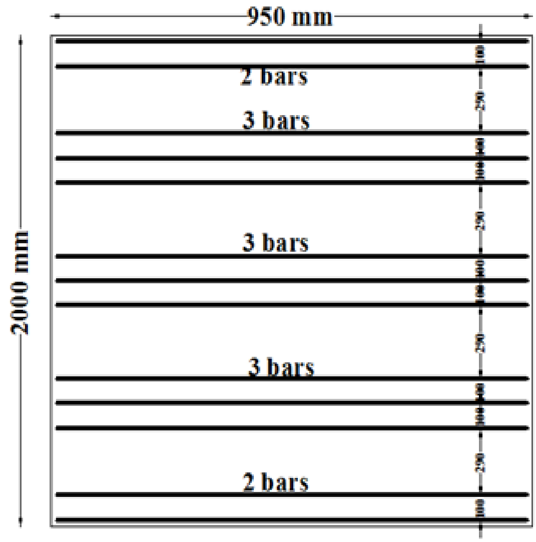

Figure (4): Plan of slab reinforcement distribution for specimen (GIIA-2)

Table 1. Summary of the different specimens

Group	Specimen Notation	Notes
Effect of misplacement of slab reinforcement on the efficiency of T-beam sections (GIM)	GIM-1	Control specimen ($t_{mis.}/t_s$) = 20 %
	GIM-2	($t_{mis.}/t_s$) = 40 %
	GIM-3	($t_{mis.}/t_s$) = 60 %
	GIM-4	($t_{mis.}/t_s$) = 80 %
	GIM-5	t_s =0
Effect of irregular arrangement of slab reinforcement on the behavior of T- beam sections (GIIA)	GIIA-1	——
	GIIA-2	——
Effect of change in bar diameter of slab reinforcement (GIIID)	GIIID-1	Slab Rft = 11Ø6/m
	GIIID-2	Slab Rft = 4Ø10/m

Table 2. Concrete mix design

Constituents	Mix proportions by weight for one m^3
Crushed stone	1256 kg
Gradate sand	628 kg
Water	150 liter
Water / cement ratio	0.50

CHARACTERISTICS OF MATERIALS USED

The cement used was from Torah Cement factory and coincided with the requirements of the Egyptian Standard Specifications (ES 4756/1-2007) for Portland cement. Crushed stone (coarse aggregate) and sand (fine) aggregate are used in the experimental program. The water used in all mixes was clean drinking fresh water free of impurities. The trial of mixes was carried out until the required workability was achieved and this was accomplished by a water/cement ratio of 0.50.

Mix Proportions: The concrete mix used in all specimens was designed according to the Egyptian code of practice. The concrete mix was designed to obtain a target strength of 25 N/mm^2 at the age of 28 days for all specimens. Mix proportions by weight (kg/m^3) are presented in Table (2). To determine the compressive strength of concrete after seven and twenty-eight days from casting, eighteen standard cube tests (150×150×150) mm had been made; nine concrete cubes were tested after 7 days, while the remaining concrete cubes were tested after 28 days.

The cubes were filled with concrete in three layers while tamping each layer with a steel rod for twenty-five times according to the Egyptian code of practice. The average compressive strength of concrete cubes measured at 7days was approximately 23.44 MPa, while at 28days, the average compressive strength was equal to 29.76 MPa.

INSTRUMENTATION AND LOADING SYSTEM

The specimens were tested in a vertical position under concentrated vertical load from hydraulic jacks on two spreader beams which have a uniform load (line load) on the two ends of the slab up to failure. The loading was applied through a spreader beam on the specimen using 100 kN capacity hydraulic jacks. Two linear variable displacement transducers (LVDTs) were placed vertically at the middle of the beam to measure the vertical deflection and midpoint of the flange at the end of the slab. The strains were measured in the main reinforcement of the slab and the lower reinforcement of the attached beam, whereas after the slab failure of the control specimen and the rectangular beam, the load was distributed equally by a spreader beam to two points along the specimen to generate a constant moment region at the midspan. The load on the beam of specimens GIM-1 and GIM-5 was applied at equal distances, where the clear span of the beam between the supports was equal to 1800 mm and two-point loads were applied at an equal distance of 600 mm.

