Floor systems with composite form-reinforced concrete slabs

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Floor Systems with Composite Form-Reinforced Concrete Slabs

Systèmes de planchers en profilés de béton armé renforcés d'acier en action combinée

Deckentragwerke (Leichtbleche) im Verbund mit Stahlbetonplatten

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INTRODUCTION

Reference is made by Dr. George Winter[1] and Dr. John B. Scalzi[2] to the development and use in the United States of many variations of light-gage steel panels which may serve as roof decks, floor decks, and walls. Particularly, Dr. Winter mentions the use of a floor slab system involving concrete permanently placed over a light gage steel panel. In this case, the steel panel may perform the dual role of functioning as a form for the concrete at the construction stage, and as positive moment reinforcement for the slab under service conditions. Thus, there may be composite action between the steel panel and the concrete. Dr. Winter further points out that it is possible to utilize composite action between the slab and the supporting beams or girders.

There are many advantages in using floor systems which employ light-gage steel panels to act in composite fashion with concrete. Obviously, eliminating the necessity of installing and removing wood forms can be cost-saving, particularly in cases where the contractor cannot take advantage of form reuse. Secondly, the light gage material is easily handled and placed, hence rapid construction is possible with a minimum of on-site labor. A third advantage is that several manufacturers have developed pre-engineered raceways for electrification, communication, and air distribution which can often be economically blended with their respective systems.

This discussion describes the use of form-reinforced concrete slabs in buildings. It presents the current state-of-the-art, with emphasis on the methods of obtaining composite action between the concrete and the light gage steel, as well as between slab and supporting members. Design concepts pertaining to both types of composite action are reviewed. The last section contains photographs which illustrate some interesting applications.

COMPOSITE FORM-REINFORCED CONCRETE SLABS

Light gage steel forms for composite form-reinforced concrete slabs are commercially available in a variety of shapes and sizes. Form units normally are corrugated to provide adequate bending strength and have some type of corrosion-resistant coating such as galvanizing. A typical unit might be 2 ft wide, 15 ft or more in length and weigh approximately 2 lbs per square foot.

The thickness of the sheet ranges from approximately 24 gage (0.024 in.) to 14 gage (0.075 in.).

The forms can be separated into two basic categories based on their means of developing shear resistance. Category I (Fig. 1) is the type of form which develops shear resistance primarily through the medium of wires welded to the top surface of the form[3]. Thus, the wires become embedded in the concrete and transfer the horizontal shear into the form at the points of weld. Forms of Category II (Figs. 2 and 3) have indentations or embossments which are rolled into the material in such a way as to provide shear resistance and vertical interlocking between concrete and steel[4,5]. Actually this type of form depends to a great extent on its transverse bending strength for much of its capacity to develop shear resistance.

The design principles for form-reinforced concrete slabs are based on those pertaining to conventional reinforced concrete design[6]. Design is based on allowable valves of concrete stress, steel stress, and shear transfer. It is assumed that concrete cannot withstand tension, i.e. the section is cracked to the neutral axis; and transformed sections are calculated accordingly. The sectional properties of light-gage steel forms are computed on the basis of commonly accepted procedures[7], and each supplier provides this information for his own product. The supplier also provides other design data, such as load tables, which would pertain to a variety of conditions.

The determination of bending stresses in any composite form-reinforced concrete slab is based on the well-known flexure formulas

$$f_s = \frac{M}{S_b} \tag{1a}$$

or

$$f_c = \frac{M}{S_t} \tag{1b}$$

where

M = the applied bending moment

f_s = the stress in the bottom fiber of the steel form

f_c = the stress in the top fiber of the concrete slab

S_b = the section modulus of transformed section, bottom fiber

S_t = the section modulus of transformed section, top fiber.

The determination of shear transfer stresses can best be discussed by considering, separately, the two categories of forms. For the forms of Category I, a relationship for the spacing of the welded transverse wires is found from the formula

$$v = \frac{V}{bjd} \tag{2}$$

where

v = is the horizontal shearing unit stress in the slab between the neutral axis and the level of the steel

b = the width of slab under consideration

V = the external shear force acting

j = ratio which defines arm of resisting couple

d = distance from top of slab to centroid of form steel.

