EXPERIMENTAL STUDY OF CONSISTED SECTIONS STEEL-CONCRETE

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Résumé

Ce travail présente une étude expérimentale et analytique du comportement élasto-plastique des sections composées en acier-béton. Ces structures sont des poutres en acier (profilés en I) complètement enrobées dans le béton.

Après les essais, certaines poutres composées présentent un comportement ductile apparent avant la rupture dû essentiellement à la plastification en traction des sections en acier , d'autres ne présentant pas une telle ductilité à cause de la fissuration excessive du béton dans la zone comprimée.

Connaissant l'existence d'une zone de plasticité après écoulement et avant rupture, il est nécessaire de bien cerner la thématique pour ces genres de structures afin de mieux comprendre le comportement des sections composées.

Mots clés **:** *Sections composées, comportement, ductilité, plasticité, elasto-plastique, écoulement.*

Abstract

This work presents an experimental study of elastic-plastic behaviour of steel-concrete composite sections. The specimens are made of steel I-beam section completely embedded in parallelepiped concrete block.

After testing, some specimens have shown apparent ductile behaviour before failure. This is mainly due to the plasticization of the tensile zone steel sections. Others did not have such ductility because of excessive cracking of the concrete in the compressive zone.

It is necessary to clearly identify the existence of a plasticity zone after flowing and before rupture, to better understand the behaviour of this type of structures.

Key words**:** *Composite sections, behaviour, ductility, elastic-plastic, flow model.*

ملخص

يتناول هذا البحث تحليليا و تجريبيا السلوك المرن و المرن – اللدن لنوع خاص من المقاطع المركبة و هو المنشآت المغلفة. هذه المنشآت المغلفة تتألف من مجموعة من مقاطع فولاذية محاطة كليا بالخرسانة.

و يبين هذا البحث أيضا أن البعض من هذه المنشآت المغلفة تظهر مطاوعة واضحة قبل الإنهيار بسبب الخضوع بالشد بالمقاطع الفولاذية و من تم تهشم الخرسانة المغلفة المضغوطة. إلا أن البعض الآخر لا يظهر مثل هذه المطاوعة بسبب كثافة التشققات في الخرسانة المضغوطة و في كل الحالات هناك مجال للدونة بعد الخضوع و قبل الإنهيار يجب تسليط الضوء عليه و لم تتم بلورة هذا المجال اللدن في مثل هذه الأنواع من المنشآت حتى الأن بسبب تعقيد العلاقات الناتجة كما سنرى.

كلمات مفتاحية : مقاطع مغلفة، المطاوعة، مرونة لدونة، سلوك، خضوع ، خرسانة – فولاد .

The composite sections made of steel I-beam section completely embedded in concrete allow the use of large span beams and slender columns and as a result the design of aesthetic and lighter structures. They also present a great fire resistant.

From the economic point of view, they also offer a gain exceeding 15%, representing an alternative on the conventional and traditional protection of steel. Thereby concrete contributes to the structural strength while protecting from the fire heat spreading to the steel which represents the core of the section.

These types of sections are widely used in steel-concrete composite slabs, floors with steel framework, composite beam, composite columns with completely or partially coated steel sections.

The present study concerns steel-concrete composite beams subjected to static bending loading.

1. STATE OF ART

The steel-concrete composite section history coincides with the history of reinforced concrete from the fact that this section is a particular case of the well-known reinforced concrete.

Knowles (1) has demonstrated that steel sections surrounded by concrete are prevented from fire. Scott (2) and Caughey *et al* (3) conducted experiments on steel beams stabilized by a concrete slab. Gillespie *et al* (4) have produced a report on a serie of experiments on steel beams I-shaped covered by concrete.

The work of Siesse (5) focused on steel sections embedded in concrete (for bridges) and steel sections collaborating with concrete slab. Viest (6) presented a historical overview of the American AASHTO and German specifications on the use of pre-stressed concrete slabs covering steel beams.

Other experiments and researches were undertaken on steel-concrete composite sections by Fisher (7) and Slluter (8). Finally Johnson (9) had established a comprehensive list of works and researches on steel-concrete composite sections.

