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STRUCTURAL RESPONSE OF REINFORCED CONCRETE WIDE BEAMS REINFORCED WITH LATTICE GIRDERS*

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Abstract– This paper summarizes the test data obtained from an experimental investigation of reinforced concrete (RC) wide beams reinforced with lattice girders, which can also be described as one-way slabs, under low-rate (static) concentrated loading applied at their mid-span. Tests were conducted on lattice girder reinforced and traditionally reinforced beam-type specimens to investigate the effect of lattice girder on load carrying capacity. Key aspects of structural response such as the load–deflection behavior, crack patterns, strength and failure modes of the tested beams were recorded and given in this paper. A total of 6 beams with two different reinforcement arrangements were tested. Tested beams were simply supported at a span of 2250 mm. All specimens were tested under static loading and midspan deflections were recorded using a displacement transducer. Similar stiffness was displayed by the lattice girder reinforced and traditionally reinforced beams, but higher resistant capacity was shown by the lattice girder reinforced beams.

Keywords– Lattice girder, load carrying capacity, reinforcement arrangement, reinforced concrete wide beam, structural response

1. INTRODUCTION

Semi-precast slabs made of precast lattice girder planks and in-situ topping are widely used in large application field (Fig. 1). In practice continuous lattice girders are mainly used to provide strength and rigidity for transient situations (such as in the case of erection) in floor plates and are incorporated generally in the longitudinal direction (i.e. parallel to the span) (Fig. 2). The bearing behavior of these semi-precast slabs with lattice girders is calculated using the similar equations of conventionally reinforced concrete slabs [1, 2]. According to the limited published data available, the slab floors from precast reinforced concrete slabs with lattice girders and a layer of concrete on top basically exhibit the same structural behavior as pure in-situ concrete slabs [3, 4].

Fig. 1. Application of semi-precast slabs made of precast lattice girder planks and in-situ topping.

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Fig. 2. Lattice girder reinforced semi-precast slab and its in-situ placement.

Current Turkish and European standards force engineers to design (the bending ultimate limit state design) the floor slabs with lattice girders by applying EN 1992-1-1:2004 and considering the strength of different materials that constitute the composite slab (i.e. use the compressive strength of the cast-in-situ concrete) [5]. Since lattice girders used in semi-precast slabs have three dimensional metallic structure comprising an upper chord, two lower chords and continuous diagonals which are welded to the chords, the author believes that they will increase the bearing capacity of the final slab. Experimental tests have shown that a structure can carry some additional load in excess to its elastic capacity after reaching its moment capacity [6]. With the aim to document the contribution of lattice girder to load carrying capacity of reinforced concrete slabs, this experimental study, which is the most reliable way for determining the moment capacity of concrete slabs reinforced with lattice girders, was organized.

2. RESEARCH HIGHLIGHTS

Two different reinforcement arrangements were analyzed to investigate the contribution of lattice girder to load carrying capacity of reinforced concrete beams. Similar stiffness was displayed by the lattice girder reinforced and traditionally reinforced beams. But, higher resistant capacity was shown by the lattice girder reinforced beams. The influence of strain distribution of the lattice girder reinforced beams and the bar slippage occurred in traditionally reinforced beams are thought to be the key factors affecting the load carrying capacity.

3. EXPERIMENTAL PROCEDURE

a) Materials

The concrete mix design used for preparation of test specimens is shown in Table 1. The average 28 day cube compressive strength of the concrete is 46,57 MPa. This strength is the upper limit to be used as normal strength concrete as stated in TS500 (Turkish Standard - Requirements for design and construction of reinforced concrete structures) [7].

Table 1. Concrete mix design for test specimens

	Amount
CEM – I 42.5 N Portland cement	410 kg/m^3
W/C	0.4
Water	165 kg/m^3
Coarse aggregate (12 – 20 mm)	377 kg/ m^3
Coarse aggregate (4 mm – 12 mm)	671 kg/ m^3
Fine aggregate (0 – 4 mm)	838 kg/ m^3
Super plasticizer – Akhidralin HP860	1 % of the binder

Two types of reinforcement are used in this study. Both reinforcements have almost the same mechanical properties but lattice girder reinforcement has higher elongation capacity as compared to the ordinary one as shown in Table 2. Lattice girder Type E, shown in Fig. 3, which has already approved by German building authorities [8] was used for preparation of Type – I beams and traditional reinforcement was used for preparation of Type – II beams.