Since a steel form with transverse welded wires was used, Eq. (2) must be modified. Let

S = the spacing of transverse wires

W' = maximum allowable weld shear per wire weld

g = transverse width of repeating section assuming one weld within each section.

It follows then, by applying Eq. (2) to an area of slab S in. long and g in. wide, that

$$W' = \frac{VSg}{bjd} . \tag{3}$$

Equations (1) and (3) provide the means of determining required steel area and transverse wire spacing for a simply supported one-way slab, based on the load carried by the composite section. Naturally, other design considerations, such as form deflection under the dead weight of wet concrete must also be taken into account.

Shear transfer for forms of Category II is treated in essentially the same way as described above. There are two cases to consider, however, which are denoted as Category II(a), and Category II(b). Category II(a) is the case where the light gage section has embossments which are primarily on a horizontal surface at one discrete interface (see Fig. 2 and Refs. 4 and 8). In this case, the design is based on the relationship

$$t = \frac{VQ}{I} \tag{4}$$

where

t = the shear transfer force, per unit length, at the level of the horizontal interface under consideration

Q = the statical moment

I = the moment of inertia of transformed section.

In the case of forms of Category II(b), where embossments are arranged on inclined surfaces, the following relationship is used.

$$u = \frac{V}{\Sigma_o jd}$$

where

u = the average unit bond stress on contact surface between steel and concrete

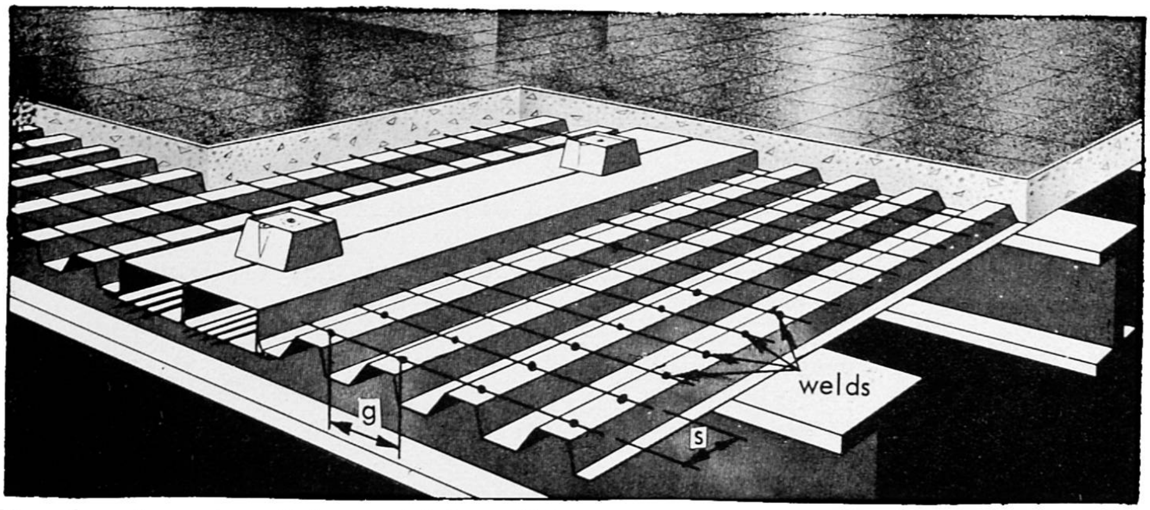

Fig. 1. Example of form which utilizes transverse wires (Category I).