In Europe over 50% of multi-story buildings are steel base made, while in other countries this material represents only one third. In the USA and Canada, steel is ubiquitous in buildings.

2. EXPERIMENTAL STUDY

2.1. Feature

The tests of the present study were conducted in the laboratory of the Department of Civil Engineering at the Frères Mentouri University-Constantine.

Two types of mechanical testing were performed :

2.1.1. Compression test

Compression tests were done on concrete cylindrical specimens in accordance with French standards NF P18.406. The test apparatus used is a universal press, where specimens are placed vertically (figure 1).

Both circular faces of all specimens in contact with the press were surfaced to ensure uniform loading. The maximum capacity of the loading of the machine is 1200 KN.

Figure 1 : Compression testing machine

2.1.2. Bending test

Bending tests were performed on a compression machine (Schenk Trebel 3000 kN). This apparatus is equipped with a cylinder and two parallel plates and connected to automatic devices to insure loading and getting results (figure 2).

Figure 2 : Bending testing machine

2.1.3. Support beam

The beam is placed on a lower plate support made-up of three metal parts welded and reinforced and two simple supports at both ends of the plate support (figure 3)

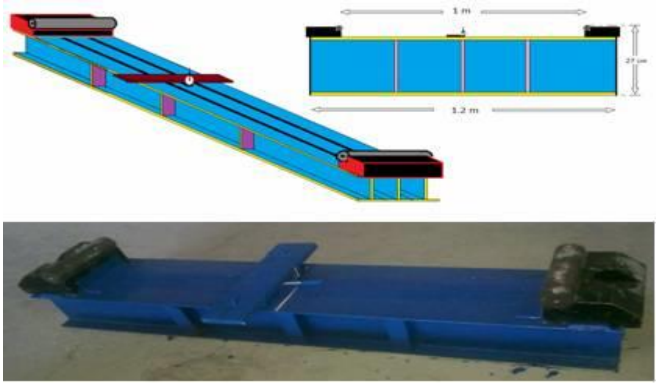

Figure 3 : Implementation of the test

2.1.4. Loading distribution

In order to divide the one force loading from the test apparatus into two testing loads, a fabricated device is placed on the study beams. This device is steel made and has two cylindrical contact points with beam specimens (figure 4).

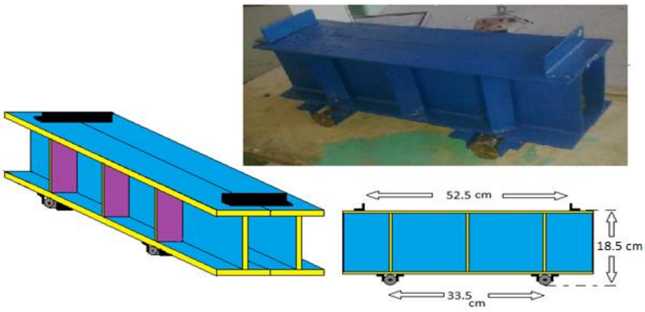

Figure 4 : Applied load distribution device

2.1.5. Displacement measurement

For measuring displacements at mid-span, a comparator is used and placed at the same spot. The comparator gives measurement up to failure load (figure 5)

Figure 5 : Comparator displacement device

2.1.6. Global test apparatus

As shown in figure 6, the one loading force from the universal press testing machine is divided into two test forces which act on the beam specimens. The displacements at mid-span are obtained from a comparator placed under the concrete beam at mid-span.

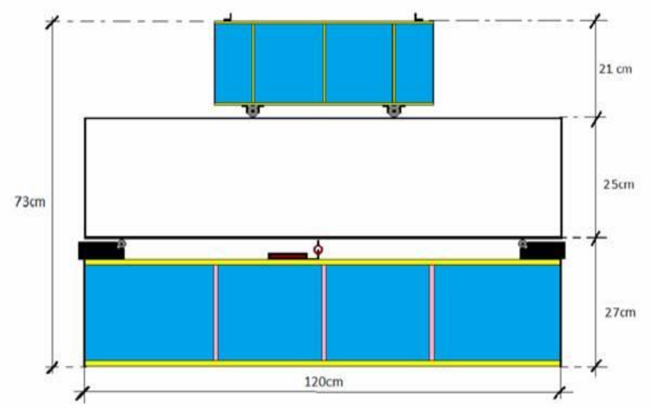

Figure 6 : Global test apparatus

3. RESULTS

3.1. Compressive strength

The compression tests on cylindrical test specimens after 28 days of age led to the determination of the average value of the compressive strength of concrete f_{c28} (Table 1)

Table 1 : fc28 values.