Table 2. Mechanical properties of longitudinal reinforcement used in tests

Mechanical Properties	Ordinary Reinforcement	Lattice Girder Reinforcement
Yield Strength (MPa)	449	486
Ultimate Strength (MPa)	627	709
Ultimate Elongation (%)	17.2	39.2

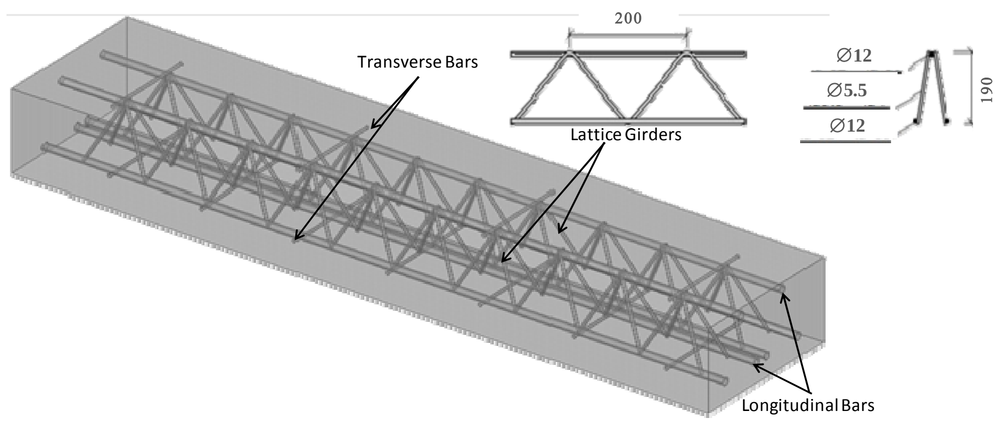

Fig. 3. Lattice girder approved by Deutsches Institut für Bautechnik [8] and used in this research

b) Properties of test specimens

The bending tests were conducted on beams with a clear span of 2250 mm. A total of 6 beams with two different reinforcement arrangements were tested. Tested beams are identified using three abbreviated terms: the first term represents the reinforcement diameter (12 for 12 mm reinforcement); the second term represents reinforcement type (KD for lattice girder and ND for traditional reinforcement) and the last term represents the number of the specimen.

Relatively small amount of reinforcement was used in order to obtain the beam failure due to the reinforcement instead of the concrete failure. Two different reinforcement arrangements that were analyzed are:

- Type – I: Beam reinforced with two 12/12/5.5 lattice girder (4ϕ12 at the bottom and 2ϕ12 at the top layer, ϕ5.5 hot rolled diagonals)
- Type – II: Beam reinforced with 4ϕ12 at the bottom and 2ϕ12 at the top layer

All main bars are of hot-rolled sections. The longitudinal section, reinforcement arrangements and reinforcement details of tested beams are shown in Fig. 4, Fig. 5 and Fig. 6 respectively.

c) Test procedure and instrumentation

Tested beams were placed on a rigid steel frame as shown in Fig. 7 and an LVDT Displacement Transducer was placed at the midspan of the beams to record deflections at different stages of loading. Tested beams were loaded by a force P at mid-span. The force was gradually increased until failure. Three beam specimens were tested for each reinforcement arrangement. During testing, the cracking patterns of the beam specimens were examined. After testing, the beam specimens were removed from the test setup and were examined to investigate the sustained damage, such as yielding/failure of reinforcement.

