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Strength of Non-Prismatic Composite Self-Compacting Concrete Steel Girders

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ABSTRACT

A study on influence of degree of web tapering ratio in flexural strength of composite non-prismatic steel beams is the scope of this study. The aim of study is to investigate an ability of non-prismatic beam procedure to increase the flexural stiffness and reduce cost. For this purpose, experimental, numerical, and theoretical parts will carried out.

The experimental work consisted of fabrication and testing number of beams arranged in five groups according to variable parameters (span length and shape of tapering). The steel profile use in this study was IPE140 and the concrete slab made from self-compacting concrete with target strength 55MPa and had width 300 mm and thickness 70 mm. The steel beam was connected to the concrete slab by reinforce bar with diameter 10 mm looks like (z-shape) which were welded on the top flange of steel beam.

The experimental results included measuring ultimate load capacities, normal, shear and shear lag strains, load-deflection curves, load-slip curves and crack patterns.

The objective of the present research work is to study, experimentally and analytically the overall behavior for limited failure modes and load carrying capacity of simply supported composite non-prismatic steel beams with different span length, shape of slopping and different angle of slope.

1. INTRODUCTION

Steel-concrete composite beam has been in use as a structural member in buildings and bridges. Mechanical properties of the traditional bridge materials, such as steel sections and concrete deck, are readily available, in highly accurate and large volume of statistical data, reducing the uncertainty in the evaluation of its performance.

Structures with large spans need sections with large section moduli. Instead of introducing large sections with heavy weights, some mechanical processes of cutting and welding will produces non prismatic members with tapered webs (see Figure 1).

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Regarding the researches in Self-Compacting Concrete SCC, use in casting the deck slab, which was beginning since 1983, the durability problem of the concrete structures was the main subject of interest in many countries. The SCC was employed to make durable concrete structures, which can be purely compacted by its own weight and without any vibrations. This type of concrete was proposed by (Okamura in 1986). Many studies were investigated by Ozawa and Maekawa at Tokyo University to improve workability of SCC (Ouchi, M., 1988).

In 1988, the prototype of SCC was achieved. First, this concrete was named “High Performance Concrete”, but almost at the same time, “High Performance Concrete” was defined as a concrete with high durability caused by the low water-cement ratio by Professor Aitcin. Hence, its name has been changed by Okamura to “Self-Compacting High Performance Concrete” this was mentioned by (Ouchi, M., 1988).

At the same times the researches related to steel structures as a thin-wall structures focus of the stability and strength of those elements. A new theory presented for the lateral buckling of web-tapered I-beams by (Zhang, Lei, and Geng Shu Tong 2008). Linear analysis was first conducted by taking account into the tapering effects of web-tapered I-beams, where the deformation compatibilities of the two flanges and web are considered in terms of the basic assumptions of thin-walled members. Subsequently, the total potential for the lateral buckling analysis of web-tapered I-beams is developed, based on the classical variational principle for buckling analysis.

The lateral buckling loads of web-tapered cantilevers and simply supported beams of I-sections from the proposed theory are compared with those from the finite element (FE) analyses using two shell element models and two widely used beam element models. The two beam element models respectively represent the equivalent method using prismatic beam elements and the typical tapered beam theory in existing literature. These comparisons show that the results based on the total potential proposed in this paper are more accurate in predicting the lateral buckling loads of web-tapered I-beams than those in existing theories, indicating that the theory proposed in this this study is superior to existing theories. It is also found that the equivalent method using prismatic beam elements may yield unreliable buckling loads of tapered beams.

(N.S. Trahair 2013) this study describes an efficient finite element method of analyzing the elastic in-plane bending and out of- plane buckling of indeterminate beam structures whose members may be tapered and of mono-symmetric I cross-section. The structure’s loading includes concentrated moments and concentrated or uniformly distributed off-axis transverse and longitudinal forces, and its deformations may be prevented or resisted by concentrated or continuous rigid or elastic off-axis restraints.

