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INTRODUCTION

The large scale expansion of the construction industry created the need for more efficient and economical prestressed concrete slabs that were not available.

Hence the creation of a flat slab covering a greater range of spans became apparent due to the fact that the existing solid slabs were not structrully efficient and economical.

The hollow-core slab has come into the industry to fill the void. The hollow-core slab is a flat slab with longitudinal cores running along the span. The structure of hollow-core slab is such that concrete is eliminated from where it is not needed. This results in a much lighter component. According to the shape of the voids dead weight is reduced up to 50 per cent of a solid slab, with equal strength and durability, allowing reduction in size of beams, columns and footings.

Hollow-core slabs have been made for several years. In the early years of their appearance in the industry hollow-core slabs were made by many different systems. Some were produced in fixed forms and some in movable forms. The variations were mostly in the coring system. There have been cores made with round paper tubes, square tubes, plastic tubes and pneumatic inflated tubes.

In reference (1) it is mentioned that one enterprising producer in Florida successfully produced a hollow-core slab by pulling long metal tubes through the forms with a truck in order to slip form the voids of the section.

The success of the industry with the hollow-core slab, convinced a number of people to begin working on automotation.

The result of research and development programs sponsored by precast concrete producers was the development of a machine to produce hollow-core slabs by extrusion. It is believed that Henry Nagy (1) first in 1954, modified a German machine and began producing prestressed hollow-core slabs in United States. These slabs were in the market under the trade name Spancrete.

Today more efficient extruders have been developed, which extrude hollow-core slabs automatically and continuously on long beds.

The hollow-core slabs have found their widest application in building construction. They are compatible with practically any type of framing system: precast bearing walls, masonry bearing walls, precast concrete frame, steel frame and cast-in-place bearing walls (Figs. 1, 2). Cantilevers for balconies or overhangs are easily accomplished. The individual slabs are joined by grouting to form a flat rigid deck. A concrete topping slab may also be poured to connect them.

The cells (voids) can be used as air ducts for heating and cooling and as electrical raceways. The units have satisfactory resistance to sound transmission, heat conductance and fire. The floor finish may be any of the range of finishes normally possible over concrete decks. The smooth undersurface of the slabs may be utilized as a finished ceiling by simply caulking and painting. Other ceiling finishes are easily applied as well.

The adaptability of precast prestressed hollow-core slabs permits their use in a variety of types of low-medium-, and high-rise buildings.

The great flexibility, efficiency and savings offered by hollow-core slabs have made them very popular in Europe, Japan and North America. Spancrete, Span-Deck, Spiroll and Flexicore are a few of the more successful producers of hollow-core slabs in United States and Canada.

CHAPTER 1

TYPES - MANUFACTURING AND ERECTION OF HOLLOW-CORE SLABS

1.1 Types of Hollow-Core Slabs

There are numerous types of precast prestressed hollow-core slabs in the market. The major difference is the shape of voids. The cross sectional dimensions and configuration of shear key also vary among producers.

Voids in the hollow-core slabs may be of circular, oval or rectangular cross section. As a rule these run in the direction of the span. The shape of voids affects the self-weight of the slab. The weight per unit area of a slab with rectangular cells is about 20% less than one with circular cells of identical thickness. For example from PCI Handbook part two pages 2-36 and 2-40, an 8-in.thick "Span-Deck" hollow-core slab (rectangular cavities) weighs 45 pounds per square feet while a "Flexicore" (circular cavities) weighs 57 pounds per square feet. This difference in unit weight saves approximately 27 per cent of concrete per unit area for the slab with rectangular voids.

An example of precast prestressed hollow-core slab with oval voids developed in Poland is shown in Figure 3a.

This slab was designed in two versions:

- Homogenous in MK 250 concrete and
- Two-layer casting with the lower 3 cm consisting of MK 400 concrete and the remainder of MK 200 concrete.

The mean thickness of the slab is 11.6 cm. The reinforcement consists of twin-twisted wires of 2.5 mm diameter. For a slab of 5.90 m × 1.49 × 19cm, the weight of reinforcing steel is only 1.6 kg/m^2 . The above slabs are manufactured on long stressing beds using sliding placing plant.

Several types of hollow-core slabs were developed in the Soviet Union. Figure 3b illustrates one such slab which has oval ducts. This slab is lighter than a similar slab with voids of circular cross section (20% saving in concrete), its production, however, is somewhat more difficult.

The slab with rectangular voids shown in Figure 3c is usually used for roof deck construction. With regard to material requirements, and therefore weight it is significantly more favourable than roof units with circular cavities as mentioned before. These slabs which are produced in the U. S. A. called "Dynacore", carry large superimposed loads and can be constructed for long spans. A section 24-in. deep can span up to 90-ft. Top and bottom flanges are transversely prestressed.

Canada and United States produce hollow-core slabs in a variety of standard sections. Depths range from 4 to 16-in. Widths range from 16 to 96-in. in limited increments depending on the product used. Spans are available for more than 40 feet. These slabs are manufactured by the extrusion process on long beds. Typical 8-in. thick sections are shown in Figure 4.

1.2 Manufacturing

The success of the precast concrete industry with the hollow-core slabs over the last 30 years encouraged the producers to continue their research and development programs for more efficient and economic ways to produce hollow-core slabs. The need for economical manufacturing of hollow-core slabs is so that they can replace the solid slabs which are low cost production.

The most advanced method of making cored slabs is by extrusion in long beds. The extruder is quite expensive, but considering that this method is meant for large-scale manufacturing it is, on the whole, rather economical.

The extruder pours the slabs one on the top of the other up to several layers in the full length of the bed (Fig. 5). In between the pouring of each layer the surface is covered with a bond breaking agent. After release strength is achieved the slabs are cut, with a concrete saw, to specific lengths ordered (Fig. 6a). The slabs are transported to storage for final curing (Fig. 6b).

The extruder extrudes at a rate approximately 3 to 10 linear feet per minute, depending on the machine's capability. Their production capacity is governed by the length and number of casting beds installed. Production also depends upon the curing facilities and on the arrangements made for the supply of the dry concrete mixture for the extruder.

Currently, a new-profile machine (2) is in development by Spancrete to meet the specific needs of small volume producers at a substantial reduction in investment.

1.3 Erection of Hollow-Core Slabs

Erection of hollow-core slabs follows procedures which are generally common in erection of precast concrete panels.

The size of hollow-core slabs is an important disadvantage compared to solid slabs. As mentioned before hollow-core slabs are produced in standard sections. The maximum width in North America is 8-ft. Solid slabs produced in the industry in almost any size. This means more lifting of hollow-core slabs per project is needed. One should taken into consideration the purchase and operation of larger lifting appliances will partly offset solid slab saving.

Another disadvantage of hollow-core slabs is because of unit size the number of joints is increased, increasing the amount of fitting and finishing work.

The cost of processing and erecting hollow-core slabs is greater than that of solid slabs.

1.4 Mechanical Installations

Because of the increased environmental demands, the ratio of costs for mechanical and electrical installations to total building cost has increased substantially in recent years. Precast prestressed hollow-core slab is used in a variety of buildings and its integration with lighting, mechanical plumbing and other services is of importance to the designer. With hollow-core slabs, additional duct work can be eliminated. The voids can provide ducts or raceways for various mechanical and electrical systems (Fig. 27). Large openings for access are usually made by lock-outs in the forms during manufacture. Angle headers are often used for framing (see Fig. 14). Smaller openings (up to about 8-in.) are usually field drilled or cut (Fig. 23).

Integration of mechanical and electrical systems with solid slab assemblies requires additional costs and greater floor or roof thicknesses. One reason is the absence of voids which involves additional work. Another reason to substantiate this is that drilling or cutting field openings in solid slabs is not an easy task.