Cracks were detected through visual observation during testing all specimens, as well as marking the propagation of cracks at each load increment. The cracking and ultimate loads were accurately recorded during each test. The test specimens were loaded to failure and the behavior regarding load-deflection response, modes of failure and strain values in the main reinforcement of the slab and beam was observed and recorded.

EXPERIMENTAL RESULTS AND ANALYSIS

Load-Deflection Behavior at the End of Slab for All Tested Specimens

The measured deflection values were plotted against the corresponding applied loads, from the start of applying the load up to failure. The load-deflection curves of the tested specimens in all groups are plotted in Figs. (5-7) and cracking load P_{cr}, ultimate load P_u, ultimate deflection at failure Δ_f and toughness for all tested specimens are shown in Table (3).

From the relation between load and deflection of specimens of group I, it was noticed that the tested specimens demonstrated linear deflection behavior before cracking. Upon cracking, stiffness was reduced as the load increased. For specimens GIM-2, GIM-3 and GIM-4, lower values of ultimate load and deflection were noticed compared with the control specimen GIM-1. The area under the load-deflection relationship up to failure is called toughness. Toughness is the ability of the material to withstand or absorb mechanical energy as shown in Table (3). It can be concluded from comparison of group I that the rate of increase for the ratio of slab reinforcement misplacement was less than the ultimate load value of the tested specimens, but the rate of decrease in the ultimate load was not the same as the rate of increase in the percentage of wrong placement in slab reinforcement. A lower position of the reinforcement leads to a lower bending moment capacity of the slab and can also lead to a brittle behavior in case of collapse.

Table 3. Summary of the experimental results for all tested specimens

Group	**Specimen Notation**	**Cracking Load (P_{cr})(kN)**	**Ultimate Load (P_u) (kN)**	**Ultimate deflection Δ_f (mm)**	$\frac{P_{cr}}{P_u}$	$\frac{P_u}{P_u}$ **(Control)**	**Toughness (kN.mm)**
Group # 1	*GIM-1 (Control)*	10	32	35	0.31	1.0	981.213
	GIM-2	5	25	31	0.20	0.781	701.81
	GIM-3	4.5	20.50	32	0.219	0.640	589.82
	GIM-4	6	18.50	34	0.324	0.578	496.95
	GIM-5 (Beam only)	8.8	45	31	0.195	0.9375	897.08
Group # 2	*GIIA-1*	7.5	28	33	0.245	0.875	828.088
	GIIA-2	12	30.5	36.8	0.428	0.953	973.09
Group # 3	*GIIID-1*	4.6	19	44.5	0.242	0.593	606.64
	GIIID-2	7	38	44	0.184	1.187	1412.71

It can be deduced from the results of group II that well-arranged distribution of reinforcement improves the ductile behavior of the slab and reduces the corresponding deflections. Meanwhile, the eccentricity of the main steel creates a sort of non-uniform stress distribution over the section and accelerates failure.

