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THE STRUCTURAL BEHAVIOR OF COMPOSITE BEAMS WITH PREFABRICATED REINFORCED CONCRETE PLATE IN NEGATIVE MOMENT ZONE

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ABSTRACT

In this study, composite beams were fabricated from reinforced concrete plates and steel profiles where bolts were used as shear connections. For each experiment, metal sheets with different dimensions were placed under the composite beams. Within the scope of the study, composite behavior of beams, comparison of the experimental results with calculations and pulling away of the plates were investigated. It was also examined in which extend the placement of bolts as well as dimensions and positions of metal sheets affected the ultimate load values of beams and crack formation.

Results were discussed through Load - Deformation, Load - Elongation and Moment - Bending graphs. It was concluded that plastic calculation was appropriate for beams. Meanwhile, it was identified that the use of sheets decreased the displacement and increased the ultimate load. Additionally, the results demonstrated that pulling away of the plate was also effective on ultimate load value.

Keywords. Composite Beams Reinforced Concrete Plate, Steel Profile, Bolt, Negative Moment and Structural Behavior.

INTRODUCTION

Most of the settled population and industrial regions of Turkey reside in the first- and second-degree seismic zones. Globally, concrete is the most widely used building component for the earthquake-resistant structures. When the development for the concrete industry and reinforced concrete based load bearing systems are analyzed, Germany, which is not an earthquake-prone country, comes to the forefront. Introduction of ready mixed concrete industry and use of blast furnace slag and Portland cement in the preparation of reinforced concrete can be considered as examples of such progress. However, it is not appropriate to apply the concrete based load bearing systems used in Germany to the earthquake - prone countries. For those countries, steel constructions, which are more resistant to seismic waves than concrete, have been developed.

Although steel constructions have advantages, they are not used widely. This can be due to the fact that the cost of steel constructions is higher than that of concrete ones. However, steel constructions offer convenient conditions in dimensions of the load bearing systems and foundations of structures for multistory buildings (more than 15 - 20 floors). Accordingly, the overall load and construction cost decreases. The main reasons for the underutilization of steel constructions are the lack of knowledge and experience on project design, calculation, fabrication, assembly and inspection.

As already used as building materials, concrete and steel have some disadvantages from engineering point of view. Concrete has low tensile strength and ductility and it is prone to contraction. Although, steel has high tensile strength, it is weaker than concrete when external effects like corrosion and fire are concerned. Composite load bearing systems are designed and fabricated to benefit from the favorable features of concrete and steel simultaneously.

In the use of composite load bearing system, the highest degree of economic advantage is achieved when they are used in beams. For positive moment systems, the reduction in cost approaches to 50 %. It should be noted that the use of concrete is required in steel framed multistory buildings to increase the fire strength of the system or to decrease the effects like corrosion caused by environmental conditions and harmful to load bearing systems. Thus, the idea of composite systems utilization has both economic and structural advantages.

Continuous use of composite beams in steel structures brings about negative moments at supports and accordingly tensile stresses at reinforced concrete plate. It is known that concrete fractures easily under tensile stress and this leads to an undesirable situation in terms of boundary condition. The aim of this study is to investigate the mechanical behavior of the composite beam made out of reinforced concrete-steel plate in negative moment conditions.

LITERATURE

Structural behaviour of composite beams reinforced with steel fibers in their negative moment zone (Yelgin, A.N., Yalman, H.Y.)(Yelgin, 1998): In the study, totally 9 samples were prepared. For each samples, a reinforced concrete plate (300 cm in length, 80 cm in width and 10 cm in thickness), an INP 120 profile (with a length of 300 cm), U 80 profiles (8 pieces), plain reinforcements (Ø 12, 6 pieces) and stirrup (Ø 8/15) were used. The samples were divided into three groups: without steel fiber and with short and long steel fibers. A force of 20 tons was applied to each sample and then displacement values and at which conditions a material could not carry a load were followed.

The increase in steel fibers caused an increase in load bearing capacity, but not in tremendous amounts. The most striking increase occurred at the loading value of first crack formation. Composite beam started to fracture at 55 % of the ultimate load value for the group without steel fiber. Ultimate load values increased 68 % with short steel fibers of 3 cm and 70 % with long steel fibers of 6 cm. Additionally, different displacement values were attained for the beams. Vertical displacement values decreased with the increase in length of the steel fibers. However, the presence of steel fibers in the reinforced concrete plate was not enough to increase the ultimate load value of the composite beams in negative moment zones. It was observed that the fibers were effective in preventing the formation and spread of fractures in the concrete plate.