Tapered finite element formulations are developed by numerical integration instead of the closed forms often used for uniform elements. Difficulties in specifying the load positions for tapered monosymmetric members caused by the variations of the centroidal and shear center axes are avoided by using an arbitrary axis system based on the web mid-line. Account is taken of additional Wagner torque terms arising from the inclination of the shear center axis.

A computer program based on this method is used to analyze a number of examples of the elastic in-plane bending of tapered cantilevers and built-in beams, and very close agreement is found between its predictions and closed form solutions.

The program's predictions of the elastic out-of-plane flexural–torsional buckling of a large number of uniform and tapered doubly and mono-symmetric beams and cantilevers under various loading and restraint conditions are generally in close agreement with existing predictions and test results. The common approximation in which tapered elements are replaced by uniform elements is shown to converge slowly, and to lead to incorrect predictions for tapered mono-symmetric beams.

(Sid Ahmed Meftah et. al. 2013) the elastic lateral torsional buckling behavior of doubly symmetric web tapered thin-walled beams is investigated in this work. For the purpose, a non-linear model is developed in large torsion context according to a new kinematics proposed model. Firstly, the elastic equilibrium governing equations are carried out from the stationary condition. Secondly, the Ritz's method is deployed in order to derive the algebraic equilibrium equations. From this system, an analytical formula is proposed for the lateral buckling strength of web tapered beams in function of the classical stiffness terms, the load height position and the tapering parameter. The proposed formula is simple and gives accurate results when compared to finite element simulations. For this aim some numerical examples are considered in the validation process.

2. RESEARCH OBJECTIVES

The objective of the present research work is to study, experimentally and analytically the overall behavior for limited failure modes and load carrying capacity of simply supported composite non-prismatic steel beams with different span length, shape of slopping and different angle of slope. The main aims of this study can be summarized as follows:

1. Carrying out experimental tests on thirteen simple supported beams having different geometry to study their performance under two concentrated loads at third points of span.
2. Investigating the effect of change tapering angle on composite non-prismatic steel beam.
3. Investigating the effect of span length on composite non-prismatic steel beam.
4. Studying the effect of shape of tapering on composite non-prismatic steel beam.

3. HYPOTHESIS OF THE STUDY

Structures with large spans need sections with large sections' moduli. Instead of introducing large sections with heavy weights, some mechanical processes of cutting and welding will produces non prismatic members with tapered webs (see Fig. 1). These members with tapered webs will have big section modulus at the zone of large bending moment's stresses (the most critical zone). While, the capacity of the member decreased from the original section near the shear zones (usually this zone not critical).

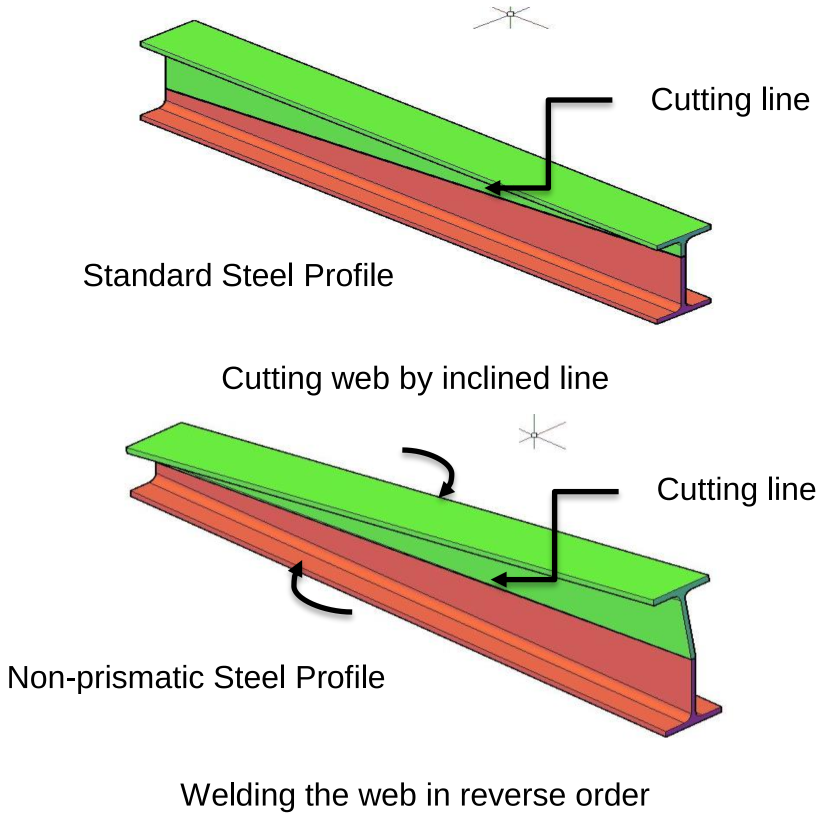
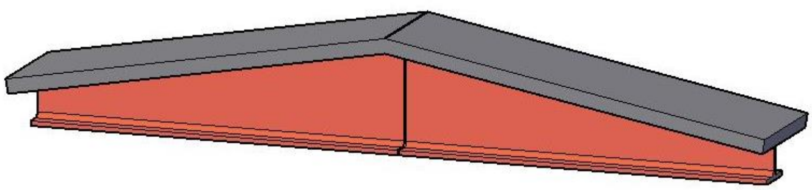