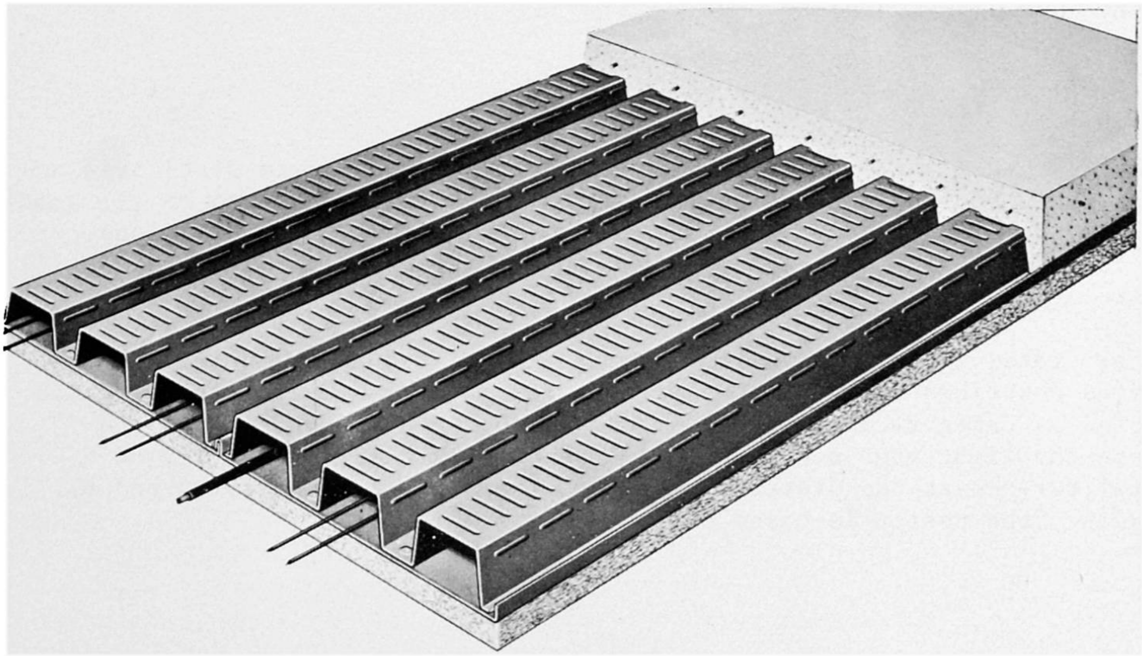

Fig. 2. Example of form which utilizes embossments on flanges and webs (Category IIa).

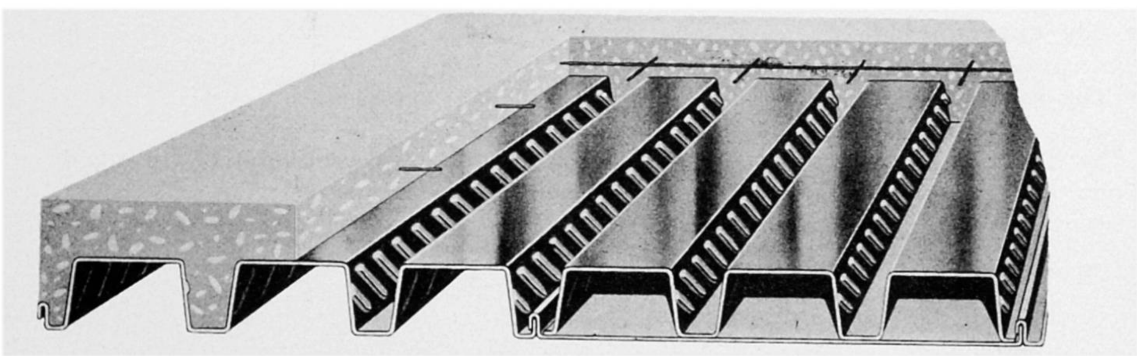

Fig. 3. Example of form which utilizes embossments on webs (Category IIb).

Σ_o = the contact surface per unit of length.

The above is illustrated in Fig. 3, and design data given in Ref. 5.

The current state of development of form-reinforced composite concrete slabs is the result of a somewhat independent effort by steel producers. A detailed examination of the separate design criteria by these firms does generally reveal employment of sound engineering principles. Further research is needed, however, which will lead to the development of commonly accepted specifications. The co-authors of this discussion are presently engaged in such a research program at Iowa State University under the sponsorship of the American Iron and Steel Institute. The primary objective is to obtain information on the application, use, and design of concrete slabs with composite steel forms which might lead to design specifications. In view of the fact that this type of construction is relatively recent, and new shapes and configurations of light-gage steel forms are anticipated, one phase of the Iowa State research has dealt with the problem of form evaluation. The emphasis has centered on evaluating the shear transfer characteristics of the various kinds of forms. Due to the fact that the research is still in progress it is not possible to report any results at this time.