Structural behaviour of composite beams with reinforced concrete and steel plates in their negative moment zone (Yelgin, A.N., Cetin O.)(Yelgin, 2004) : In this study, 5 reinforced concrete plates (300x80x10 cm), INP 120 profile (300 cm in length) and six UNP 80 profiles were bonded to each other via epoxy resin. The effects of the change in dimensions of the steel sheets as well as relative positions of sheets on ultimate load values were examined. Meanwhile, it was investigated if the deformation of the composite beam prevented the removal of the reinforced plate from steel profile. In the preparation of the composite beam, arc welding was used to join concrete plate and steel profile. In this study, the theoretical and experimental ultimate load values were compared with each other for negative moment zones of the composite beams supported by steel sheets and joined by epoxy resin.

As a result, calculations demonstrated that the steel sheets used in the tensile region increased the ultimate load nearly 250 %.

Modeling of steel-concrete composite beams under negative bending (Gaetano M., Giovanni F., Edoardo C.)(Gaetano,1999): The study was presented as a model to explain composite beams loaded under negative bending conditions. By experimental work and collected data, shears between beam and plate as well as steel and reinforcing concrete interfaces were explained in detail. Some numerical results were also obtained to demonstrate the applicability and validity of the model.

Numerical results predicts a model predicting both local (shears, bending and forces) and global (plastic rotation, directional changes) quantities. The generalized moment-bending relation does not only define a numerical problem but also controls the behavior of the beam at all cross sections. The proposed model is known to a suitable method to evaluate the effect of each component of the composite beam present in the negative bending zone and to evaluate the effect of the softening of the steel.

LOADING CAPACITY IN THE NEGATIVE MOMENT ZONE

When composite beams are used as a continuous layout, negative moment zone forms near to the inner supports. In this zone, supporting reinforcements are used in the reinforcing concrete plate along the length of the beam and it is assumed that the plate carries the load only by means of these reinforcements. In such a case, joints against shearing should also be used. In these conditions, stress diagram of a beam (Figure 1-a) can be considered as the combination of three distinct stress diagrams: the diagram in which the stresses related to the plasticity moment change its sign as given in (Figure 1-b); the contribution of the support reinforcement as given in (Figure 1-c); and axial difference balancing moment, ΔM_2, as given in (Figure 1-c). For such a member, negative moment bearing capacity (W_{pa}) is equal to the plastic moment defined by the axis dividing the steel beam into two equivalent parts.

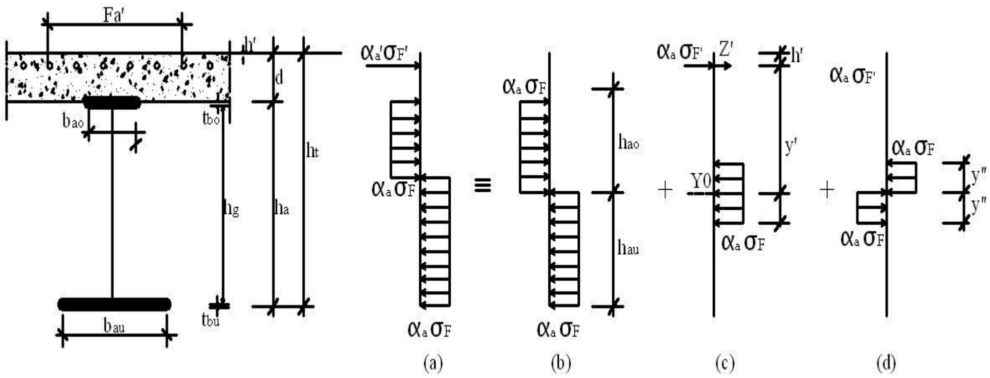

Figure 1. Stress distributions and internal forces in the negative moment zones of the composite beams

$$W_{pa} = \int |y| . dF_a = S_{x,o} + S_{x,u} \quad (1)$$

$$M_{pa} = \alpha_a \, \sigma_F \, W_{pa} \quad (2)$$

$$Z' = \alpha_a' \, \sigma_F' \, F_a' \quad (3)$$

$$y' = h_t - (h_{au} - h') \quad (4)$$

$$\Delta M_1 = Z' . \, y' \quad (5)$$

$$y'' = Z' / 2(t_g . \alpha_a . \sigma_F) \quad (6)$$

$$\Delta M_2 = \alpha_a \, \sigma_F \, t_g \, y'' |y''| \quad (7)$$

$$|-Mu| = M_{pa} + \Delta M_1 - \Delta M_2 \quad (8)$$

The amount of F_a' reinforcement should not be increased extensively so that calculations based on the plasticity could be applied to the supports [2].