Fig. 1: Manufacturing processes

In condition, there are three types of composite members with non-prismatic shapes;

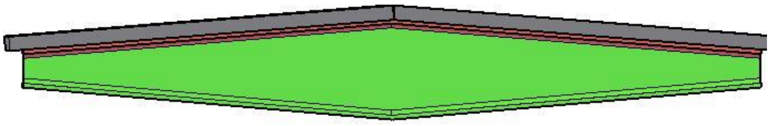
i. With neutral plane but cumbered deck. (see Fig. 2-a)
ii. With cumbered neutral plane and cumbered deck. (see Fig. 2-b)
iii. With folded down neutral surface with plane deck. (see Fig. 2-c)

A study on influence of degree of web tapering ratio in flexural strength of composite non-prismatic steel beams is the scope of this thesis. The aim of study is to investigate an ability of non-prismatic beam procedure to increase the flexural stiffness and reduce cost. For this purpose, experimental will carry out.

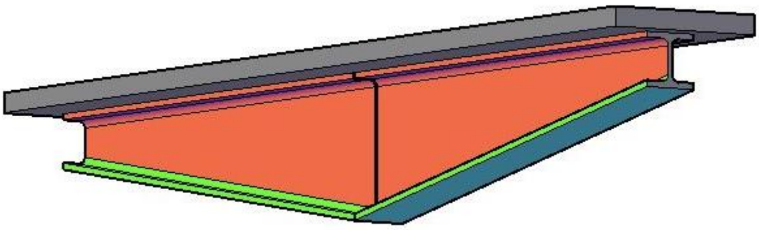


a) Cumbered Neutral Surface and cumbered decks (for Roofs)

Fig. 2: Types of non-prismatic tapered webs members (continue)



b) plane Neutral Surface and cumbered decks (for Roofs)



c) Folded Down Neutral Surface and plane decks (for floors)

Fig. 2: Types of non-prismatic tapered webs members (continued)

4. EXPERIMENTAL TESTS

The experimental work will consist of fabrication and testing number of beams arranged groups according to variable parameters (shape of tapering and angle of tapering) with span length equal 1800 mm. The steel will use in this study with section IEP140 and the concrete slab make from self-compacting concrete with strength 65 MPa and had width 300 mm and thickness 70 mm. The steel beam will connect to the concrete slab by reinforcing bar with diameter 10 mm looks like (z-bar) that will weld to the top flange of the steel beam.

The material properties such as mechanical and chemical properties of the specimen's materials (cement, fine and coarse aggregate and limestone powder) were tested according to the (Iraqi specifications IQ.S 1984) and the American Society for Testing and Materials (ASTM 1986).