CHAPTER 2

DESIGN CONSIDERATIONS

2.1 General

In flat slabs the prestressing, if it is economically designed will cause camber of the units. As a result of minor variations in the eccentricity of the tendons and in the quality of the concrete the amount of camber will generally differ a little from one unit to another. This phenomenon may cause particular difficulties in connections with the installation of internal walls, besides presenting awkward irregularities at the joints. Reasonably economical prestressing is possible only with hollow floor units. The solid slab requires a very large prestressing force and therefore a relatively large quantity of prestressing steel.

The small self-weight of the hollow-core slabs compared to solid ones, allows the cored slabs a great span. This greater span, up to 50-ft or more, allows for reduction of supporting elements in a building without increasing elements' size.

The load-span curves shown in Figures 6, 7 show the span and load ranges for various depths of hollow-core available in all areas in the United States and Canada. The loads shown are based on the provisions of the American Concrete Institute building Code (ACI 318-71).

The maximum span to depth ratio shown is 50 and is the recommended maximum for roofs. Ratios above 40 (shaded areas) are not recommended for floors. The curves indicate safe load capacity for a given span and may be used to tentatively select the depth of the hollow-core units. At this stage of the design consult the local hollow-core slab manufacturers as camber and deflection may limit the use of a particular depth unit even though the load carrying capacity is satisfactory.

2.2 Cantilevers

Hollow-core slabs are often used as cantilevers in building construction (Fig. 9). This means negative moment is developed over the support. For a hollow-core slab to be used as a cantilever it must be designed for that use, hollow-core producers have technical data available on the capabilities of their product when used as a cantilever.

For long cantilevers the negative moments on the supports are large enough and negative reinforcement is required. A traditional approach of cantilever slab design is by placing mild steel reinforced bars (Fig. 10). The cores are cut open directly behind the extruder and the bars and concrete are placed shortly thereafter.

Pretentioned strands are sometimes used to improve performance characteristics of cantilever systems. In prestressed cantilever systems the strands are not efficiently used because unnecessary strands are placed where not needed (4). This often necessitates "blocking out" (retarding, taping, etc.) other strand in order to control stresses at the cantilever support or back span. When unstressed strand is provided instead of mild steel bars, the stress factor load should be limited to 6000 psi (5).

It is suggested (5) that service load tension be limited to 100 psi (including prestress) when prestressed strands are used and to the cracking tension ($6\sqrt{f'_c}$) when non prestressed steel is used for negative moment resistance.

2.3 Structural Continuity of Hallow-Core Slab Systems

Heavy loadings or fire considerations require greater flexural capacity than that of the most heavily prestressed section of a given thickness. In such cases negative moment continuity at the support can help.

Tests (6) have indicated that continuity reinforcement placed in the grouted key joints and clamping action of walls provide only limited negative moment continuity.

A sizeable negative moment capacity can be achieved with a composite structural topping reinforced over the supports.

The objective of tests (7), conducted by Rosenthal, was to find an efficient continuous connection for a multispan system of precast prestressed hollow-core slabs without a concrete topping. Continuity was obtained by casting in place the inner support slab zone and filling its voids in the negative moment zone with reinforcing bars (Fig. 11). The tests show that it is advantageous to use continuity in precast prestressed hollow-core slabs without a concrete topping, provided that the cast in place portion over the inner supports is adequately strong. This proposed technique produced a high degree of continuity indicating that the reinforcing bars in the negative region were properly anchored with practically no slippage. In comparison to the simply supported slab, the continuous hollow-core slab tested carried higher loads with proportionately smaller deflections.

Reduction of positive moment can be achieved for superimposed loads after continuity is established. Load due to the self weight of the slab is carried by simply supported spans unless the slabs are shored while continuity is established.

Structural continuity is appropriate for a floor only if it is assembled from small units, as these enable a top reinforcement (continuity reinforcement) to be more easily installed (3).

2.4 Load Distribution - Vertical Loading

Vertical shear is induced in the keyway when adjacent slabs are subjected to different vertical loads e.g., one slab supports a concentrated load such as a partition wall while the adjacent slabs carry only their own weight(Fig. 12). The problem is essentially to deflect the adjoining slab edges thus ensuring participation of such slabs in the structural response. The distribution to adjacent members is achieved by the shear strength of the grouted keys.

Former ACI standard 711-58 (8) permitted distribution of concentrated loads uniformely over three units on each side of the loaded unit but never over a greater total width 0.4 of the clear span distance. Concentrated loads near a support may not distribute in this manner.

B. Lewicki (9) considers that for slabs 1.8 mm wide with keyways completely filled with grout the loaded slab will carry 50% and the adjacent slabs 25% each of the concentrated load (Fig. 13a). When the concentrated load occurs at the joint between two slabs it may be assumed that they share the load equally (Fig. 13b).

Relative considerations are found in Soviet literature. Z. W. Kaplunov has found that when two slabs carry loads differing in their intensity by 400-500 kg/m^2 the shear stresses in the key are of the order of 0.25-0.50 kg/cm^2. A. S. Kalmanok investigated analytically the problem of load distribution by assuming the longitudinal joints to act as hinges. His conclusion was that the linear load due to a partition parallel to the span of the slabs may be considered to be uniformely distributed over a width of the floor equal to the span (9).

Since the width of precast prestressed hollow-core units has greatly increases since the writing of ACI 711-58 provision for "three identical units on each side", it is believed today that it can no longer be applicable. However, it is also believed that a design width of 0.4 of the span is still an adequate conservative provision.

Tests (10) were conducted to demonstrate the ability of grouted shear keys to transfer concentrated loads to adjacent slabs. The results indicate a fairly uniform distribution of the load and that these adjacent slabs can be designed to carry distributed load. Further, the panel width is 0.56 of the clear span, a ratio greater than permitted in ACI 771-58. Therefore the load distribution procedure of ACI 711-58, is a conservative design procedure. In these tests is not anticipated that shrinkage of the grout in the grout key would cause inferior behaviour in comparison with the above results had the test been conducted at a later age. The width of the grout joint at the widest point is only slightly over an inch. Assuming a free shrinkage coefficient of 0.001 in/in this would produce a crack of 0.001 in. which would be of no concern.

In many applications of prestressed concrete hollow-core slabs as floor systems, it is necessary to provide large openings through some units for mechanical and plumbing requirements (Fig. 14). In such a case the design can be accomplished by transferring the load to adjacent full units. Tests (10, 11) have been conducted to assist in verifying such a design approach.

2.5 Diaphragm Action - Horizontal-Loading

Lateral loads from wind or earthquake are usually transmitted to shear walls or moment resisting frames by in plane action of the floor or roof decks. To accomplish this the floor components must be assembled to create a rigid diaphragm in the plane of floor or roof. The rigidity of the diaphragm must be maintained by adequate connections between floor or roof elements.

To assure diaphragm action connections between individual units must be capable of resisting the following stresses (Fig. 15):

a) Compressive and tensile forces at the longitudinal boundaries of the diaphragm,

b) Shear stresses at the transverse boundaries of the diaphragm and,

c) Shear stresses along the longitudinal and transverse edges of the floor planks

Because of the size of the diaphragm, the anticipated stresses are necessarily small.

It is apparent that the shear in the rigid diaphragm acting as a deep beam must be transferred between adjacent members and also to the supporting elements. The "web" shear must also be transferred to the cord elements. Thus the design of diaphragm is essentially a connection design problem.

The shear transfer between hollow-core slabs is usually accomplished by grout keys. A conservative value of 40 psi (5) can be used for the average design strength of the grout key. If necessary, reinforcement placed as shown in Figure 16 can be used to transfer the shear. This steel may be designed by the shear friction analysis. Mechanical ties between hollow-core slabs, in the grout key, help in transferring shear, and, greatly, improve the rigitidy of the diaphragm. This type of joint is not necessary under normal conditions but may be advisable in areas where there is a possibility of mining subsidense or earth tremors.

