Shear Strength of Composite Plate Girder

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ABSTRACT: The composite action of steel-concrete composite plate girder increases the flexural capacity and shear strength of girders. AISC calculated Shear strength of composite steel-concrete composite girders based on the capacity of steel plate girder neglecting the composite action between steel and concrete in addition to the increase of capacity due to concrete slab. This paper presents numerical evaluation of the shear strength of composite steel-concrete plate girder. Finite element modelling is used to evaluate the ultimate strength of composite steel-concrete simple span girder. The ultimate shear strength of the girder is evaluated analytically using AISC requirements and compared to the FE results. FE results verified using experimental results and showed good agreement. Results showed that the composite action improves capacity of steel plate girder to resist higher shear load as well as bending capacity. The composite action had more effect to increase shear capacity of composite steel-concrete girder with larger d/t_{web} ratio. Web aspect ratio of composite steel-concrete plate girder affects the benefit of composite action of girders.

1 INTRODUCTION

The composite steel-concrete girders composed of cast in place concrete slab and steel girders are commonly used in bridges and buildings. The use of composite steel-concrete structures reduces the construction cost in addition to the better use of materials advantages. Composite steel-concrete plate girders have some advantages such as reducing the weight and depth of the steel beams, in addition to the increasing of the floor stiffness which give opportunity to increase the span length of the member. Finite element modeling of simple span composite plate girder carried out by Baskar et al. (2003). Numerical results showed that the composite action of the plate girder increases the load carrying capacity of the girder, and the composite action is more effective for girders subject to combined shear and positive bending compared to those composite girders subject to combined shear and negative bending or composite plate girders under pure shear loading. Experimental investigation on simply supported steel–concrete composite plate girders subject to shear loading carried out by Shanmugam and Baskar (2002). Four composite and two bare steel plate girders were tested up to failure to study the ultimate strength behavior of those girders . Tahmasebinia and Ranzi (2011) did a three-dimensional finite element analysis using commercial software ABAQUS to predict the response of composite steel-concrete beams under different type of loading up to failure load. Numerical results showed agreement with experimental data.

This paper numerically evaluates the effect of composite action of steel-concrete composite plate girder on shear and bending behavior of the composite plate girder up to failure load. Shear is the effective concern in this study as all design approaches neglect the composite action in calculating shear capacity of composite steel-concrete plate girders. Finite element modeling of a simple span composite steel-concrete plate girder carried out using the commercial software ANSYS to investigate the behavior of girders. Then numerical results of composite plate girders and steel girder verified with existing experimental results carried out by Shanmugam and Baskar (2003). Web slenderness ratio $(d/t)_{web}$ and web aspect ratio (a/d) are the main parameters investigated in this study.

2 MODELED GIRDER

Simple span steel and composite concrete-steel plate girders tested by Shanmugam and Baskar (2003)are used for modeling. The dimensions of steel and composite plate girder are shown in Fig. 1 and Fig. 2 respectively. All girders modeled under the effect of one point load at the mid of the span. The stress-strain diagrams of steel and concrete are shown in Fig. 3 and Fig. 4 respectively which obtained from Shanmugam and Baskar (2003) experiment. Different steel and composite plate girder models with different web depth/thickness ratio $(d/t)_{web}$ and web aspect ratio (a/d) were modeled as shown in table 1. Depth/thickness ratio of 150, 200 and 250, and web aspect ratio of 1.5 and 0.75 were used in this study to see the effect of $(d/t)_{web}$ and (a/d) ratios on the composite action of composite plate girder.