The tests of fresh concrete used in this study to investigate characteristics of fresh self-compact concrete like segregation resistance, filling ability and passing ability; further three test methods are used to display production quality. These tests are slump-flow, L-box and V-funnel and tested according to the (EFNRK 2005)

5. EXPERIMENTAL RESULTS

To investigate the overall structural behavior, load-carrying capacity, types of failure and stiffness ratio of the composite non-prismatic steel beams; nine steel beams in three groups were tested with variables included shape of tapering and angle of tapering.

5.1 Test Results

All beams were tested under the same type of loading and had different shape of tapering for different angle of tapering; therefore, different mechanisms and failure modes occurred for these tested beams such as overall bending failure and shear failure in concrete slap, as well as the slip between concrete and steel was noticed and measured. In addition to that, two patterns of cracks appeared in concrete slabs; flexure-shear and splitting cracks. The ultimate load and mid-span deflections at ultimate step is shown in Table (1).

Table (1): Experimental Results of the Tested Beams.

Group No.	Beam designation	Total applied load (kN)	Mid-span deflection (mm)
Control	P-0	234	32.657
1	NPB-4	250	23.266
	NPB-8	258	21.874
2	NPU-4	273	23.520
	NPU-8	275	21.437
3	NPN-4	271	16.560
	NPN-8	274	14.951

5.2 Load versus Mid-Span Deflection Results

The monotonic load was applied to find mid-span deflection that was recorded by dial gage for all tested beams. The structural performance as experimental load-deflection curves for all tested specimens are shown in Figs. (3) to (5).

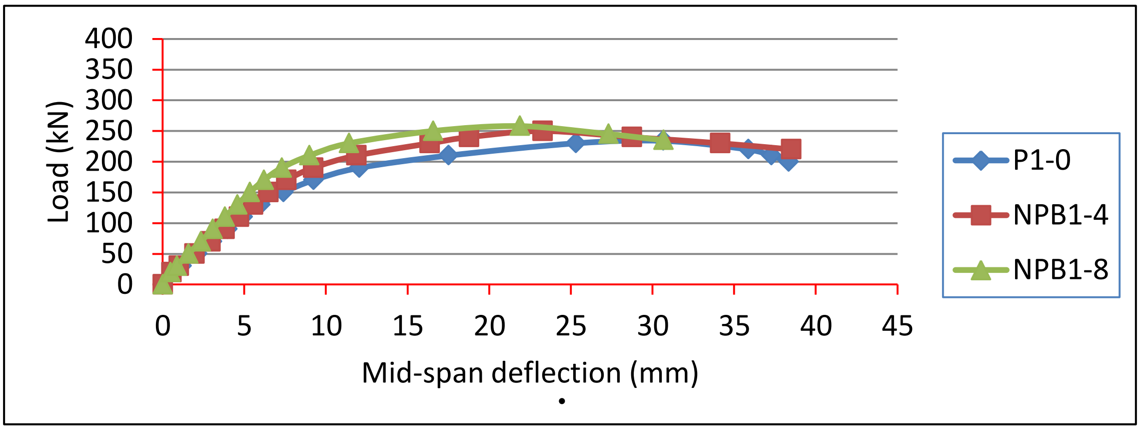


Fig. (3): Load-Deflection Curves for Beams in Group One.