Transfer of shear from the diaphragm to the supporting elements can be achieved with connections which are analysed in the same manner as the connections between slab units. For floors or roofs with intermediate supports as shown in Figure 15, the shear stress is carried across the support with bars in grout keys as shown in section A-A. Bars are designed by shear friction. Stresses are usually quite low and only as many bars as required should be used.

Concrete topping, bonded to hollow-core slabs may serve as a diaphragm connection. Reinforcement requirements may be determined by shear friction analysis.

CHAPTER 3

CONNECTIONS

3.1 Longitudinal Connection between Floor Elements

This connection which occurs at adjacent vertical faces of individual floor elements, in the span direction, is usually termed a "shear key".

The space between the longitudinal edges of the adjoining panels is filled with grout not necessarily the same strength as the panels. Near the panel supports this joint also accomodates the longitudinal ties as discussed in section 2.5.

The joints introduce discontinuities which can adversely affect the floor's overall performance. To minimize such effects the horizontal connection of shear key must resist with minimal deformation the following (Fig. 17):

V_v = vertical(out of plane)shear induced form adjoining floor/ roof elements subject to varying superimposed loads;

V_n = horizontal (in place) shear resulting from the floor's diaphragm action; and

H = normal force (tensile or compressive) resulting from the floors diaphragm action.

The ability of shear key in transferring the vertical shear was investigated in load distribution tests (11) on an assembly of hollow-core slabs. Two principal findings of these tests were:

1) The shear keys were effective in providing load transfer up to ultimate flexural failure. Concrete topping or mechanical ties are apparently not required for this action.

2) The successful performance of the shear keys took place without the presence of end anchorages to resist lateral forces.

Other tests (10) show that the ultimate vertical shear stress of the grouted keys is approximately $3\sqrt{f'_c}$. Although shrinkage of the grout in the key can produce a crack of 0.001-in. (.03 mm), such a crack width is too small to affect the joint's shear capacity.

Grouted keys, as mentioned above, also transfer diaphragm shear. A conservative value of 40 psi (5) can be used for the average design strength of the grouted key. If necessary reinforcement can be placed along the key. This steel may be designed by shear friction analysis. Reference 15 contains numerical examples for designing shear transfer reinforcement induced by diaphragm action of the hollow-core slab roof or floor assembly.

In addition to grouted keys, mechanical ties can be used to transfer diaphragm shear along the keys. Their application is sometimes necessary, mostly in structures constructed in seismic zones. Special shear connector as the one shown in Figure 18a was developed by "Span-Deck" hollow-core slab rpducers. According to manufacturer specifications each connector shall have an allowable load of 2200 pounds. No increase shall be allowed for load duration or seismic or wind loads.

In Figure 18b another type of mechanical tie connection is shown, developed by "Spiroll" hollow-core slab producers. Provisions have been made in the extruding equipment to embend transverse reinforcing bars in the top of the slab when required for diaphragm action or other uses. These bars are 1/8-in. by 1½-in. flat A_{36} steel-straps with 1-in. minimum coverage and at on 8-feet 0-inch on center maximum spacing. The ends of the bar straps are exposed by scraping the fresh concrete away immediately after the slabs are extruded to permit installation of 3/16-inch by 1-inch A_{36} flat steel splice bars joining the two adjacent slabs. The splice bars are welded in the field to each transverse bar strap with 1/8-inch by 1½-inch fillet weld.

At Frankon, a precast prestressed concrete producer in Montreal, the extruder lays wire mesh, in the top of the slab, extending across both sides. When erecting, the extending wire mesh of two adjacent slabs are connected to each other improving the rigidity of the diaphragm.

According to PCI Design Handbook the design strength of the shear key should be tested by:

$$\frac{V_{uh}}{\phi V_{nh}} + \frac{V_{uv}}{\phi V_{nv}} \leq 1$$

where:

V_{uh}, V_{uv} = applied factored loads in the horizontal and vertical directions, respectively.

V_{nh}, V_{nv} = nominal strength of the connection in the horizontal and vertical directions, respectively

ϕ = undercapacity factor (0.85 in this case)

3.2 Slab-to-Beam Connection

The design of all slab-to-beam connections whether for floors or roofs, should consider the effects of volume changes and the transfer of horizontal forces form the slab to the beam when the floor or roof is assumed to act as a diaphragm. Movements at the connection between roof slabs and beams may damage the roofing thus special expansion detail should be considered. On floors with cast-in-place topping additional mesh or reinforcement should be placed across the beam to minimize cracking.

The detail in Figure 19a shows one way to develop diaphragm action at a beam in a hollow-core roof system if friction is not sufficient to transfer the lateral forces and thus a positive connection is required. Plates are cast into the upper portion of the ledger beam and welded deformed stud bars extend into the grouted joint between slabs. Erection considerations may dictate a different detail such as having the beam top lower than the tops of the slabs to allow for placement of continuous reinforcing bars in slab keyways (Fig. 19b).

Details should be limited to those recommended by the local producers as long as they are consistent with the design requirements. Floors with topping usually do not require any additional connection to the beam.

Connection details of hollow-core slabs on steel beams is explained in Figure 20.

3.3 Slab-to-Masonry Wall Connection

The detail shown in Figure 21a is a typical installation of hollow-core slabs on masonry walls. A bond beam is provided directly under the slabs and the joint between the ends of slabs is grouted full. In multi-story construction it is necessary to insure that the ends of the slabs can transmit the vertical compressive forces. A joint with 8-in. plank ends without concrete fill has an ultimate bearing capacity of 100 kips per linear feet with continuous bearing strips. This is the result of tests conducted by Spancrete. In multibay construction consideration must be given to the forces developed due to restraint of volume changes.

Positive anchorage of the hollow-core units to the wall can be accomplished by inserting hair pin bars into the bond beam and embending them into the grout closure between the slab ends (Fig. 21b). If required, L-shaped bars are cast into the bond beam and into mortar filled cores of the block as shown in Figure 21b in order to transfer forces into the wall. For positive roof diaphragm action, or when topping is not used on floors a reinforcing bar can be grouted into the keyways between hollow-core slabs. This reinforcing steel can be designed by shear friction approach. This bar also serves to tie the slabs together preventing roofing problems at the joint.

In most designs some degree of continuity is required at the slab-to-wall connection. However, a fully fixed connection is generally not desirable and this is prevented by the use of bearing pads.

3.4 Slab-to-Precast Bearing Wall Connection

Various details are currently in use for this connection. Most widely used among these is the "platform" connection (also known as the "closed" or "American" type connection) shown in Figure 22a.

In the typical "American" connection, the prestressed hollow-core slabs extend over wall panels and are continuously supported on bearing pads. Cast-in-place grout fills the vertical space between floor planks and usually a portion of the hollow cores of the plank itself. In latter case paper or plastic dams are inserted into the cores to limit the extend of core-filling.

This grout usually has strength and elastic characteristics somewhat different from the wall or floor panel. Space between the top of the planks and bottom face of the wall is dry-packed with mortar, usually of strength equal to or greater than that of the wall panel. Other connection details of hollow-core slabs on precast bearing wall are also shown in Figures 22b, c, d.

CHAPTER 4

ACOUSTICAL, THERMAL AND FIRE RESISTIVE PROPERTIES

4.1 Acoustical Properties

In order to understand acoustical design standards and how a hollow-core slab can be used to achieve a high level of performance, it is first necessary to be familiar with the basic acoustical properties and how they are measured. One important parameter which is the basis for measuring the resistance of a material or system to sound transmission is the STC rating. This (STC) stands for Sound Transmission Class which is a measure (in decibels) of the ease at which air-borne sound is transmitted through a floor system. The larger the value of the STC for a given system, the greater the sound insulation. The STC "rating" is an average value in the frequency range for audible sounds.