Specimens	1	2	3
f_{c28} compressive strength (MPa)	25.75	22.82	26.33

The average compressive strength is 24.96 MPa.

3.2. Bending test on IPE steel beams

Figure 7 presents the bending tests on (IPE160) steel beams in order to determine their bearing capacity.

Figure 7 : Specimens under bending test

- Load-displacement relationship for IPE steel beams (figures 8 to 10)

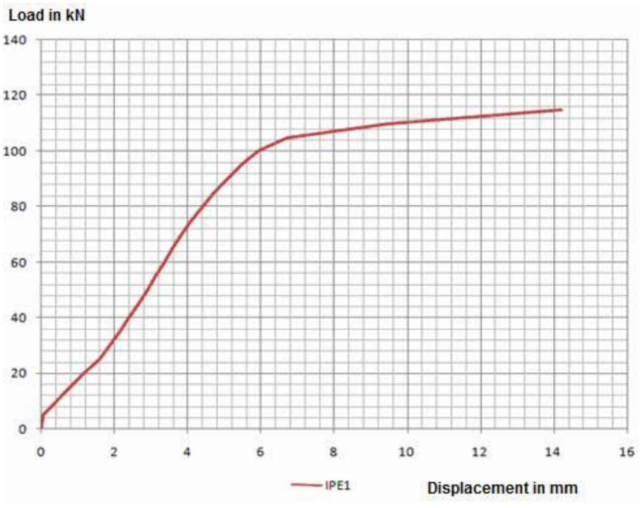

Figure 8 : Load/displacement relationship IPE 160/1

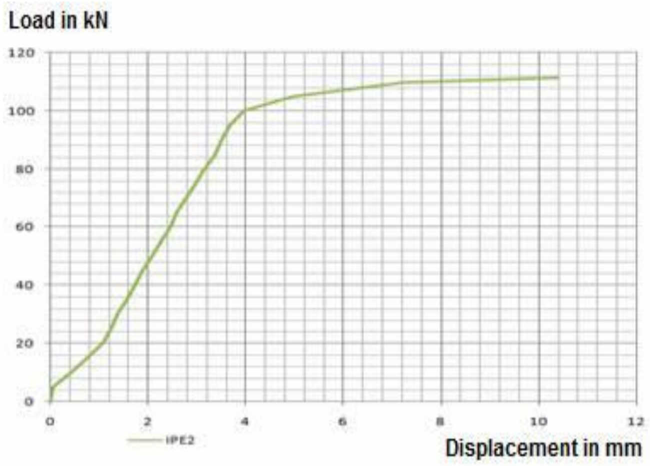

Figure 9 : Diagram load/displacement IPE160/2

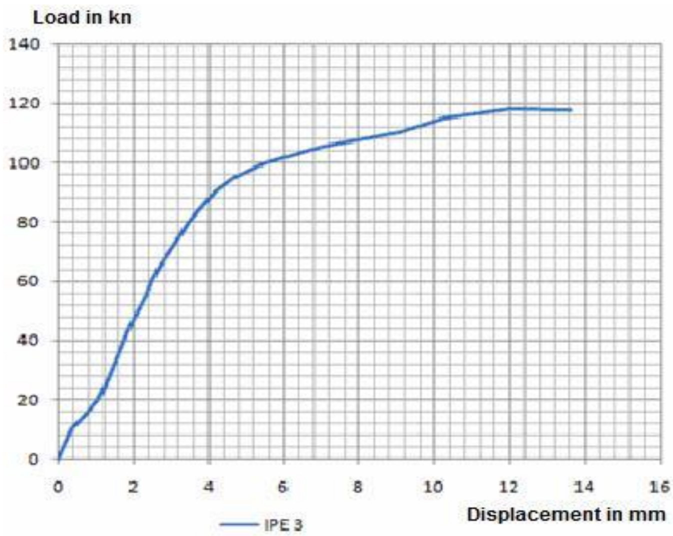

Figure 10 : Diagram load/displacement IPE 160/3

- Table 2 gives shows the maximum loads and displacements for each IPE steel beam.