COMPOSITE BEAMS WITH FORM-REINFORCED CONCRETE SLABS

The establishment of composite action between the light gage steel form and concrete leads to the possibility that the form-reinforced floor slab may be designed to act compositely with supporting beams and girders. It must be recognized, however, that current knowledge should be strengthened to cover and guide the complete design of such systems. This is because information covering the design and construction of composite steel beam floor systems is based upon research work involving conventionally reinforced concrete slabs anchored to the top flange elements by some type of mechanical shear connector[9,10].

The performance of composite beams utilizing form-reinforced concrete decks is primarily dependent upon 1) the type of mechanical shear connectors and 2) the geometry of the steel forms[11]. A number of steel form suppliers have conducted individual research concerning this type of composite system. Design data is usually provided by these firms and in all cases applies only uniquely to their product. For example, Fig. 4(a) shows a typical composite section beam detail with a newly developed mechanical shear connector shown in Fig. 4(b). These shear connectors are welded through the steel form to the top flange elements. Figure 5 illustrates a typical composite section girder detail. Most popular are stud shear connectors. A typical composite section beam detail, employing this type of connector is shown in Fig. 6. There are two means of welding the connectors. In Fig. 6(a), the connector is welded through the steel form. In Fig. 6(b), the connectors are welded in an open space between the ends of the form. The latter procedure is primarily due to the designer's concern that chemical coatings, such as galvanizing, may hinder complete fusion in the welding process.

It is evident that additional investigation of individual floor systems is necessary to develop information leading to specifications governing composite steel beams supporting, form-reinforced concrete decks.

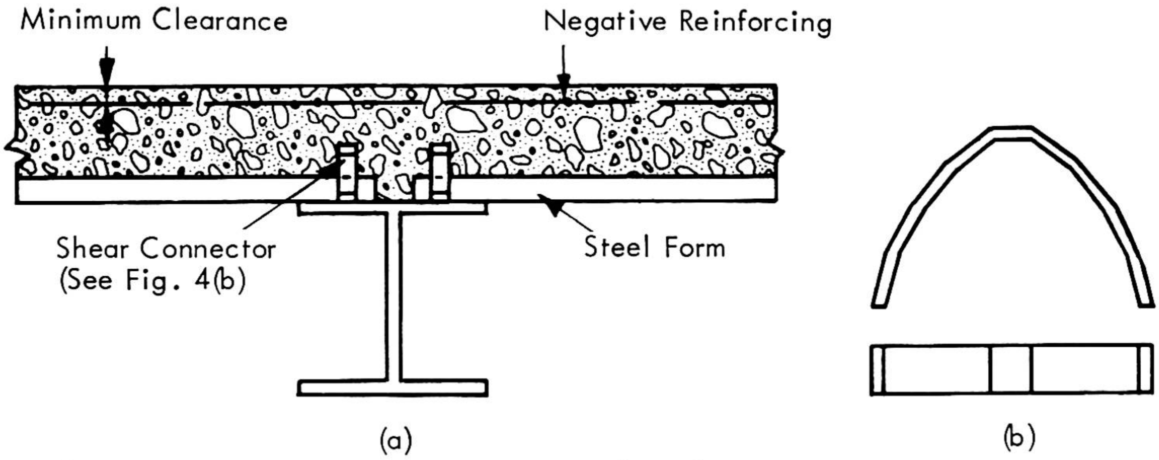

Fig. 4. Typical composite section beam detail.

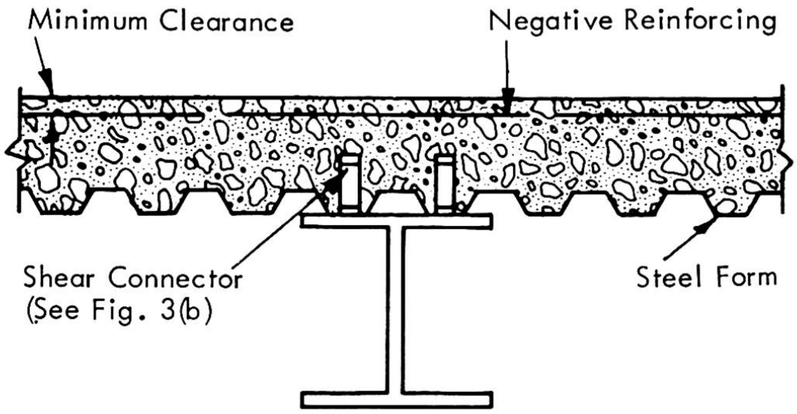

Fig. 5. Typical composite section girder detail.