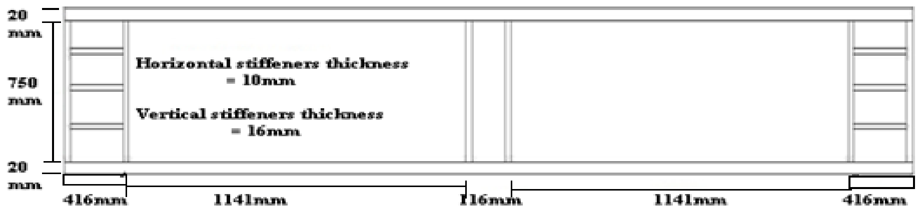

Fig. 1 Geometry of steel plate girder

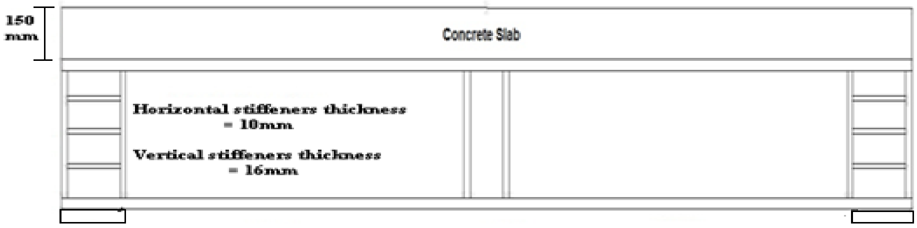

Fig. 2 Geometry of composite plate girder

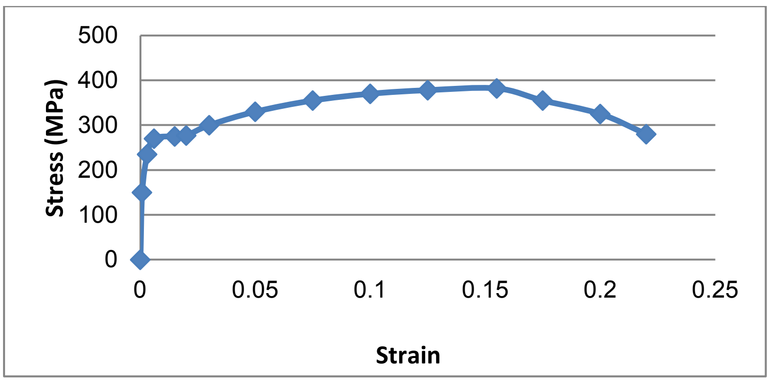

Fig. 3 Stress-strain diagram of steel

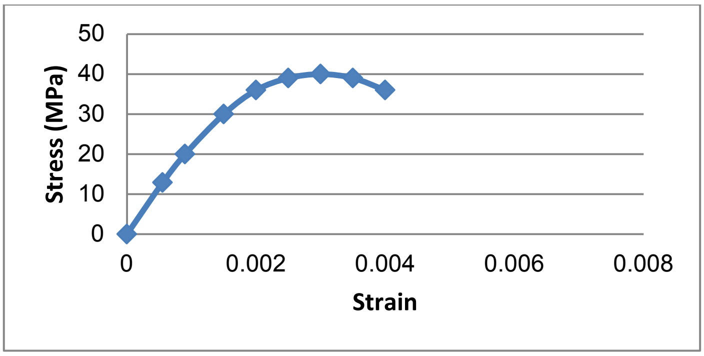

Fig. 4 Stress-strain diagram of concrete

Table 1 Details of girder specimens (dimensions in mm)

Specimen	Panel aspect ratio (a/d)	Flanges Top B_f	Flanges Top T_f	Flanges Bottom B_f	Flanges Bottom T_f	$(d/t)_{web}$	t_{web}
SPG1	1.5	260	20	260	20	150	5
CPG1	1.5	260	20	260	20	150	5
SPG2	1.5	200	20	200	20	250	3
CPG2	1.5	200	20	200	20	250	3
SPG3	1.5	220	20	220	20	200	4
CPG3	1.5	220	20	220	20	200	4
SPG5	0.75	260	20	260	20	150	5
CPG4	0.75	260	20	260	20	150	5

3 FINITE ELEMENT MODELING

A three-dimensional non-linear finite element model is developed using ANSYS 12.1 to analyze steel and composite plate girders. The concrete slab is considered fully composite with steel girder. A typical finite element model of a simple span composite plate girder and model meshing is shown in Fig. 5.