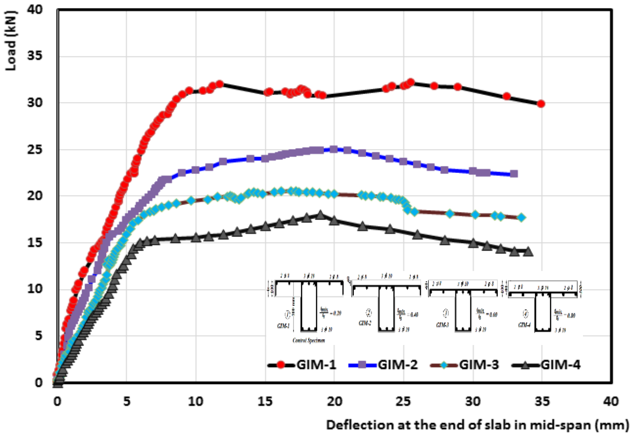

Figure (5): Comparison between the tested specimens of group I

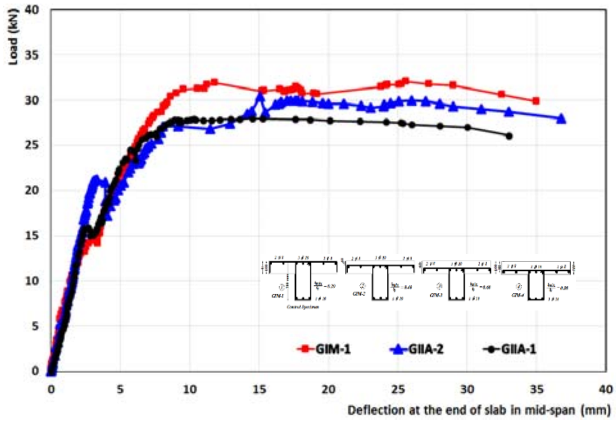

Figure (6): Comparison between the tested specimens of group II

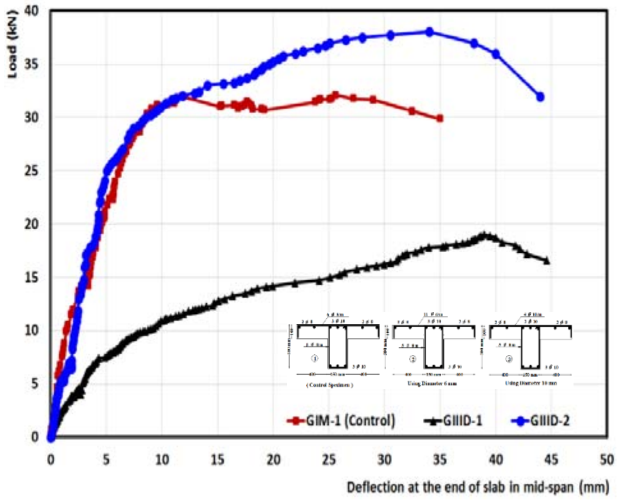

Figure (7): Comparison between the tested specimens of group III

A comparison of group III showed that the use of 10 mm diameter in the reinforcement of the slab exhibited high resistance to loads, while on the contrary, 6 mm diameter reinforcement offered a weak resistance to the loads affecting the slab. Load-deflection responses for specimens GIM-1 and GIIID-2 showed approximately the same trend, and no significant difference was observed at low loading level, while the third specimen GIIID-1 exhibited a significant difference in values of the deflection from the beginning of loading.

It is concluded from the test results of group III that increasing the diameter of slab reinforcement while keeping reinforcement ratio constant enhanced the behavior of T-beam to withstand the loads and increased the ductility of the T-beam. Also, to improve the efficiency of T-beam section under the loading effect, the minimum bar diameter for the reinforcement of the slab was set at 8mm, because 6mm diameter reinforcement was found to be weak in resisting loads.

Load-Deflection Behavior at the Mid-span of the Beam for All Tested Specimens

Figure (8) displays the applied load against the vertical deflection at the mid-span of the reinforced concrete beams for group I. It is apparent that the shape of the load-deflection curves in the elastic region before cracking is the same for the all specimens. However, it appears that after cracking, both specimens GIM-1 and GIM-2 produced higher values of deflection than specimens GIM-3 and GIM-4 for the same level of loading. The maximum deflection of specimens GIM-1, GIM-2, GIM-3 and GIM-4 was 5.9mm, 6.7mm, 7.55mm and 6.3mm, respectively at failure load. It could be said that the harmful effect resulting from wrong position of slab reinforcement is more defective on the behavior of the slab and the attached beam than the correct place for reinforcing steel for the slab.

It can be observed from the load-deflection relationship for the two specimens GIM-1 and GIM-5 shown in Figure (9) that specimen GIM-1 demonstrated higher deflection than specimen GIM-5 and the failure load of specimen GIM-1 was higher than that of specimen GIM-5. The maximum load of specimen GIM-5 is less than the ultimate load of specimen GIM-1 and the toughness is increased with the increase of the stiffness of specimen GIM-1. This indicates that the specimen with a slab (flange) has a higher performance in resisting loads affecting it compared to the specimen which does not have a slab (rectangular beam). This is mainly attributed to the existence of the flange in the T-section that resulted in higher stiffness than in the R-section. T-beams are more efficient than rectangular beams where a part of the slab contributes to the resistance of the loads.