The unit weight of the slab affects considerably the Sound Transmission Class of a slab. For sections of similar design, but different weights, the STC increases approximately 6 units for each doubling of weight as shown in Figure 23. From this we can easily conclude that a solid and a hollow-core slab designed for the same conditions possess different STC rating with solid slab being superior. Acoustical test data of hollow-core and solid slabs are shown in Figure 24.

Another parameter which must be accomodated in a proper acoustical design is the resistance to impact noise transmission. This parameter is measured by the Impact Insulation Class (IIC). The IIC classification is a recent term and replaces the now obsolete INR (Impact Noise Rating) term.

The IIC ratings of hollow-core slabs are inferior of solid ones. This can be visualized by comparing tests data as given in Figure 25.

A great improvement of hollow-core slabs IIC rating is achieved with the use of carpet and pad (Fig. 25). As it is shown in this figure the IIC rating of an 8-inch bar hollow-core slab is 28 and with carpet and pad reaches a considerably high value of 73.

It must be emphasized that to properly develop an acoustically adequate system both air-borne sound (STC) and impact noise (IIC) must be considered. To provide only one aspect is not satisfactory and will certainly lead to problems. For design purposes the engineer has to contact the local producer for available acoustical ratings of its product.

4.2 Thermal Properties

To determine the heat loss and heat gain in a building structure the thermal properties of each component have to be known.

An important property is thermal conductance. This is defined as the time rate of heat flow expressed in Btu per (hr) (sq.ft.) (deg. F average temperature difference between two surfaces). The reciprocal of conductance called thermal resistance and is denoted by R.

Table 1 gives the thermal properties of various weight concretes,

Description	Concrete Weight, pcf	Thick-ness, in.	Resistance, R	
			Per Inch of thick-ness, 1/k	For thick-ness shown, 1/C
Concretes including normal weight, lightweight and lightweight insulating concretes	145		0.075	
	140		0.083	
	130		0.11	
	120		0.14	
	110		0.19	
	100		0.24	
	90		0.30	
	80		0.37	
	70		0.45	
	60		0.52	
	50		0.67	
	40		0.83	
	30		1.00	
	20		1.43	
Normal weight tees[2] and solid slabs	145	2		0.15
		3		0.23
		4		0.30
		5		0.38
		6		0.45
		8		0 60
Normal weight hollow core slabs	145	6		1.07
		8		1.34
		10		1.7[illegible]
		12		1.91
Structural lightweight tees[2] and solid slabs	110	2		0.38
		3		0.57
		4		0.76
		5		0.95
		6		1.14
		8		1.52
Structural lightweight hollow core slabs	110	8		2.00
		12		2.59

1) Based on normally dry concrete

2) Thickness for tees is thickness of slab portion including topping, if used. The effect of the stems generally is not significant, therefore, their thickness and surface area may be disregarded.

Table 1. Thermal Properties of Concrete (Ref. 5).

including insulating concretes. It also gives the R-values of some of the commonly used prestressed concrete floor roof and wall units.

Elaborating on the R-values of hollow-core and solid slabs the superiority of cored ones for any quality of concrete is coming out. This superiority is attributed to the air space in cores which air space possesses a large thermal resistance R.

The thermal resistance of a hollow-core slab is improved considerably by filling up the cores with some insulating material (16). For example a 6-inch hollow-core slab of normal weight concrete, and with filled cores has an R-value increased by 74 per cent of a cored slab without insulation filled cores.

4.3 Fire Resistance

To insure that fire resistance requirements are satisfied the engineer can use tabulated information provided by various authoritative bodies. In the United States and Canada, Underwriter Laboratories Fire Resistance Directory alone provides information on more than 120 assemblies incorporating precast prestressed concrete members. This information is based on the results of standard fire tests on various assemblies.

In the absence of tabulated data the fire resistance of precast prestressed concrete hollow-core slab assemblies can be determined in most cases by calculation. These calculations are based on engineering principles and take into account the conditions of a standard fire test. This is known as the Rational Design Method of determining fire resistance.

It is based on extensive research sponsored in part by the Prestressed Concrete Institute and conducted by the Portland Cement Association and other laboratories. For examples, design charts and a complete explanation of the method in order to calculate the fire resistance of hollow-core slab assemblies refer to reference 17.

4.3.1 Fire Endurance-Fire Ratings

The fire resistance of an assembly is measured by its fire endurance defined as the period of the time elapsed before a prescribed condition of failure or end point is reached during a standard fire test. According to ASTM E119-76 an end point is reached when the temperature of the unexposed surface of a floor or roof does not exceed an average of 250° F or a maximum of 325° F at any point (heat transmission end point).

The fire endurance as determined by the criteria for temperature rise of the unexposed surface heat transmission) depends primarily on the slab thickness and aggregate type (Fig. 26). For a hollow-core slab this thickness may be obtained by dividing the net area by its width. Then it is obvious for the same fire endurance the depth of a hollow-core slab required is more than that for a solid one.

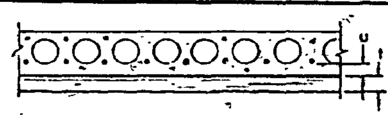
Hollow-core slab producers have available data concerning the fire endurance of their product. The fire endurance rating has been assigned to these proprietary products after tests carried out by authoritative laboratories and according to the local or national standards. Table 2 shows fire resistive ratings for "Span-Deck" hollow-core slabs. These tests have been performed by Underwriters Laboratories Inc., and sponsored by Span Deck manufacturers.

The effect of spray-applied insulation on hollow-core slabs was investigated in tests (18) conducted by Abrams and Gustaferro. The results are shown in Table 3. This table gives the thicknesses of coating materials required in conjuction with 3/4 and 1-inch of concrete cover for unrestrained conditions and for fire endurances of 2 and 3 hours. Table is based on siliceous aggregate concrete and is therefore conservative for lightweight and carbonate aggregate concrete.

Abrams (19), also performed fire tests on hollow-core specimens with and without roof insulation in order to determine the effect of insulation on the temperature of the strand. The results indicate that strand temperatures were not signifcantly affected by the presence of the roof insulation.

THICKNESS OF SPAN-DECK (Unit Inches)	TOPPING REQUIRED (Inches)	TIME PERIOD RATING (Hours)	CONCRETE COVER ON STRAND FOR (INCHES) AGGREGATE GRADE A, B AND LIGHTWEIGHT (LW)					
			Exposed Soffit			½-Inch Vermiculite "MK" on Soffit under Span-Deck		
			"B"	"A"	"LW"	"B"	"A"	"LW"
6 8 10 12	None	1	1¼	1	¾			
8 10 12	None	2	1⅞	1½	1⅛	1¼	1	¾
8 10 12	None	3				1⅞	1½	1⅛
8 10 12	2	3	2½	2	1½			
8 10 12	2	4			2			1½

Table 2. Fire-Resistive Ratings for "Span-Deck" Hollow-Core Slabs (Ref. 14)



Fire endurance, hr.	2		3	
Concrete cover, u, in.	3/4	1	3/4	1
Vermiculite, Type MK, t, in. Sprayed mineral fiber, t, in. Intumescent mastic, t, in.	1/4 5/16 3/16	3/16 1/4 3/16	7/16 1/2 —	3/8 7/16 —

Table 3. Thickness of Sprayed coatings for 2 - and 3-hr Fire endurance (Ref. 18)

CONCLUSION

During the last 25 years, tremendous progress has been achieved in the field of industrial production and utilization of precast prestressed hollow-core slabs. Their widest application has been in the building construction industry, especially in the residential sector.

The importance of manufacturing hollow-core slabs at an acceptable cost in comparison to that of solid slabs has paved the way to advanced technology. Today mass production, automotation and production scheduling are considered the most important factors in reducing hollow-core slab production cost.