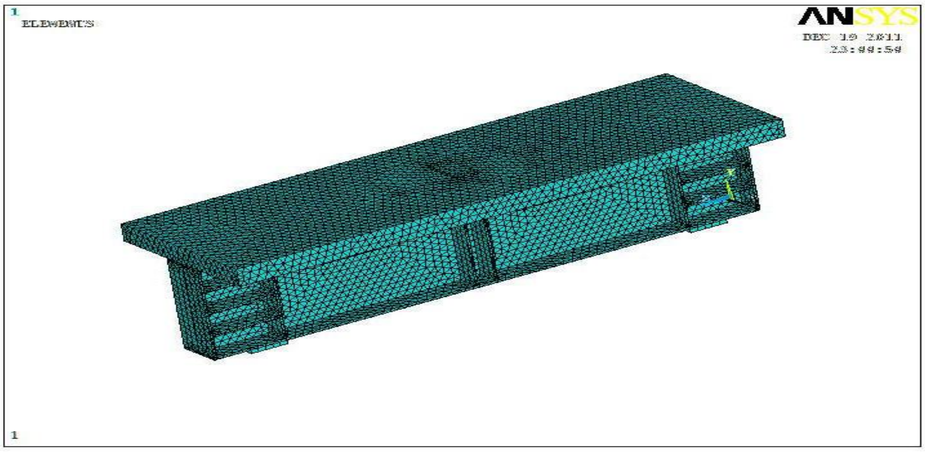

Fig. 5 Typical Finite element model

The flanges, web, and stiffener plates of the steel girder modeled using a 3-D eight nodes element SOLID45 that has a plasticity, creep, stress stiffening, and large strain capability. The concrete slab modeled using 3-D element SOLID65. This element is capable of cracking in tension and crushing in compression as concrete.

The steel modeled as a multilinear isotropic material whereas concrete modeled with initial linear-elastic material up to 30% of its compressive strength, then it described as multilinear isotropic material. All girders modeled under single point load at the mid-span and the load increased incrementally up to failure load.

4 RESULTS AND DISCUSSION

4.1 Verification of the model

The finite element results of CPG1 and SPG1 validated with experimental results of steel and composite plate girders carried out experimentally by Shanmugam and Baskar (2003). The FE results showed good agreement with experimental results in the elastic and plastic ranges. Fig. 6 and Fig. 7 showed comparison between the experimental and numerical load-deflection curves of CPG1 and SPG1 respectively.

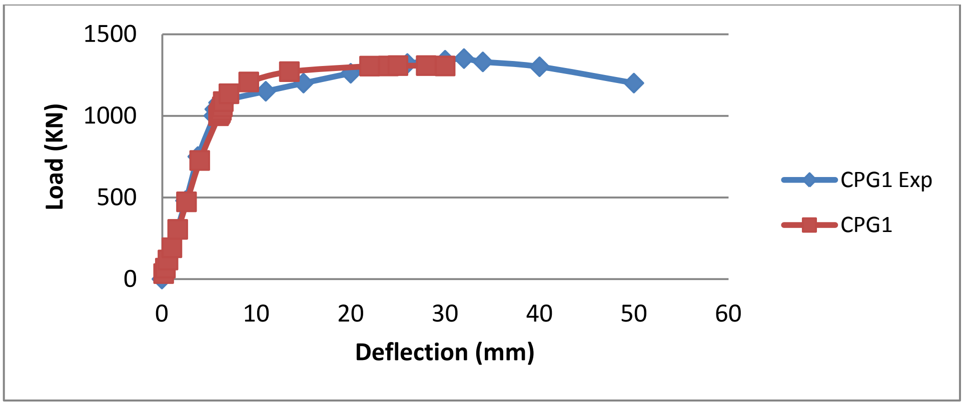

Fig. 6 Load- deflection curve of CPG1

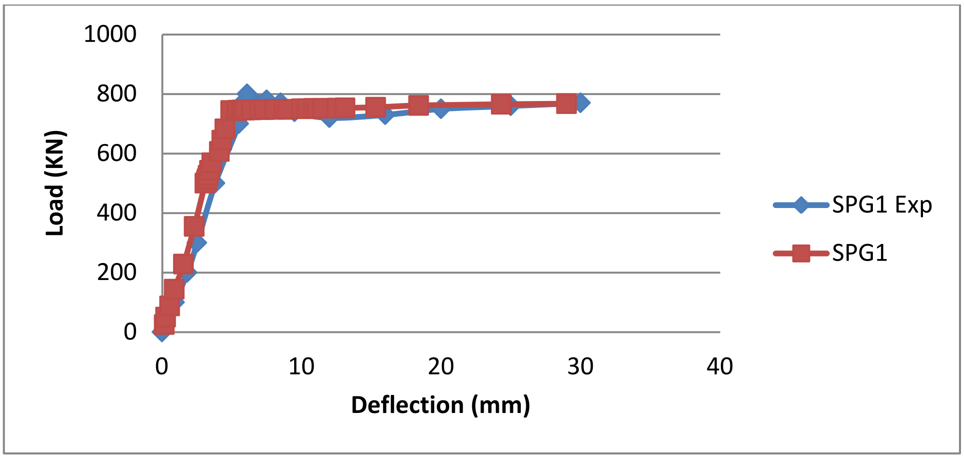

Fig. 7 Load-Deflection curve of SPG1

Depth/ thickness $(d/t)_{web}$ ratio and web aspect ratio (a/d) of the steel section are the main parameters were investigated in this study. These parameters studied to see their effect on the composite action of steel-concrete, flexural and shear capacities, in addition to failure mode.