MATERIALS USED IN THE COMPOSITE BEAMS

The properties of the concrete, steel bar and steel profile comprising the composite beams examined in this study are given in Table 1. The reinforcing concrete plate used in the composite beam was 300 cm in length, 80 cm in width and 12 cm in thickness.

Table 1. The properties of the concrete, steel bar and steel profile comprising the composite beams examined in this study.

Concrete	Steel Bar	Steel Profile
Class = C 30	BÇ III a	St 37 HEB120
σ_{br} = 380.8 kg/cm^2	σ_F' = 4.610 t/cm^2	σ_F = 2.4 t/cm^2
α_b = 0.74	α_a' = 0.95	α_a = 0.95
γ_{bet} = 2.39 t/m^3	f_a' = 6.79 cm^2 (6Ø12)	f_a = 34.0 cm^2
E_b = 321350 kg/cm^2	E_a = 2119540 kg/cm^2	H= 12 cm
h' = 1.5 cm		H_i = 9.8 cm

EXPERIMENTAL PROCEDURE

Preparation of the Composite Beams

Reinforcing plate (3000 x 800 x 120 mm) was bonded to HEB 120 profile (3000 mm in length) by means of bolts and sheets and the final composite samples were tested. 6 samples were prepared in 3 different sets: 40 bolts and 10 sheets in the first set; 40 bolts and 20 sheets in the second set; and 40 bolts without sheet in the third set.

The first step of sample preparation was the preparation of the reinforced concrete plate. In each reinforced concrete plate, stirrups were used as span reinforcement (6Φ12) and as transverse reinforcement (Φ8/15). For this purpose, first, the mold of the reinforced concrete plate was prepared. As bolts were used for joining, tubes suitable to the dimensions of the bolts were put into the mold. For each specimen, these bolts were positioned at different distances from each other. Plain reinforcements and stirrups made out of S420 steel were used as reinforcements in the mold. Then, the mold was lubricated to eliminate adherence of the concrete. C30 type concrete was used in the study. A shaker was used during casting of the concrete after which curing was applied.

After complete solidification of the reinforced concrete plate, its surface facing the steel profile was cleaned by means of a spiral grinder. In parallel to this, bolts and spaces for sheets were prepared. As a final preparation step of the composite beam, the plate was joined to the HEB 120 profile through these bolts and sheets.

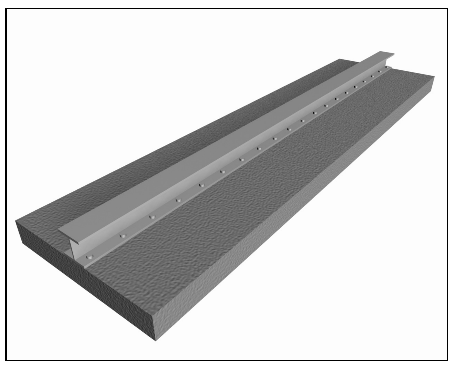

Figure 2. The overall view of the composite beam.

Experimental Set-up

Experiments were performed at the Construction Laboratory of Sakarya University, Faculty of Engineering. In the experiments, a hydraulic press of 200kN capacity (ENERPAC) was used to apply loads. A HI – TECH MAGNUS type frame was used in the set-up.

During experiments, the data were collected from 5 different sources.

1. Load cell was defined as P which was applied at the midspan.
2. A linear variable differential transformer (lvdt), i.e., displacement transducer, was mounted at the midspan to measure the maximum displacement. The lvdt was capable to measure the displacements up to 150 mm. However, this value reduced to 130 mm due to the apertures of the lvdt.

3. and 4. Electronic differential transformers were mounted laterally to the top and bottom of the head of the steel beam so as to measure the lateral displacement and to obtain moment-bending diagram. The electronic displacement transducer was capable to measure the displacements up to 50 mm.
5. In order to measure the elongation of the beam, strain gauge was mounted to the mid span of the beam.

Additional crosses were included on to the frame. Apart from this, different steel apertures were placed below the load cell to transfer the load. A supporting aperture was placed between load cell and steel apertures to prevent the damage of the load cell.