Although hollow-core slabs cost more than solid slabs to be manufactured, however the overall cost is less, because their reduced weight and their structural efficiency helps in two ways:

1) allows hollow-core slabs to span greater range, thus reducing the number of supports, and
2) the supporting structure is lighter due to reduced weight of the slab as much as 50 per cent.

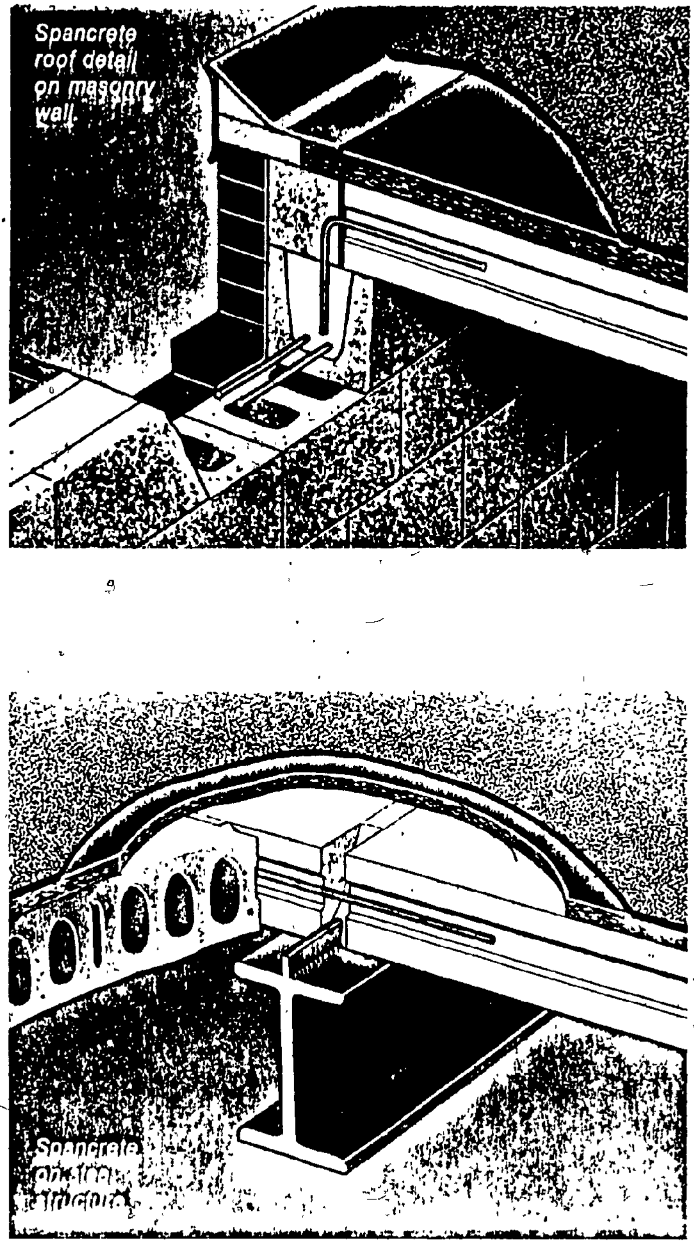
Sound proofing which depends on concrete's unit weight gives a superiority to solid slab. An acceptable alternative when using hollow-core slabs is inexpensive flooring or a pad carpet. This increases the air-borne and impact noise resistance considerably.

Thermal properties of cored slabs are outstanding. Today this is an important fact because of the great concern for the conservation of energy.

Fire resistance of solid slabs is superiror to cored slabs. The fire endurance rating of cored slabs is high enough to satisfy the most of the local and national codes.

Today precast prestressed concrete hollow-core slabs are used the most for flat slabs needed in building construction in Europe and North America.

FIGURES



(a)

(b)

Figure 1. Hollow-Core Slabs on (a) Masonry bearing wall and (b) Steel beam, framing systems. (Ref. 2).

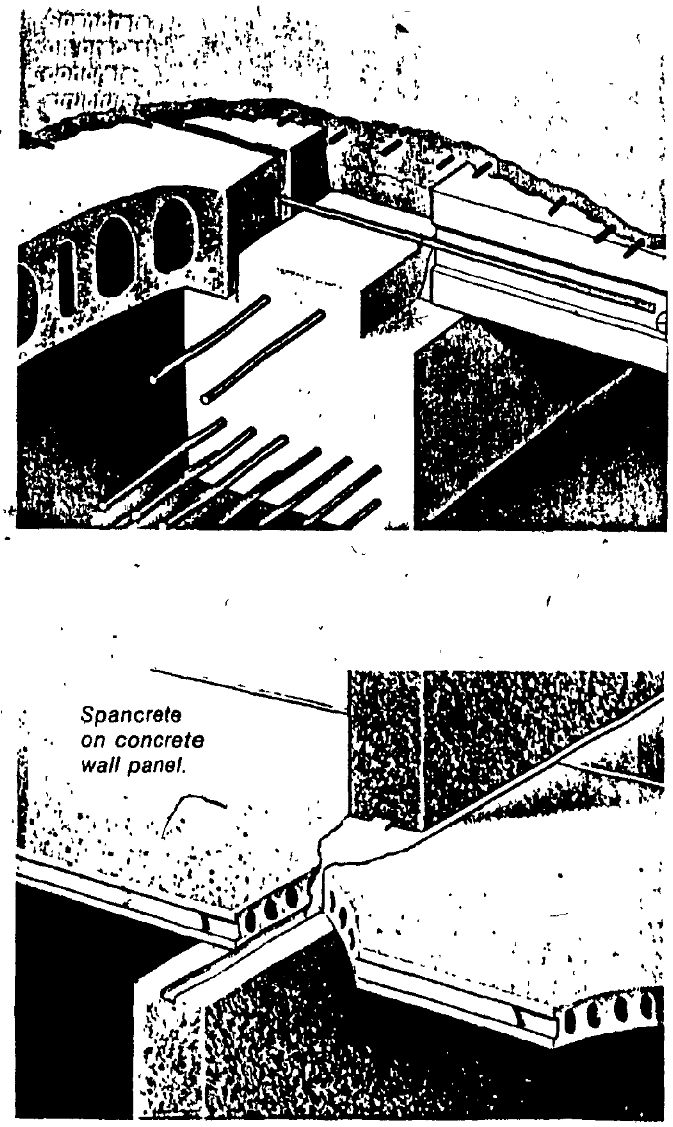
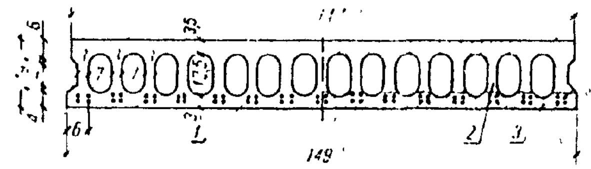
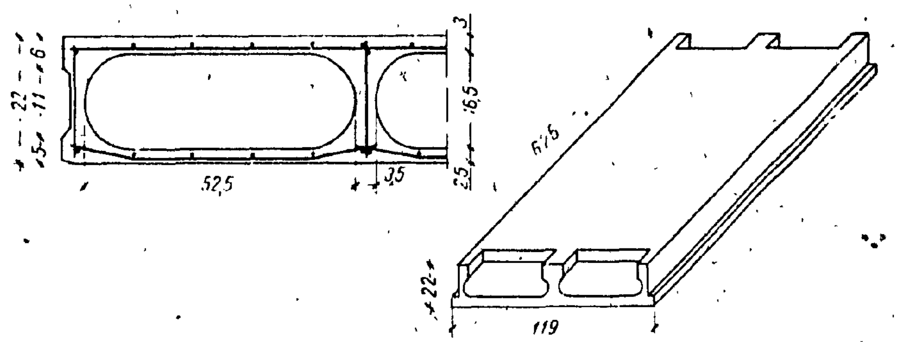


Figure 2. Hollow-Core Slabs on (a) Precast concrete beam and (b) Concrete wall panel, framing systems. (ref. 2)



(a)



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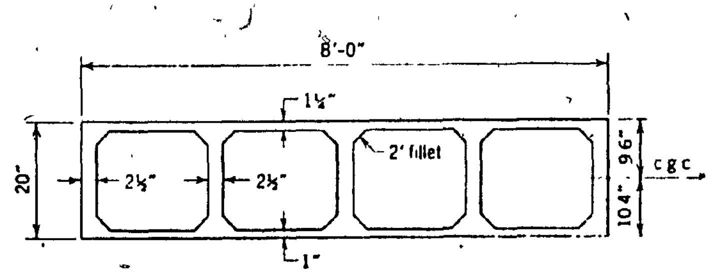


(c)

Dynacore

Figure 3. Types of Hollow-Core Slabs Developed in (a) Poland, (b) Soviet Union and (c) United States.