4.2 Effect of composite act

All girders were investigated in the study failed in shear (they designed as short span to fail in shear), so that, the load carrying capacity of the girders represent the ultimate shear strength of the girders.

It's noted that the ultimate load carrying capacity of the composite girders is much more than plate girders. Clearly, the stiffness of the composite plate girder is also improved. The load-deflection curve used to compare the ultimate capacity of plate girders in addition to the stiffness of theses girders. Fig. 8 shows the load deflection curve of CPG1 and SPG1. The ultimate load carrying capacity of SPG1 is 767 KN whereas the ultimate load carrying capacity of CPG1 is 1305 KN as shown in the figure.

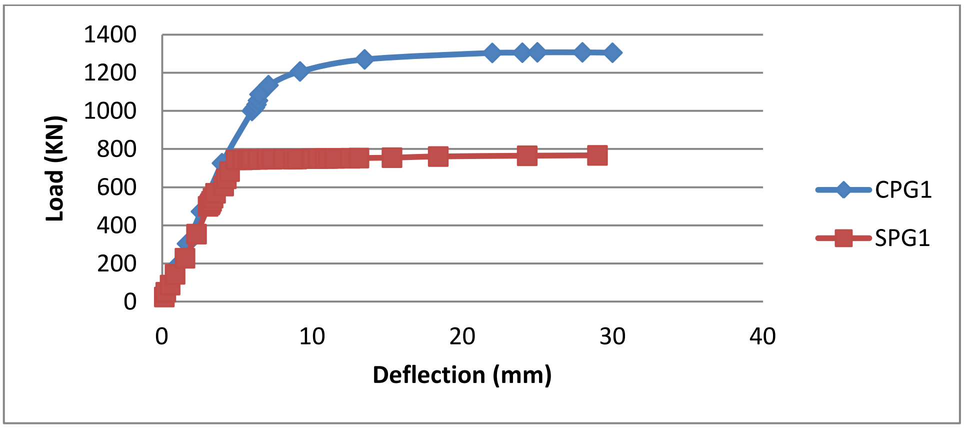

Fig. 8 Load-Deflection curve for composite and plate girders

4.3 Effect of depth/thickness ratio $(d/t)_{web}$

Fig. 9 shows the load deflection curve of CPG1, CPG2,CPG3, SPG1, SPG2, and SPG3. It's obvious that the load carrying capacity of the composite plate girders is more than steel plate girders. The results showed that as the $(d/t)_{web}$ ratio increases i.e. slender web, the capacity increase of composite plate girder over plate girder is higher. For $(d/t)_{web}$ ratio of 150, 200 and 250, the increase in capacity is 71% and 87% , and more than 110% respectively.

Composite steel-concrete girders have linear deflected shape up to 75-85% of the load-deflection curve as shown in Fig. 9. Composite action increases the stiffness of the girder as well as increases the linear segment of load-deflection curves of the composite plate girders.