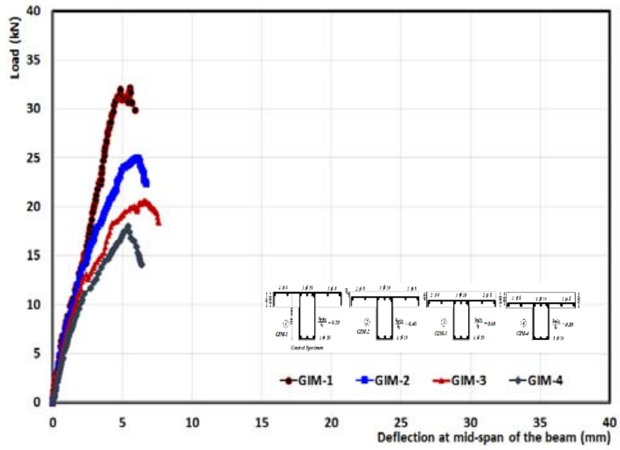

Figure (8): Load-deflection relationship at the mid-span of the beam for specimens of group I

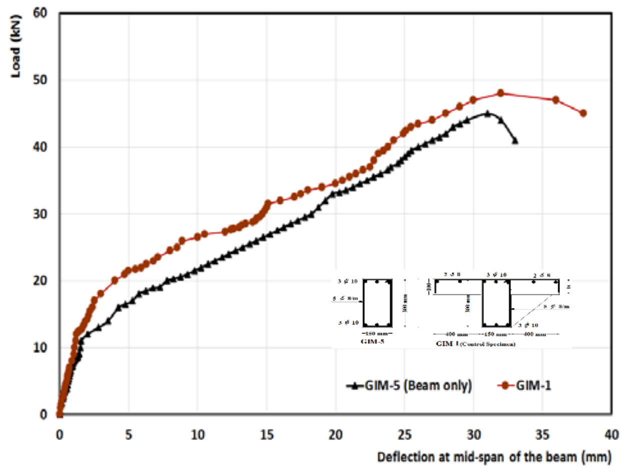

Figure (9): Load-deflection relationship at the mid-span of the beam for specimens GIM-1 and GIM-5

The load-deflection curves for specimens of group II are shown in Figure (10). There are no significant differences between the three specimens in the values of deflection, especially at the beginning of loading before the initiation of cracks. The maximum deflection for specimens GIM-1, GIIA-1 and GIIA-2 at failure load was 5.90mm, 6.80mm and 5.75mm, respectively. It is evident that the irregularity of the reinforcement of the slab does not have any significant effect on the efficiency of a concrete beam connected with the slab. Furthermore, the beam attached to the slab was not significantly affected by the irregularity of the shape of the slab reinforcement.

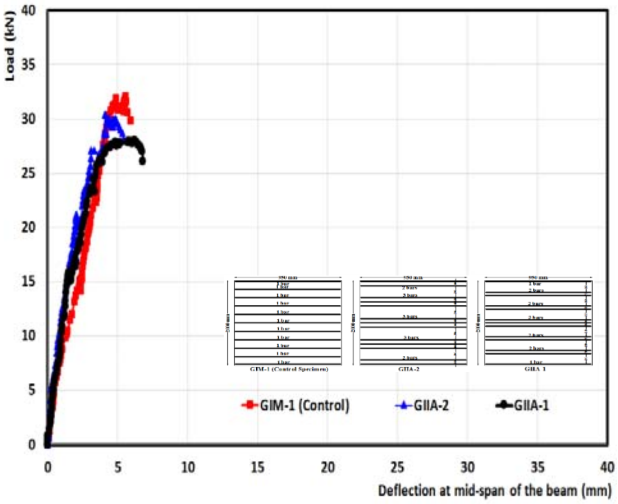

Figure (10): Load-deflection relationship at the mid-span of the beam for specimens of group II