RESULTS AND DISCUSSION

It was observed that, by means of production technique mentioned above, a full composite behavior between profile and reinforced concrete plate steel was attained Neither fracture nor pull away was observed in the shear members. It was detected that bolts were good joining members. In almost all samples, cracks were formed symmetrically around the point at which the load was applied.

Figure 3. A view of the symmetrical cracks on the beams.

The examination of the concrete cracks demonstrated that they formed around the bolts. Similar to steel members, cracks formed around the holes of the bolts where the cross-sectional area was minimum.

Figure 4. Concrete cracks formed around the bolts.

Table 2. General information, fracture loads, experimental and theoretical ultimate load values of the samples

Sample No	Cracking Load (kN)	Experimental Load (kN) P_{ud}	Theoretical Load (kN) P_{ut}	Average Experimental Loads (kN) P_{ud}
DN1	52	118.31	95.8	DN1 and DN2 112.15
DN2	46	105.99	95.8	
DN3	47	107.85	95.8	DN3 and DN4 103.72
DN4	44	99.6	95.8	
DN5	46	100.13	95.8	DN5 and DN6 98.33
DN6	43	96.53	95.8	

General information, fracture loads, experimental and theoretical ultimate load values of the samples are given in Table 5.1. As seen from the table, the difference between experimental and theoretical ultimate load values was between 0.73 kN and 22.51 kN. In other words, theoretical ultimate load value was 0.7 - 23.5 % higher than the experimental value. The average ultimate load of the first set (DN1 and DN2) was 8.13 % higher than the average value of the second set (DN3 and DN4). Similarly, the average ultimate load of the second set (DN3 and DN4) was 5.48 % higher than the average value of the third set (DN5 and DN6). The average ultimate load of the first set (DN1 and DN2) was 14.05 % higher than the average value of the third set (DN5 and DN6).

As given in Arda and Yardimci, the main function of the shear joints in a composite beam is to attach reinforced concrete plate and steel cross section to each other in a way that they could work together. It is known that for such a system, under the loading conditions, it is possible to prevent removal of the concrete from steel parts and by this way, complete transfer of the shear forces could be achieved. Meanwhile, it is also possible to calculate the number and dimensions of the shear connections to prevent removal of the concrete plate from steel piece. However, there is no a specific calculation method for plate removal, while precautions for this bases on the experiences. For this reason, the main purpose of this study was to investigate the condition at which the plate pull away from the steel beam. It was observed that samples with sheets had higher ultimate load values than those without sheets. This was attributed to the high rigidity of samples having sheets.

Table 3. Fracture loads, experimental and theoretical ultimate load values of the samples

Sample No	Dimensions of Concrete (cm)	Steel Profile	Steel Sheet
DN1	300.80.12	HEB 120	20 pieces (150.120.2)
DN2	300.80.12	HEB 120	20 pieces (150.120.2)
DN3	300.80.12	HEB 120	40 pieces (120.70.2)
DN4	300.80.12	HEB 120	40 pieces (120.70.2)
DN5	300.80.12	HEB 120	without sheet
DN6	300.80.12	HEB 120	without sheet

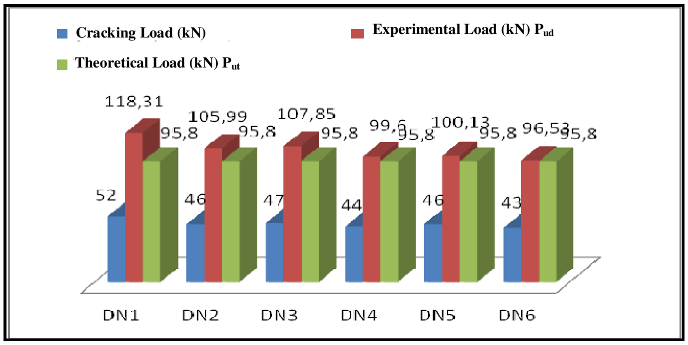

Figure 5. Cranking loads, experimental and theoretical ultimate load values of samples used in the study.

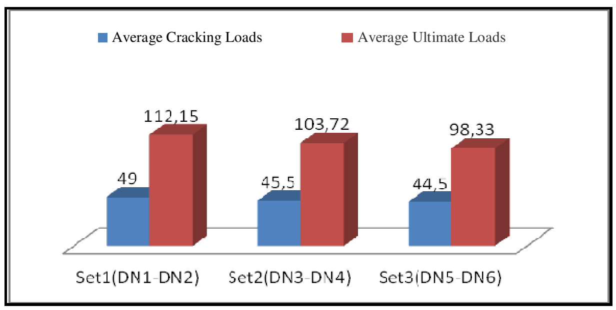

Figure 6. Average cracking loads and ultimate loads of each set of samples.