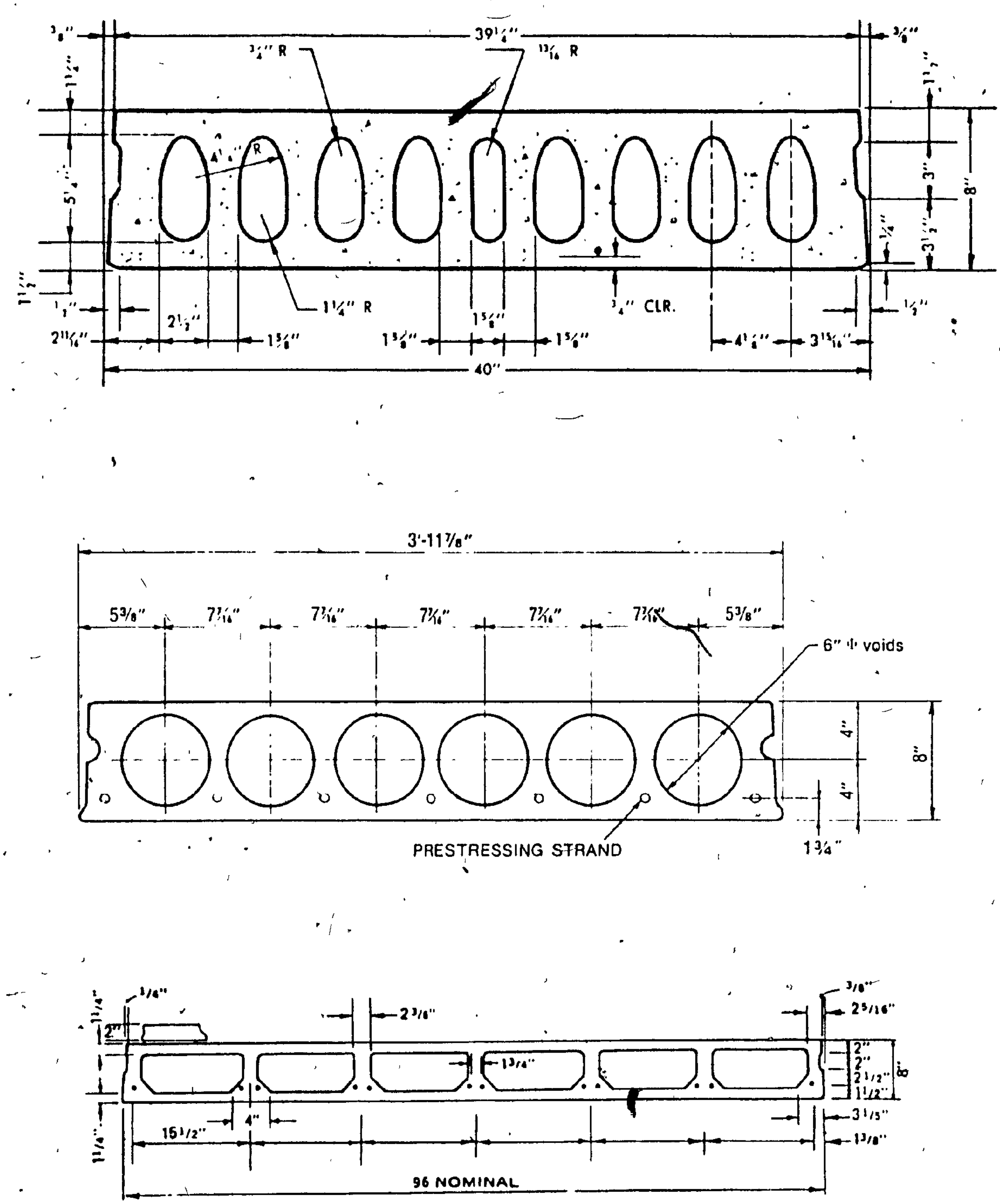


Figure 4. Typical Hollow-Core Slabs widely Used today in United States and Canada.