Table 2 : Experimental results of each section

	IPE/1	IPE/2	IPE/3	Average
Failure load (kN)	115	113	117	115
Ultimate load (kN)	96	98	88.5	94.16
Ultimate displacement (mm)	5	3.4	3.6	4
Max displacement (mm)	14.2	10.4	13.65	12.75

3.3. Bending test on composite beams

Figure 11 illustrates test setting of the four-point bending for the beam specimens.

Figure 11 : Beams specimens test setting

The static loading is performed incrementally. The beams bent. The comparator device gives real-time displacement values, while the test machine shows the incremental loading force values.

The 25/1, 25/2 and 25/3 beams begin to crack at respectively force loading of 45 KN, 40 KN and 35 KN and reach the ultimate loading value of 175KN, 176 KN and 184 KN (figure 12).

Figure 12 : Beams specimens craking

Figures 13 to 15 show the load-deflection relationship for the three types of specimen, while table 3 shows the loads and the displacement values for each composite beam.

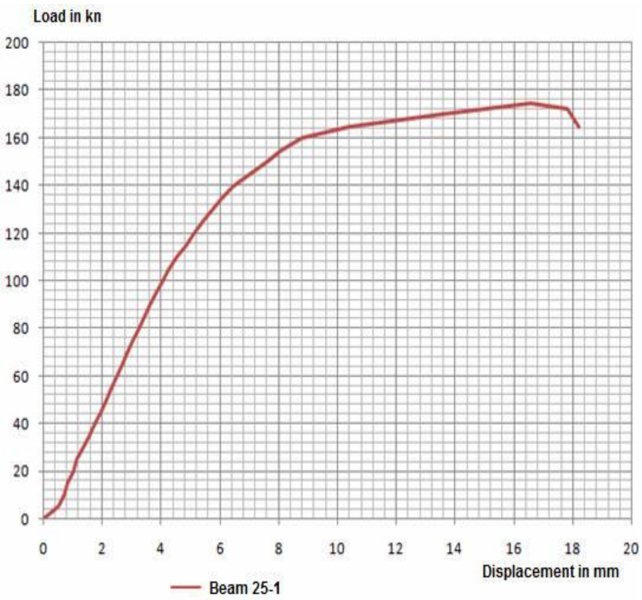

Figure 13 : Load-deflection relationship of 25/1 beam

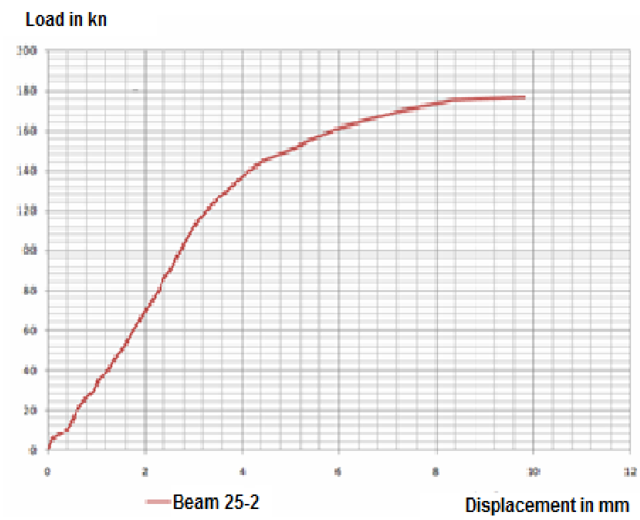

Figure 14 : Load-deflection relationship of 25/2 beam

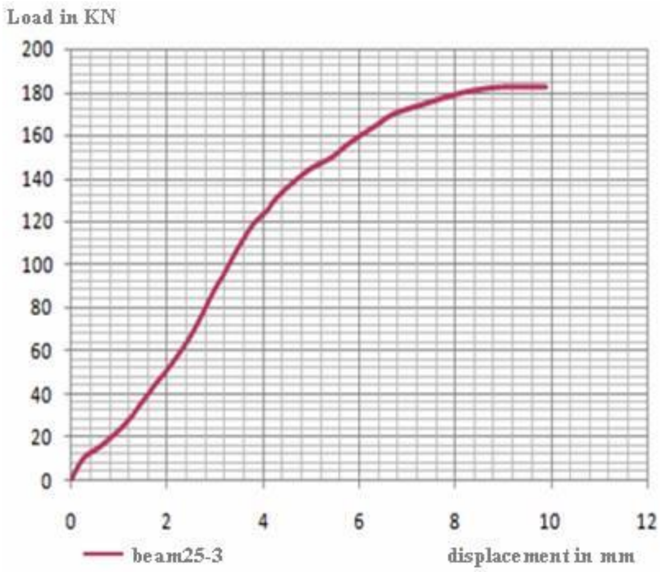

Figure 15 : Load-deflection relationship of 25/3 beam

Table 3: Experimental result values

	Beam 25/1	Beam 25/1	Beam 25/1	Average
The failure load (kN)	175	176	184	178.333
The ultimate load (kN)	108	113	116	112.33
Ultimate displacement (mm)	4.8	3	3.4	3.73
Max displacement (mm)	16.55	9.8	9.9	12.08

4. ANALYSIS