Figure (11) shows the comparison between specimens of group III. It was found that the use of 10mm diameter in reinforcing the slab in T-section significantly improved the flexural behavior of the slab to resist the load. Thus, the behavior of the beam connected to the slab was improved to withstand loads. Also, there is no clear difference between the behaviors of specimens GIM-1 and GIIID-2 with slab reinforcement with diameters of 8mm and 10mm in load-deflection values. The maximum deflection value for the beam at failure was 5.9mm, 8.75mm and 10.25mm for specimens GIM-1, GIIID-1 and GIIID-2, respectively. Specimen GIIID-2 demonstrated higher deflection than specimens GIM-1 and GIIID-1, where this specimen reinforced the slab with a diameter of 10mm, giving the beam connected to the slab a high resistance to loads. Therefore, it is preferable to use 10mm diameter in reinforcing slabs with diameters less than 10mm.

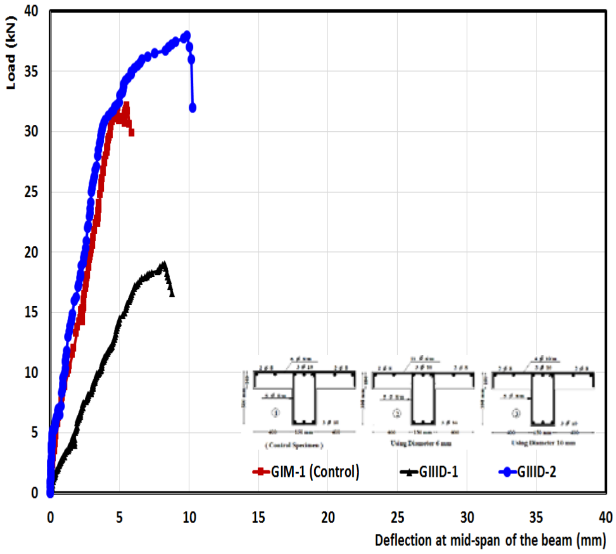

Figure (11): Load-deflection relationship at the mid-span of the beam for specimens of group III

Load-Strain Variation in Main Reinforcement of Slab for All Tested Specimens

For Group I: At strain value at the ultimate load of specimen GIM-1 (at a load of 32kN), specimen GIM-1 exhibited 5.88%, 28.43% and 43.13% higher strain than specimens GIM-2, GIM-3 and GIM-4, respectively. It can be concluded that faulty placement of slab reinforcement affected the value of strain in the steel of the slab, where the value of the steel strain decreased with the height of the slab reinforcement. Hence, the misplacement of reinforcing steel for the slab indicates that the concrete did not allow the reinforcement steel along the specimen to participate efficiently in tensile stress resistance.

For Group II: The results showed that specimen GIM-1 exhibited 11.17% and 9.80% higher strain than specimens GIIA-1 and GIIA-2, respectively. It was found that the rate of strain increase was small just after the formation of the first flexural crack and increased rapidly when specimens approached failure load. The main steel of the slab developed tensile strains, thus indicating that the main–steel slab was successful in resisting tensile stresses in the test specimens.

For Group III: Test results indicated that specimen GIM-1 exhibited 4.37% lower strain than specimen GIIID-2 and 18.95% higher strain than specimen GIIID-1. These results illustrate that reinforcement of slab using 10mm diameter was the main reason for the higher resistance to the loads.

Load-Strain Relationship of the Main Reinforcement of Beam for All Tested Specimens

For Group I: At the failure of control specimen GIM-1, the steel strain increases to 17.78%, 20.44% and 26.67% for specimens GIM-2, GIM-3 and GIM-4, respectively. In the second group, the steel strain value in the main steel of the beam increases in specimens GIIA-1 and GIIA-2 by 15.33% and 14.17%, respectively. For the last group, specimen GIIID-2 showed 5.11% higher strain than specimen GIM-1 and specimen GIIID-1 displayed 4.44% lower strain than specimen GIM-1. The steel strain of rectangular beam GIM-5 was higher than the steel strain of the T- beam GIM-1 by 11.61%.

By investigating the aforementioned comparison, it may be noted that the presence of higher reinforcement area in T-concrete beam section compared to R-concrete beam section increased the strain capacity of the beam, while the strain in the main reinforcement of the T-concrete beam reached the yielding range through testing the slab. After the slab test, the beam was tested again under the loading effect and the lower reinforcing bars in the beam reached beyond the yielding point again.