By means of lvdt, deflection values were collected and load-deflection graphs were drawn. Experimental deflection values, deflection values based on the initial cross section, deflection values based on the fractured cross section, and average of them are given in Table 4.

Table 4. Experimental and calculated deflection values of samples.

Sample No	Experimental Deflection Value (mm) f_d (60 kN)	The Average Experimental Deflection Value (mm)	Deflection Based on Initial Cross Section Elastic Calculation (mm) f_d (60 kN)	Deflection Based on Fractured Cross Section Elastic Calculation (mm) f_d(60 kN)	Average Deflection values of f_1 and f_2 Elastic Calculation) (mm) $f_{average}$ f_d (60 kN)
DN1	13.34	13.97	3.25 mm	6.85 mm	4.35 mm
DN2	14.60				
DN3	15.92	18.86			
DN4	21.87				
DN5	20.08	20.51			
DN6	20.95				

In the first set (DN1 and DN2), the amount of experimental deflection was 3.21 times of the theoretical value. In the second set (DN3 and DN4), the amount of experimental deflection was 4.33 times of the theoretical value. In the third set (DN3 and DN4), the amount of experimental deflection was 4.71 times of the theoretical value. In these calculations, it was found that the deflection value based on the fractured cross section was the closest to the experimentally found one.

It was detected that the deflection value in the first set was 35 % and 46.81 % less than the values found in the second and third sets, respectively. Similarly, the deflection value in the second set is 8.74 % less than the deflection value of the third set. This concludes that the use of sheet reduces the amount of deflection.

Ductility can be defined as the ability of a material to change its shape against any kind of external loading. For all samples, load-deformation graphs, similar to those used to define the ductility, were drawn. When the energy absorbing capability of the composite beams reached to their limit values, the load - deformation graphs got close to the horizontal axis, i.e. while the material could not absorb energy, deformation carried on.

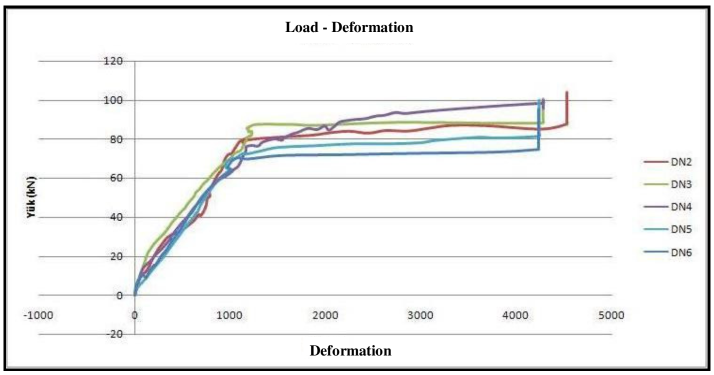

Figure 7. Load - Deformation graphs of all samples.

The elastic modulus and initial moment of the cross section determine bending rigidity of that cross section, EI = M/ø. In all samples, Moment - Bending diagram became horizontal as the load increased. This can be concluded that bending rigidity decreases. This behavior is a plastic type which is defined as a more realistic approach than elastic one.

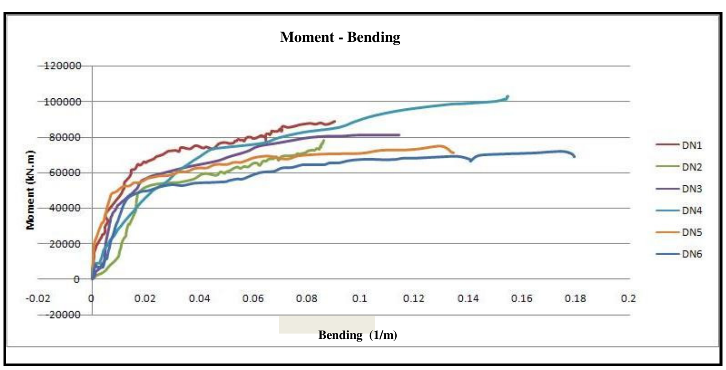

Figure 8. Moment - Bending graphs of all samples.

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