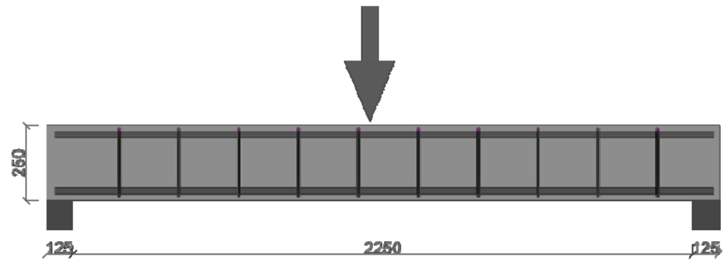

Fig. 4. Longitudinal section of tested beams (Dimensions in mm)

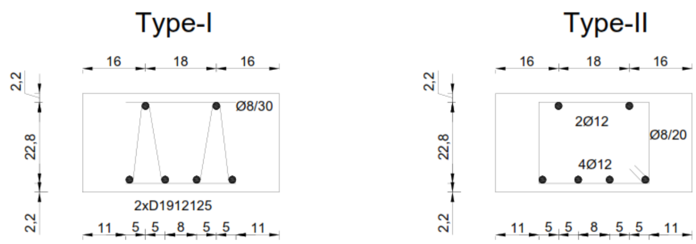

Fig. 5. Reinforcement arrangement of tested beams (Dimensions in mm)

Fig. 6. Details of tested beams

Fig. 7. Testing unit and tested beam appearance before testing

4. EXPERIMENTAL RESULTS

The experimental results of tested beams with two different reinforcement arrangements are shown in this section. Tested beams were gradually loaded by a force at mid-span until failure.

a) Cracking and deflection evolution

The cracking patterns of two different types of beams are shown in Fig. 8. The deflection capacity of traditionally reinforced beams is found to be more than lattice girder reinforced beams. The results are tabulated in Table 3. Although maximum deflections are different, cracking loads are almost the same. The reason can be attributed to the concrete behavior which is dominant in early loading levels. The system behaves almost elastically up to cracking and no contribution of reinforcement is seen. Reinforcement contributes to the load carrying capacity when the cracking develops. After that, reinforcement plays an important role on both load and deflection capacities. Traditionally reinforced beams experienced more deflection when compared to the lattice girder beams. This can be explained by their stiffness. Although the reinforcements in traditional beam behave like bending elements, it is not the case in lattice girders. They behave like truss elements and introduce additional stiffness to the system which results in less deflection.

12-KD-1 (Type – I)

12-ND-1 (Type – II)

Fig. 8. Cracking patterns of tested beams

Table 3. Results of the tests

Test group	Specimen	Cracking load, kN	Maximum load, kN	Maximum deflection, mm
TYPE I	12-KD-1	41.030	119.227	128
	12-KD-2	39.033	114.020	101
	12-KD-3	40.064	115.555	124
	AVERAGE	40.042	116.267	117
TYPE II	12-ND-1	40.128	78.196	173
	12-ND-2	37.165	81.867	157
	12-ND-3	37.552	82.061	221
	AVERAGE	38.282	80.708	184

b) Force-deflection diagrams

The force-deflection diagram for Type – I and Type – II beams is shown in Fig. 9. Beams reinforced with lattice girder and traditionally reinforced beams initially have similar stiffness because concrete is dominant up to cracking. After cracking stiffness degradation starts and reinforcement becomes active. From both figures, it is seen that post-cracking stiffness of traditionally reinforced beams and lattice girder beams are not similar. Lattice girder beams have higher stiffness and higher resistant capacity is observed for the beams reinforced with lattice girders which lead to the higher load carrying capacity. The ultimate load carrying capacity of lattice girder reinforced beam is 45.12 % larger than Type –II beams. The comparison of the experimental and analytical load carrying capacity of Type-I and Type-II beams is given in Table 4.

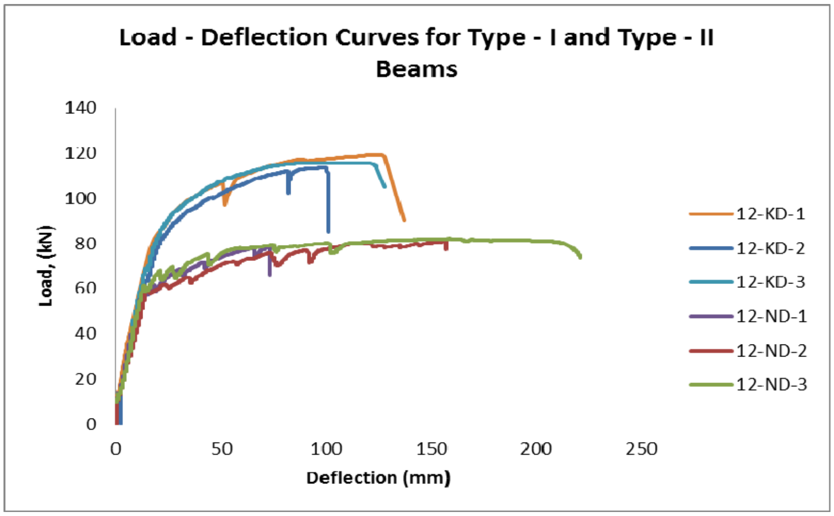

Fig. 9. Deflections at the mid-span of Type – I and Type – II beams as a function of midspan point load