4.1. Steel beams

Figure 16 shows the load-displacement relationship for the three IPE steel specimen beams under bending loading.

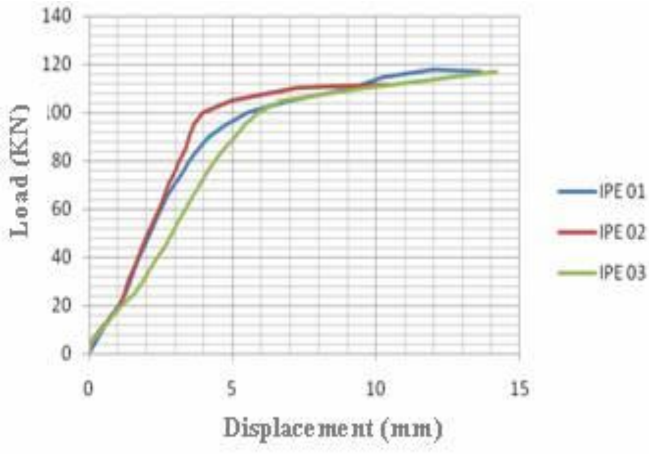

Figure 16 : Load/displacement relationship for the three IPE steel beams

Table 4: Limits values in kN of the IPE steel beams

	Profile 1	Profile 2	Profile 3
Elastic	[0 - 96]	[0 - 98]	[0 – 88.5]
Elasto-plastic	[96 - 115]	[98 - 113]	[88.5 - 117]
Plastic	From 115	From 113	From 117

Three phases emerge from the IPE steel beams global behaviour (table 4).

1st Elastic phase

This phase represents the linear relationship between load and displacement.

2nd Elastic-plastic phase

This phase begins at the end of the previous phase. It represents the beginning of the lamination of the extreme fiber of the cross-section IPE beam and the linear relationship obtained in the elastic phase is broken; at the end of this phase the plasticizing of all fibers takes place.

3rd Plastic phase

A horizontal plateau characterizes this phase, reflecting an increase in displacement under constant loading.
The resulting diagram shows:

- The bearing capacity obtained at the end of the elastic phase.
- The breaking load obtained from the horizontal level.
- The profile reaching the total lamination with a carrying capacity of rotation forming the plastic hinge without saving a local buckling, confirming class 1 profile.

4.2. Composite beams

The following diagrams show the load/displacement relationship for the composite steel-concrete beams.