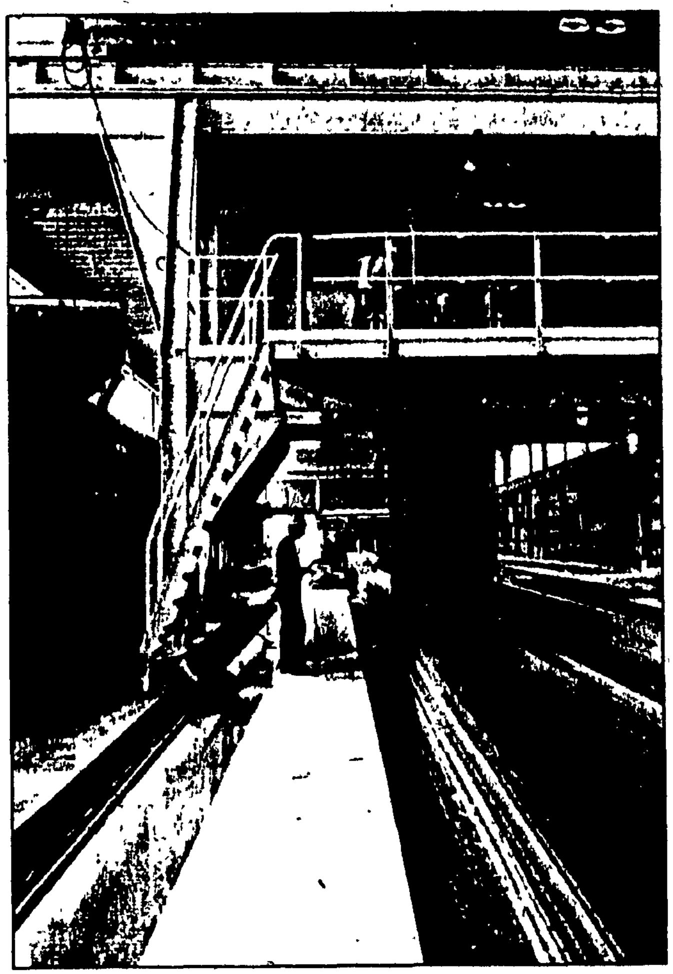
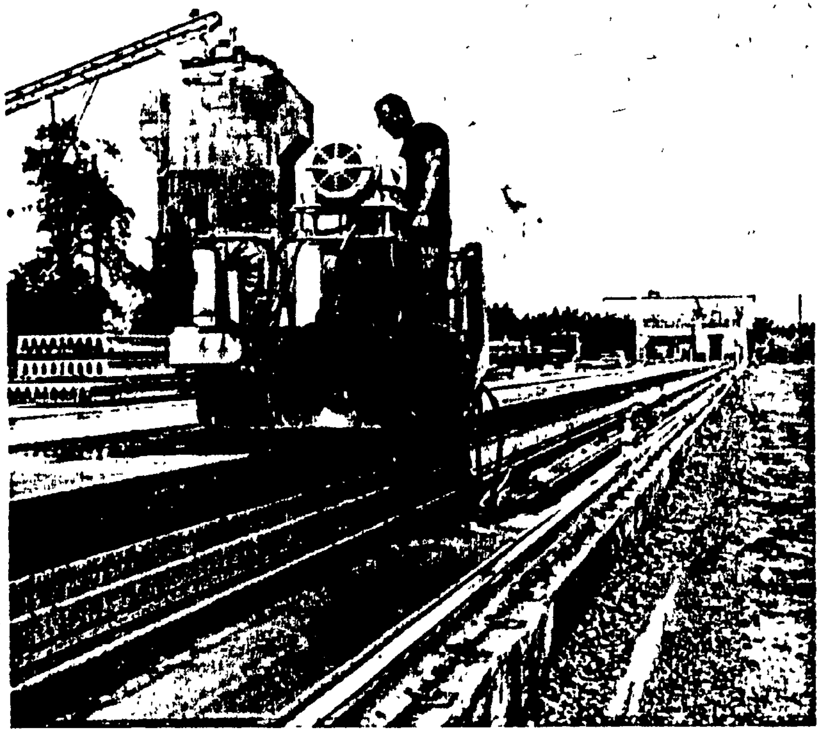
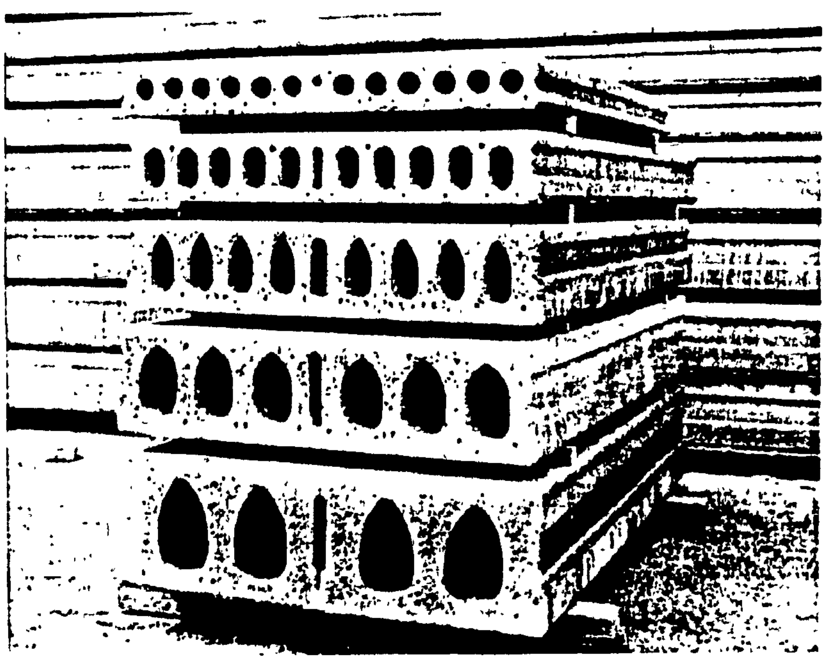


Figure 5. Extrusion of Hollow-Core Slabs on Long Bed (Ref. 2).

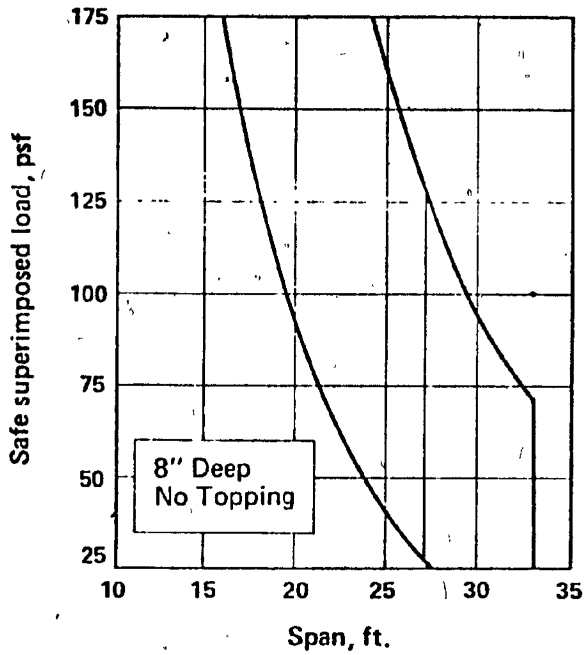


(a)



(b)

Figure 6. (a) Slabs are sawed to Length
(b) Stacked Products after Extrusion
(Ref. 2)



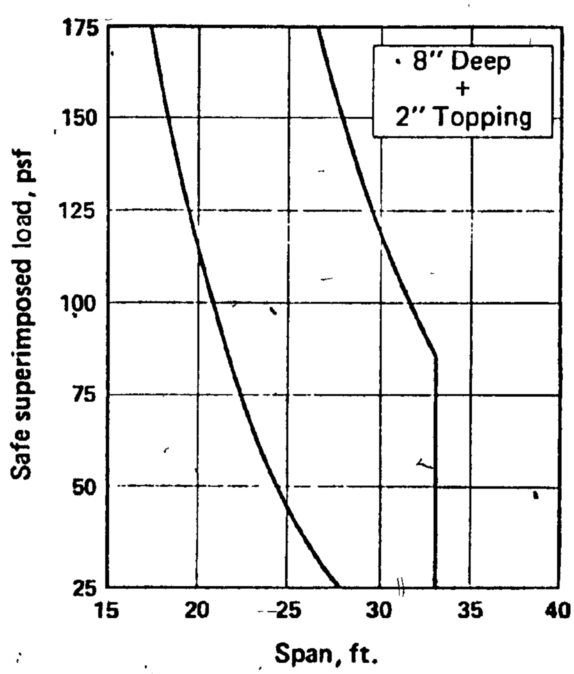


Figure 7. Safe superimposed load for Various Span Ranges of 8-in Deep Hollow-Core Slabs.
(Ref. 5).

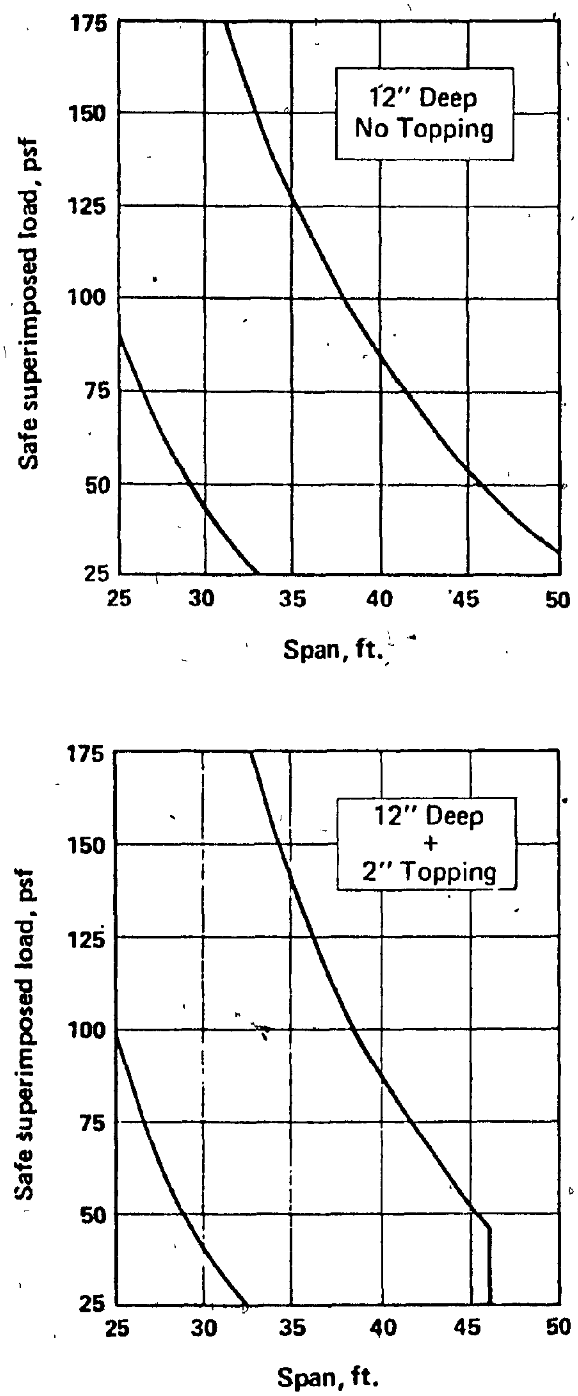


Figure 8. Safe Superimposed Load for Various span Ranges of 12-in. Deep, Hollow-Core Slabs. (Ref. 5).