Table 4. Comparison of experimental and analytical load carrying capacity

Specimen	ρ_{min}, %	ρ, %	ρ_{max}, %	$\phi_{lattice}$	β	M, kNm	$P_{experimental}$, kN	$P_{analytical}$, kN	Difference, %
Type – I (KD12)	0.30	0.36	2.00	5.5	1.43	60.2	116.27	107.0	-9.1
Type – II (ND12)	0.30	0.36	2.00	-	1	42.1	8.71	74.8	-7.3

c) Failure mode, evolution of damages and deformed shape

The observed crack pattern suggests that flexural failure occurred for all four types of beams. Cracks were concentrated around the midspan (at the plastic hinge region).

It is known that traditionally reinforced concrete beams fail due to crushing of concrete. The crushing takes place at about 0.003 to 0.004 strain. This phenomenon is valid for most of the beams. Therefore, in lattice girder beams the same collapse behavior can be expected too. Concrete crushing can be seen clearly in Fig. 8. It can be said that in lattice girder beams since steel bars will not be stressed as in the case in traditionally reinforced beams because of their higher stiffness, crushing of concrete may take place earlier without allowing the bars to be strained to their elongation capacity. This can be seen in deflection capacity of beams. Lattice girder beams experienced less deflection and fewer cracks, and narrower crack widths were seen for these beams.

One of the important tasks of the longitudinal reinforcements in beams is to prevent excessive cracking. As seen from the failure patterns given in Fig. 10, wider cracks were observed for traditionally reinforced beams (Type – II). This may be attributed to the occurrence of slippage between the longitudinal reinforcing bars and the surrounding concrete for these beams and yielding of the reinforcement. In these beams longitudinal reinforcements are connected to each other by stirrups and core concrete. No additional connection exists. Therefore, bottom reinforcements are almost the only element to resist the crack widening. However, as for lattice girder beams, since they are welded by diagonals, slippage and crack widening is resisted by both bottom and top longitudinal reinforcements, and consequently more load is carried with lower deflections. Cracks are spread along the span for the beams reinforced with lattice girder (Type – I). Since bond-slip affects the stress transference, cracks do not spread along the span for Type –II beams and significantly wider cracks are observed for these traditionally reinforced concrete beams (Fig. 10).

Fig. 10. Crack pattern of Type – I and Type – II beams after test

5. CONCLUSION

Although similar initial stiffness was displayed by the lattice girder reinforced and traditionally reinforced beams, higher resistant capacity was shown by the lattice girder reinforced beams due to the higher stiffness beyond cracking. The traditionally reinforced beams exhibited higher midspan deflection. The beams reinforced with lattice girders have three reactions against the applied load. The two reactions come from concrete and longitudinal reinforcement in bending. The third one is from the lattice girders which behave as truss elements. Truss behavior introduces higher stiffness and contributes much to the load carrying capacity.

Comparison between the two types of tested beams has helped further understanding of the effect of lattice girder reinforcement on moment capacity of RC slabs. The influence of strain distribution of the lattice girder reinforced beams and the bar slippage in traditionally reinforced beams are thought to be the key factors affecting the load carrying capacity. Therefore, the slab floors reinforced with lattice girders do not exhibit the same structural behavior as traditionally reinforced concrete slabs. For evaluation of load carrying capacity of lattice girder reinforced concrete beams and slabs, the bond-slip mechanism and the strain transfer cannot be disregarded. The results obtained in this study will help to understand the effect of lattice girder reinforcement on moment capacity of RC beams and slabs. Further parallel studies will allow civil engineering researchers to upgrade and calibrate numerical models for the accurate calculation of the load carrying capacity of the lattice girder reinforced beams and slabs.

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