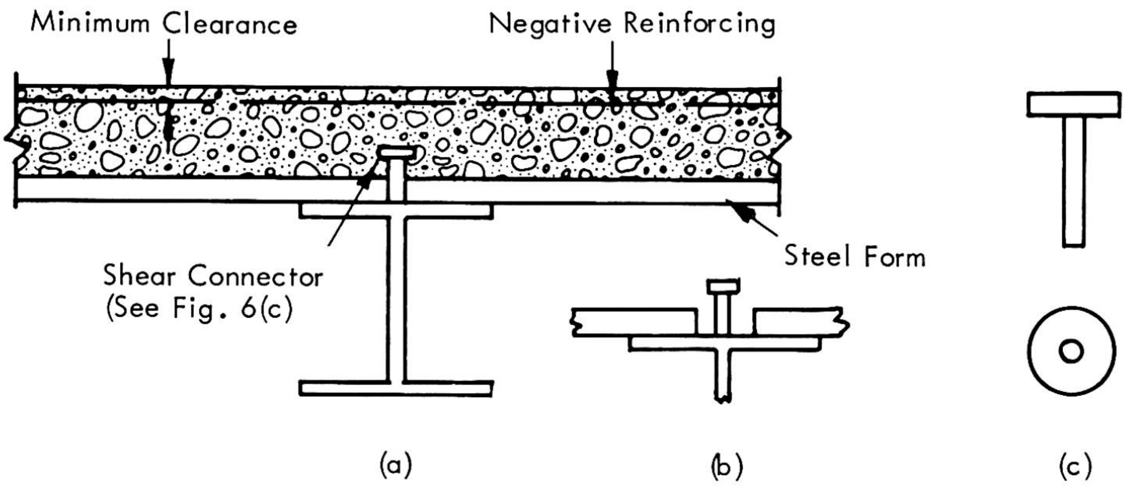

Fig. 6. Typical composite section beam detail.

ILLUSTRATIVE EXAMPLES

This section contains photographs of actual applications of light gage steel forms in buildings. Two types of forms are shown, Category I and Category II(b), as well as the installation of raceways or ducts. Each figure from 7 through 14, is shown with a descriptive title.

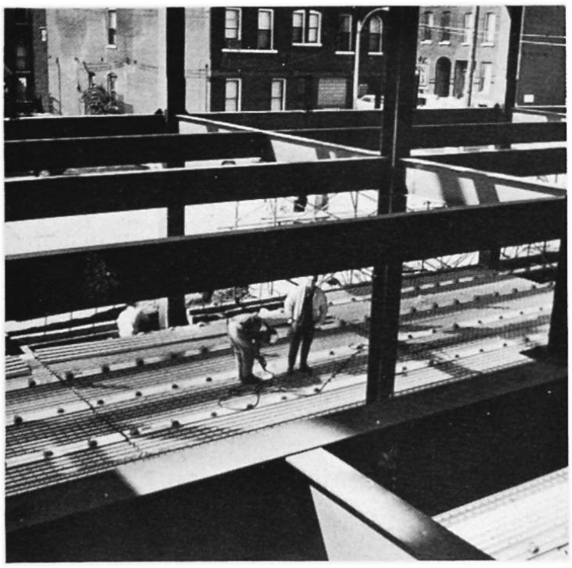

Fig. 7. Category I Form — Overview of installation showing raceways with uniformly spaced service fittings.