Crack Pattern and Failure Mechanism for All Tested Specimens

For Group I: Figure (12) shows the pattern of cracks for control specimen GIM-1. The first visible crack was initiated in the borderline between slab (flange) and beam (web) at a load equal to 10kN on both sides of the slab. These cracks were inclined in the direction of the slab towards the loading effect; i.e., the crack started in the region of the maximum tensile stress. These cracks extended on the boundary between the slab and the beam along the entire length of the specimen. Then, by increasing the loading value, the existing cracks grew wider and deeper until failure occurred in the slab and then cracks became inclined towards tensile stress trajectories. At later stages of loading, cracks were concentrated on the section of the maximum bending moment and failure occurred in the slab at the load of 32kN in the connected region between slab and beam.

For the remaining specimens of group I, it was observed the first cracks visible by the naked eye were at one side of the border line between slab (flange) and beam (web) spread along the length of the specimen. These cracks started at a load of 5kN, 4.5kN and 6kN for specimens GIM-2, GIM-3 and GIM-4, respectively. At failure, the width of the cracks was noticeably wider and highly propagated at the face of the intersection between slab and beam, where the height of reinforcement in slab reduced. Failure occurred at a load equal to 25kN, 20.5kN and 18.5kN for specimens GIM-2, GIM-3 and GIM-4, respectively. Based on test observations, failure of specimens GIM-2, GIM-3 and GIM-4 could be classified as pronounced sudden and flexural mode of failure in the slab, where the misplacement of slab reinforcement affected the efficiency of the slab, leading to faster failure in the slab. Figures (13), (14) and (15) show the photos of specimens GIM-2, GIM-3 and GIM-4, respectively after failure.

Figure (12): Crack pattern in the slab of specimen GIM-1

Figure (13): Crack pattern in the slab of specimen GIM-2

Figure (14): Crack pattern in the slab of specimen GIM-3

Figure (15): Crack pattern in the slab of specimen GIM-4

The appearance of the tested specimen GIM-5 after loading is shown in Figures (16) (a) and (16) (b). Specimen GIM-5 showed typical cracking behavior of under-reinforced concrete simple beam and failed in ductile flexural tension. At early loading levels, vertical cracks appeared in the region of shear towards loading points at a load equal to 8.8 kN. Upon increasing the load, the cracks started at maximum tensile stresses (region of maximum bending moment). With increasing the load, the number, width and extension towards the compression zone of the cracks increased. Cracks were concentrated at the section of the maximum bending moment and at later stages of loading, failure occurred in the middle third of the beam span. However, at a load of 45kN, the specimen failed with ductile mode failure when the load reached its peak value.

Figure (16) (a): Crack pattern in the beam of specimen GIM-5

Figure (16)(b): Cracking pattern of specimen GIM-5 (mid-span of the beam)

For Group II: Specimens GIIA-1 and GIIA-2 exhibited basically the same cracking pattern and final mode of failure in nature of loading. The failure of these specimens was flexural tensile at maximum bending moment region (the vicinity region between slab connection and the beam), where the moment is concentrated in this region. Also, the cracks started to appear in the region where there are no reinforcing bars in the slab and propagated towards the loading points. The first crack occurred at a load of 7.5kN and 12kN for specimens GIIA-1 and GIIA-2, respectively. As the load was further increased, the crack became wider and extended at both sides of the beam along the overall length of the specimen. Specimens GIIA-1 and GIIA-2 failed primarily at the ultimate conditions in a flexural mode, which occured at loads equal to 28kN and 30.5kN, respectively. Failure occurred along the entire borderline between beam (web) and slab (flange) interface. The cracking patterns of tested specimens GIIA-1 and GIIA-2 at failure are shown in Figures (17) and (18), respectively.