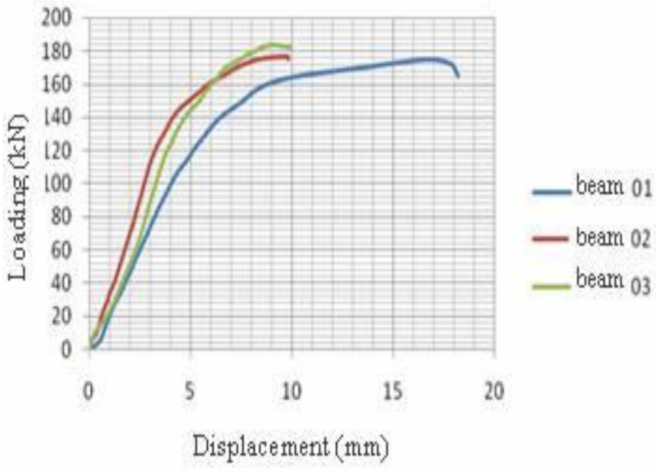

Figure 17 : Load/displacement relationship for the three steel-concrete composite beams.

The principal values for the three phases of the overall behavior for each beam are presented in table 5.

Table 5 : Limits values in kN of the steel-concrete composite beams

	Beam 25/1	Beam 25/2	Beam 25/ 3
Elastic	[0 - 108]	[0 - 113]	[0 – 116]
Elasto-plastic	[108 - 175]	[113 - 176]	[116 - 184]
Plastic	From 175	From 176	From 184

Three phases are identified :

1st Elastic phase

The relationship between load and displacement is linear; the cracks occurrence in the three beams starts respectively at loads of 37KN, 44KN and 41KN. The average of these values is 40.67 KN which is close to the 35.6 KN, value calculated with the moment causing section cracking according the ACI code.

2nd Elastic-plastic phase

It starts from the end of the elastic phase which sees the beginning of the extreme fibers yielding of the cross section and ends with the complete yielding of the section at the plateau outset.

3rd Plastic phase

A shortening of the plateau is recorded especially for the beams 1 and 2. These beams become brittle and lose their stability just after the maximum load. On the other hand, beam 3 records larger ductility compared to beams 1 and 2. The difference in the global behavior may be caused by the bond between steel and concrete or by vibration of the concrete during casting.

Figure.18 : Concrete-steel cohesion

4.3. **Determination of the maximum displacement**

It is about to compare the experimental results with the theoretical ones and the used code to find the flexural rigidity of the section with the condition in limiting the elastic phase with Δ = 3mm.

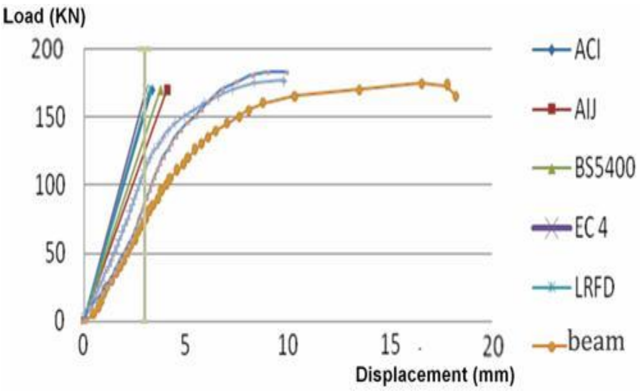

Figure 19 : Curves experimental and theoretical load-deflection.

It can be noticed that the theoretical results are totally different from experimental results. Table 6 shows the results for P = 60 KN with displacements not to exceed the allowable deflection.

Table 6: Arrows and theoretical reports on P = 60 kN

Code	ACI	AIJ	BS5400	EC4	AISC	Experimental Average
Δ_{max} (mm)	1.1778	1.4514	1.33	1.077	1.155	2.26
Ratio	0.52	0.642	0.589	0.476	0.511	1

The ratios obtained were very small; the AIJ code seems closest to experimental results.

CONCLUSION

Calculation methods according to several codes have resulted in significant progress for the calculation of the bearing capacity of composite beams under four-point bending.

This means we can improve the elastic-plastic behaviour of steel-concrete composite sections by varying the different parameters of the section (dimensions, coating etc. ...).

Concerning the codes used, it seems that EC4 Code and ACI Code are best suitable to calculate the bearing capacity of the beam and the cracking moment of the composite section.

Finally there was an increase of 19% and 55% of the carrying capacity for all composite sections, while the flexural rigidity of composite beams is increased by 36% compared to IPE steel beams.

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