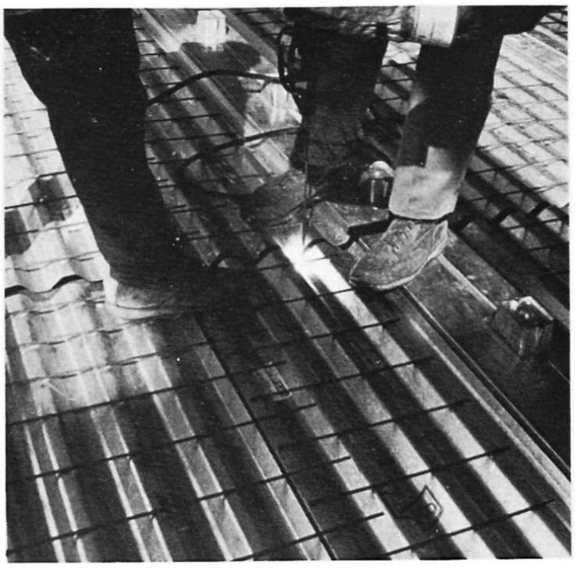

Fig. 8. Category I Form — Closeup showing form being fastened to structural frame.

Fig. 9. Category I Form — Overview showing all forms and raceways with service fittings in place.

Fig. 10. Category I Form — View showing placement of concrete. (Note negative reinforcing bars.)

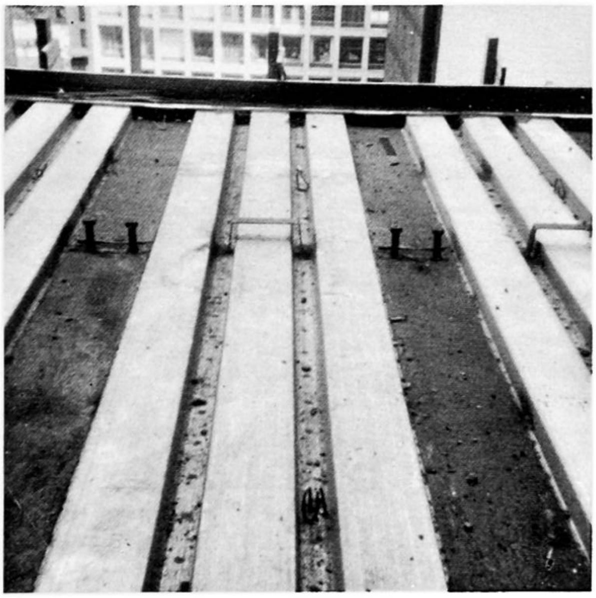

Fig. 11. Category II(b) Form – Special module designed to carry service wiring.

Fig. 12. Category II(b) Form – View showing raceways for wiring with uniformly spaced service fittings.

Fig. 13. Category II(b) Form – Overview showing composite beam and girder construction. (Note temperature steel.)

Fig. 14. Category II(b) Form – Application of spray-on fireproofing.

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SUMMARY

Floor systems with composite form-reinforced concrete slabs is a rapidly growing and developing method of construction. The utilization of composite action between slabs and supporting beams and girders is expected to increase correspondingly.

Further research and development is necessary to establish commonly accepted design criteria. This would ultimately improve conditions for further development of new concepts.

RÉSUMÉ

Les systèmes de planchers en profilés de béton armé renforcés d'acier en action combinée gagnent rapidement d'importance dans la construction. On peut donc s'attendre que parallèlement à ce développement, on s'intéresse de plus en plus à une action combinée entre le plancher et la structure maîtresse.

Il serait donc nécessaire de pousser les recherches et le développement dans ce domaine, afin d'établir des critères de projection communément admis. Cela permettrait à la suite d'améliorer les conditions pour le développement ultérieur et pour des conceptions nouvelles.

ZUSAMMENFASSUNG

Deckentragwerke (Leichtbleche) im Verbund mit Stahlbetonplatten sind eine rasch wachsende und entwicklungsfähige Konstruktionsmethode. Gleichzeitig wird die Anwendung des Verbundes zwischen Platten und Hauptträgern (Unterzüge) erwartet. Künftige Forschung und Entwicklung wird nötig sein, um allgemein anerkannte Entwurfskriterien zu erhalten. Dies würde die Bedingungen für weitere Entwicklungen verbessern.