Figure (17): Crack pattern in the slab of specimen GIIA-1

Figure (18): Crack pattern in the slab of specimen GIIA-2

For Group III: Crack patterns for specimens GIIID-1 and GIIID-2 are depicted in Figures (19) and (20), respectively. The first cracks were horizontal flexural cracks in the vicinity of the tension zone within and near the constant moment region at the connection of the slab (web) with the beam (flange) at a load of 4.60kN and 7kN for specimens GIIID-1 and GIIID-2, respectively. These cracks continued along the overall length of the specimen (i.e., parallel to the loading effect). At higher loading stages for specimen GIIID-1, the rate of formation of new cracks significantly decreased. Moreover, the existing cracks grew wider, especially the first cracks formed. The specimen failed at a lower loading value of 19kN in the region of negative moment concentration affecting T-beam section where tension reinforcement of the slab was yielded, indicating that 6mm diameter reinforcement was weak in load resistance. For the second specimen GIIID-2, with the increase in load, cracks appeared along the borderline between the beam and the slab. The width of the cracks increased with the increase in the loading effect till specimen failure occurred at a load value of 38kN. Crushing of concrete in one corner of the specimen occurred when loading increased. This specimen exhibited high resistance to loads compared with specimens GIM-1 and GIIID-1.

Figure (19): Crack pattern in the slab of specimen GIIID-1

Figure (20): Crack pattern in the lab of specimen GIIID-2

CONCLUSIONS

The following conclusions can be drawn from the test results of the experimental investigation:

1. The phenomenon of wrong placement of reinforcing steel during the casting of the concrete slab occurs widely in the construction sector. The movement of workers during casting of the balconies affected the height of the reinforcing steel of the balconies and concrete slab. A lower position of the reinforcement can be caused by insufficient support of the reinforcement during the execution and the pouring of concrete, leading to a lower bending moment capacity of the slab and also to a brittle behavior in case of collapse.
2. The rate of increase of the ratio of slab reinforcement misplacement was less than the ultimate load value of the tested specimen, but the rate of decrease in the ultimate load was not the same as the rate of increase in the percentage of wrong placement in slab reinforcement.
3. The harmful effect of the wrong position of slab reinforcement is more defective on the behavior of the slab and the attached beam than the correct place of reinforcing steel for the slab. The movement of labors during casting of concrete slab leads to the fall of the upper reinforcement in the slab from the position where this steel is resisting the tensile stresses of the slab and the beam and the loads on the slab (flange) affected the value of strain for reinforcement of the beam (web). Therefore, when there are defects in the steel slab and beam, precautions must be taken during the treatment of these defects.
4. The specimen with a slab (flange) has a higher performance in resisting loads affecting it than the specimen which does not have a slab (rectangular beam). This is mainly attributed to the existence of the flange in the T-section that resulted in higher stiffness than in the case of R-section. T-beams are more efficient than rectangular beams where part of the slab contributes to the resistance of loads.
5. The presence of higher reinforcement area in T-concrete beam section compared to R-concrete beam section increased the strain capacity of the beam, while the strain in the main reinforcement of the T-concrete beam reached the yielding range through the testing of the slab. After the slab test, the beam was tested again under the loading effect and the lower reinforcing bars in the beam reached beyond the yielding point again.

6. The regularity of reinforcement of slab plays an important role in the resistance of slab to loads. Also, it was found that well-arranged distribution of reinforcement improves the ductile behavior of the slab and reduces the corresponding deflections.
7. The existence of large spacing between reinforcement of the slab (i.e., the irregularity of steel configuration for the slab) affects the efficiency of slab resistance to loads. Furthermore, the beam attached to the slab was not significantly affected by the irregularity of the shape of slab reinforcement.
8. The absence of regular reinforcing steel in the negative moment zones at the intersection of the slab with the beam affected the efficiency of slab in resisting loads. Consequently, reinforcement should be used according to the structural drawings prepared according to the Egyptian code and engineering specifications during the implementation of concrete structures.
9. Increasing the diameter of slab reinforcement while keeping reinforcement ratio constant enhanced the behavior of T-beam to withstand loads and increased the ductility of T-beams.
10. To improve the efficiency of T-beam section under loading effect, the minimum bar diameter for the reinforcement of slab should be 8mm, because the 6mm diameter reinforcement was found to be weak in terms of resistance to loads. The reinforcement of slab with 10mm diameter helped the slab withstand more loads and delayed the occurrence of yielding in the main steel of the slab and connected beam.

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