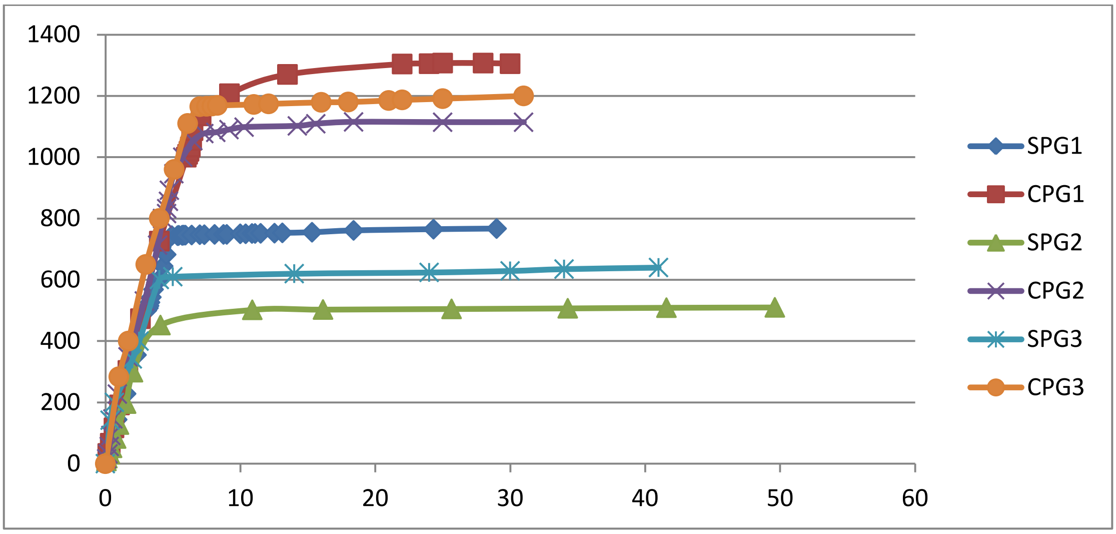

Fig. 9 Effect of $(d/t)_{web}$ on the ultimate capacity

4.4 Effect of web aspect ratio (a/d)

The web aspect ratio of CPG4 is half that of CPG1. Fig. 10 shows the increase of ultimate capacity of the composite girder CPG4 compared to CPG1. The ultimate load capacity of CPG4 is much more than that of CPG1 as well as SPG1 and SPG4 as expected. It's also clear the increase in the stiffness of CPG4 compared to CPG1. However, CPG4 behaves linearly more than CPG1 because of the stiffness that added by additional stiffeners.

The increasing in the ultimate load capacity of compoiste girder with larger (a/d) ratio is less than that of smaller (a/d) compared to the steel plate girder. For example, the increase of ultimate capacity of CPG1, CPG4 with respect to SPG1 and SPG4 is 70% and 62% respectively. In other words, the composite action becomes more effective in case of larger (a/d) ratio.

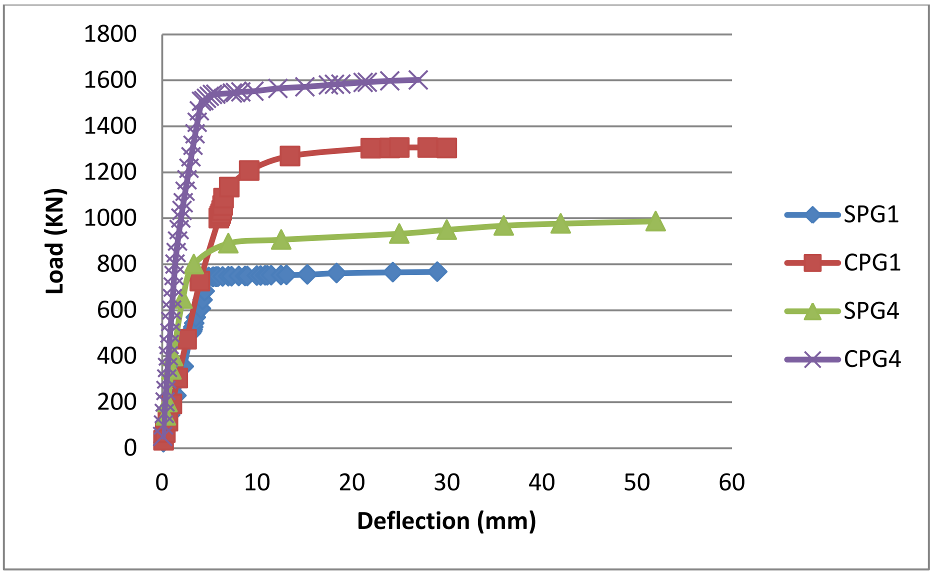

Fig. 10 Effect of web aspect ratio

4.5 Shear stress

Shear stress distribution along the girders span is important because it will control the failure mode and the location of failure. For the steel plate girders, the spreading of maximum shear stress at any loading covers most of the web . Whereas for the composite sections the maximum shear stress at yielding covers part of the web and progress to cover the whole web at ultimate load. The maximum shear of composite steel-concrete girders spreaded diagonally and progress to cover the whole steel web at the ultimate load.

The shear stress in CPG1 calculated based on AISC manual. AISC neglect the slab in calculating the shear capacity. Based on the manual, the value of the shear stress equal to 116 MPa, and using ANSYS, the value is 133MPa.

5 CONCLUSION

- FE Analysis was able to predict the behavior of composite plate girder. FE results compared with experimental results and showed good agreement.

- It is concluded from this research that the composite action improves the effectiveness of plate steel girder to resist more shear load as well as bending stress, and increase the ultimate load capacity of the girder.

- The composite action is more significant in the case of plate girders with a larger $(d/t)_{web}$ ratio; significant enhancement was also observed in the load carrying capacity of composite plate girders with a smaller $(d/t)_{web}$ ratio.

- Small spacing between stiffeners improved the capacity of the girders. The composite action becomes more effective to increase the capacity of plate girder in case of higher (a/d) ratio.

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