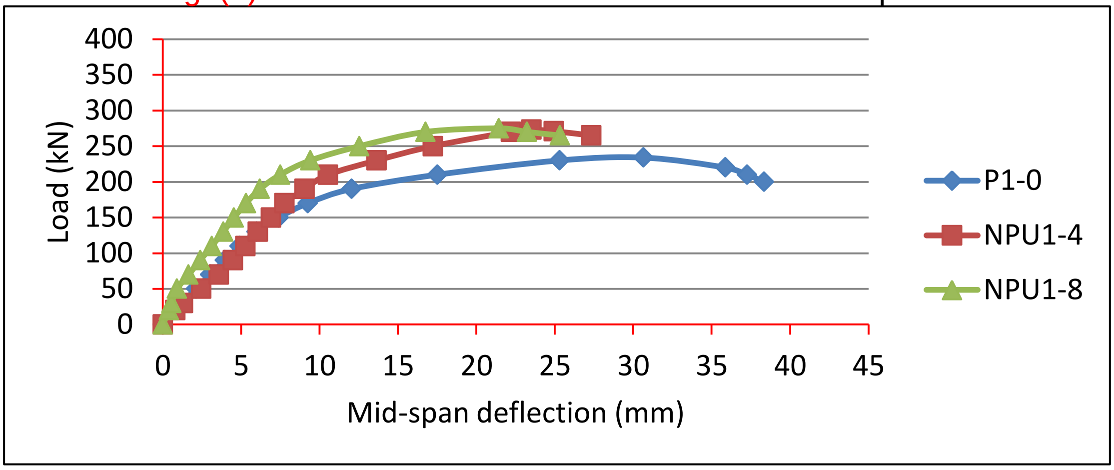


Fig. (4): Load-Deflection Curves for Beams in Group Two.

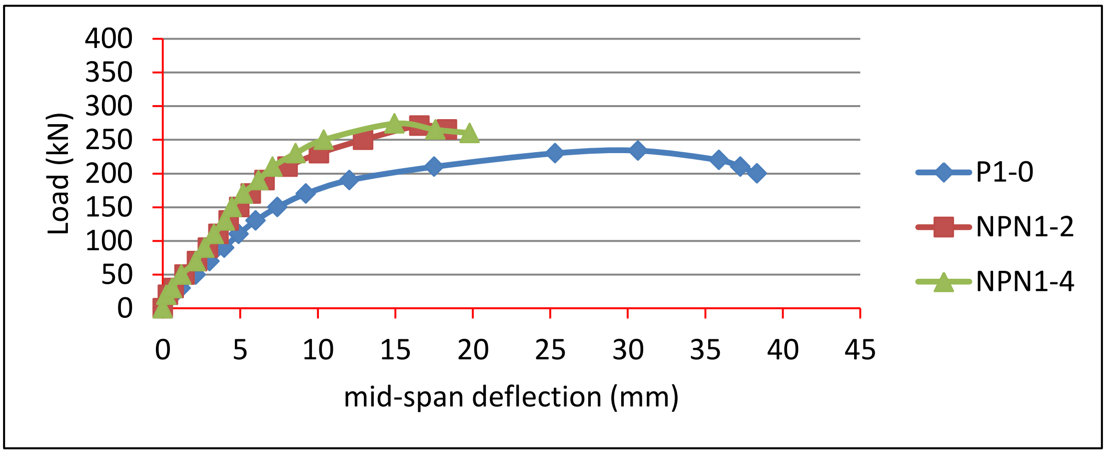


Fig. (5): Load-Deflection Curves for Beams in Group Three.

5.3 Ductility Ratios

Beam ductility is defined as its ability to resist inelastic deformation without any reduction in its load-carrying capacity up to failure. That means, the ductility can be considered as a ratio between the deformations at ultimate stage to yield deformation. That deformation can be strains, curvatures or deflections. From the load-deflection curves, the deflection at yield limit indicated by intersection two lines; line of best fit as a tangent line and horizontal line passed through the ultimate load. This is for elasto-plastic behavior as shown in Fig. (6).

The ductility ratios for all tested beams shown in Table (2), displayed that the non-prismatic beams had a ductile behavior more than prismatic beam with percentage increment at about (4.5-12) %.

