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Composite Structures Steel/Prestressed Concrete

Structures mixtes acier/béton précontraint

Verbundkonstruktionen Stahl/Spannbeton

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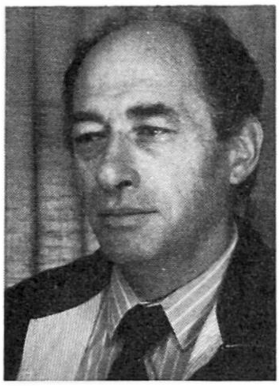

Pierre Thivans, born 1925, got his Civil Engineering degree at the Ecole Nationale des Arts et Métiers and joined Campenon Bernard in 1954. For ten years he was involved in job site organization and conception of various specific equipment for all kinds of Civil Engineering structures. He now deals with research of new construction techniques.

SUMMARY

Composite structures with steel corrugated webs and prestressed concrete bottom slab have been thoroughly studied. The description of calculation methods and tests performed show the importance of this new type of construction for long-span structures.

RÉSUMÉ

Les structures mixtes à âmes métalliques ondulées et hourdis en béton précontraint ont été étudiées en détail et l'on présente les aspects théoriques et expérimentaux les plus marquants de ces travaux qui montrent l'intérêt de telles structures notamment pour des grandes portées.

ZUSAMMENFASSUNG

Verbundsysteme mit Stegen aus gewelltem Stahlblech und Platten aus vorgespanntem Beton wurden detailliert untersucht. Die wichtigsten theoretischen und experimentellen Aspekte dieser Untersuchungen werden dargestellt. Sie zeigen die Bedeutung solcher Konstruktionen für grosse Spannweiten.

1. INTRODUCTION

Composite structures hereafter described, originate from the idea of improving performances of conventional concrete and designing ever lighter and more economical cross-sections.

Thanks to prestressing, concrete has a perfect resistance to bending moment, however steel is much more convenient to resist shear force.

A first approach of the problem leads to conventional composite bridges in which the steel web is designed rather according to stability than to resistance.

Besides, longitudinal stresses due to concrete creep as well as shrinkage, do not facilitate concrete-steel association.

The second approach leads to use a corrugated iron web thiner than a flat one and able both to transfer shear force with a greater resistance to warping and to avoid longitudinal stresses of the steel plate. However, it has to be noted that the idea of improving stability to warping thanks to corrugation is not new.

2. BEHAVIOUR OF THE COMPOSITE STRUCTURE

2.1. Behaviour of the corrugated web

As the corrugated iron cannot transfer longitudinal forces, the only possible stresses are shear forces. The usual Morsch frame with strained brackets and compressed brackets can appear in the corrugated web since inward thrust of the stressed strip perfectly equilibrates the outward thrust of the compressed strip.

2.2. Behaviour of a beam

2.2.1. General considerations

Vertical forces applied to a beam entail shear forces and moments. Because of its shape, the web cannot bear any normal force, bending moments can only be equilibrated by forces in the tables :

$$F = \frac{M}{h}$$

The immediate consequence of this phenomenon is the improvement of the cross section compared with a concrete section or section with concrete slab and plane steel webs.

In an isostatic system, the force of a prestressing cable placed in one of the slabs, is entirely applied to this slab ; the other one, as well as the web, does not receive any normal force.

Concrete creep does not entail any force in the slabs as it would with flat webs. In fact, as webs are fixed on footings (which number will be limited to the minimum admissible) slight tensile forces may appear in concrete.

However, we must precise that the small part of the web next to the upper slab is submitted to interfering stresses entailed by compatibility of local deformation with the slab. It is to be noted that this phenomenon is less important with corrugated iron webs than with flat ones.

2.2.2. Design of a cantilever

In order to verify our calculations, we have designed a cantilever 9.60 m long, 5.00 m large and 3.00 m high.

The first loading applied was an axial compression on the upper slab. The finite elements confirm that 99.62 % of the loading remain in the upper slab, the 100 % represent the light compression supported by the upper part of the webs.

The second loading considered was a vertical one applied at the end of the cantilever. The calculation has been made according to the usual formulas, considering that :

- the only flexural inertia is that of the bottom slab ;
- the shear section for the calculation of the shear force is only given by the web, the thickness of which has been reduced.

The interval between the two calculations is 3 % on the cantilevers and 2.5 % on the shear stress in the current part of the web. On the contrary, important distortions appear near the restrained ends of the cantilever at the level of the flexure stresses in the botton slabs.

The reason of this behaviour is the tendency of the web to distort its shape into a lozenge, i.e. it forms an angle with the horizontal plane (value : τ/G, τ shear stress, G shear modulus) while the slabs have a distorsion with an horizontal tangent.

The strain compatibility between bottom slab and webs entails shear planes which generate the bending moments found out in the bottom slabs.

We have worked out a theory enabling to provide these parasite phenomenons with a great precision and to choose necessary dispositions to reduce them a good deal.

It is important to precise that this phenomenon is not particular to this type of structure.

2.2.3. Tests

We have tested our theoretical calculations on an isostatic beam, 12.70 m long and 1.50 m thick. The beam has been submitted to circular stresses and symetrical local loads or loads not applied at mid-span.

Thanks to the very complete instrumentation proposed by the Laboratoire Central des Ponts et Chaussées, we have been able to verify our theoretical calculations with the utmost precision.

3. WEBS STABILITY

The stability of webs in steel structures is always a critical problem, since the thickness of the webs and intervals between stiffeners are designed to meet stability requirements.

In the case of corrugated iron webs, the thickness of the web will be decided according to the ultimate shear stress only, any instability problem being left aside.

Then, shape and amplitude of the wave will be calculated to insure web stability with a convenient safety factor.

The buckling of corrugated iron plates had previously been calculated by Easley from both theoretical and experimental points of view : in 1976, he had proposed the following formula for webs restrained at their ends :

$$\tau_{crit} = 68.4 \frac{D_x^{3/4} \, D_z^{1/4}}{e \, H^2}$$

with :

- $D_x = EI_x$ where I_x is the inertia of corrugated plate per linear meter
- $D_z = \dfrac{E \, e^3}{12\,(1 - \mu^2)}$ where e is the plate thickness
- H = web thickness

However, owing to the importance of these phenomenons, we have considered it as necessary to perform new tests in our Laboratory.

We have noted that on the different tests performed, the Easley formula duly represented the phenomenon.

As we have a good knowledge of the critical shear stress to warping, we propose to adopt a safety factor of 1.8 to comply with the security coefficient imposed by the regulations for composite structures as regards stability problems.

CONCLUSION

The detail design of the composite structures with corrugated iron webs, has shown that they exactly behaved like classical ones.

Tests confirm this appraisal and justify the calculation methods we intend to use for practical design.

We now consider that the thorough knowledge we have of these structures allows us to safety design and build structures of this type which would certainly prove economical in the field of long span structures.