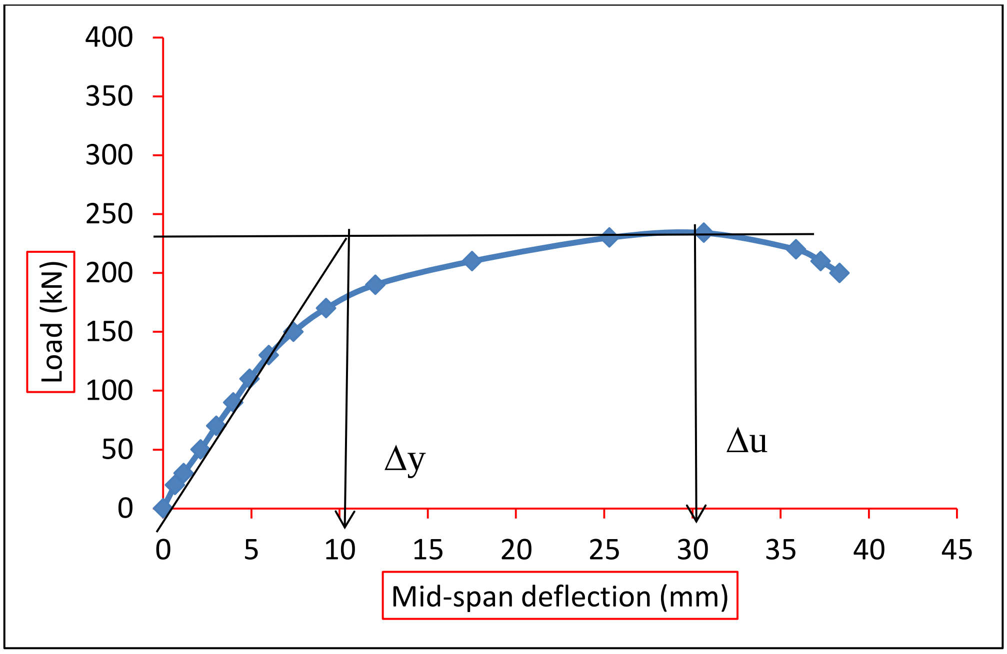


Fig. (6): Indication of Yield Limit for Elasto-Plastic Behavior.

Table (2): Ductility Ratio for the Tested Beams

Specimen	Deflection (mm)		Ductility Ratio	Increase in Ductility Ratio %
	Δ_y	Δ_u		
P-0	11.0	30.657	2.620	N/A
NPB-4	8.5	23.266	2.737	4.5% (P-0)
NPB-8	7.9	21.874	2.768	5.6% (P-0)
NPU-4	8.3	23.520	2.833	8.1% (P-0)
NPU-8	7.5	21.437	2.936	12% (P-0)
NPN-2	5.6	16.560	2.806	7% (P-0)
NPN-4	5.3	14.951	2.931	11.8% (P-0)

6. CONCLUSIONS

From this study the following points are drawn

1. Bearing of non-prismatic beam more efficiency from prismatic beam for the same section weight and the increase in bearing capacity about (6.8 -17.5) % from prismatic beam.
2. Increase in angle of slop has a little effect on ability to endurance.

3. Increase load capacity and decrease vertical deflection for specimens sloping from top compared with sloping from bottom.
4. Increase load capacity and decrease vertical deflection for specimens sloping from both top and bottom compared with sloping from bottom.
5. Non-prismatic beam has ductility ratio more than prismatic beam and the shape of sloping from top only or from both top and bottom are more ductility ratio from beams sloping from bottom only.
6. Vertical deflection for non-prismatic beam less than from the deflection of prismatic beam about (24 - 51) %.
7. Vertical deflection for specimens sloping from bottom only or from top only equal almost but decrease the vertical deflection for specimens sloping from both side (top and bottom) compared with the other specimens.

NOMENCLATURE

P: Prismatic beam.
NP: Non-prismatic beam.
B, U, N: the form of the samples sloping from the bottom side, top side and both sides respectively.
-0,-2,-4, -8: angle of sloping, deg.
P-0**:** Prismatic composite beam with zero degree angle of slope (0°).
NPB-4: Non-prismatic beam sloping from bottom side with angle 4°**.**
NPB-8: Non-prismatic beam sloping from bottom side with angle 8°**.**
NPU-4: Non-prismatic beam sloping from top side with angle 4°**.**
NPU-8: Non-prismatic beam sloping from top side with angle 4°**.**
NPN-2: Non-prismatic beam sloping from both sides (top and bottom) with angle 2°.
NPN-4: Non-prismatic beam sloping from both sides (top and bottom) with angle 4°.
Δ_y: Mid-span deflection corresponding to yield load.
Δ_u: Mid-span deflection corresponding to ultimate load.

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