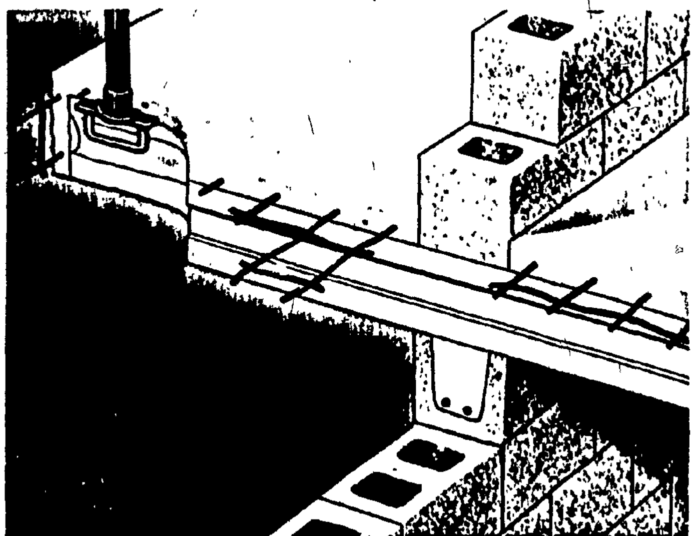


Figure 9. Hollow-Core Slabs Cantilever (Ref. 2)

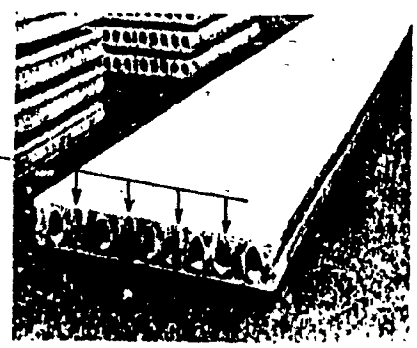


Figure 10. Cantilever End of Hollow-Core Slab is Reinforced with Mild Steel Bars concreted into four cores.

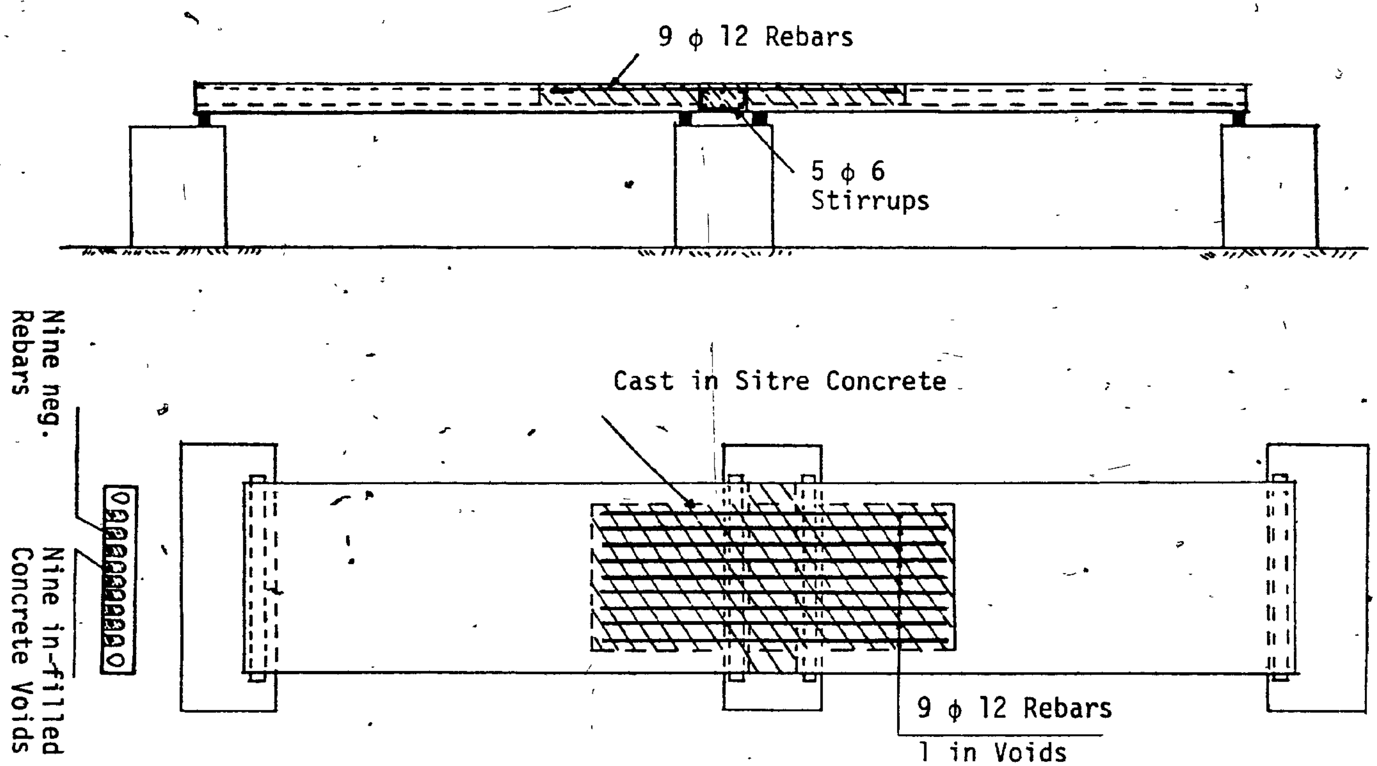


Figure 11. Test Set Up of Continuous Hollow-Core Slab Showing Location of Reinforcement. (Ref. 7).

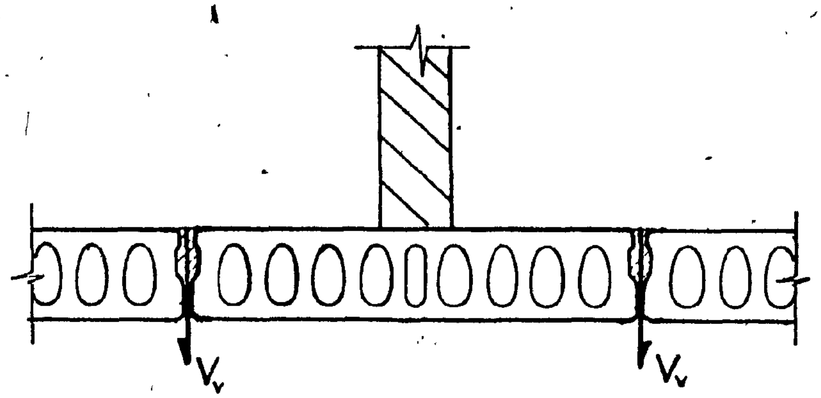


Figure 12. Partition Wall on Hollow-Core Slab Floor Deck.

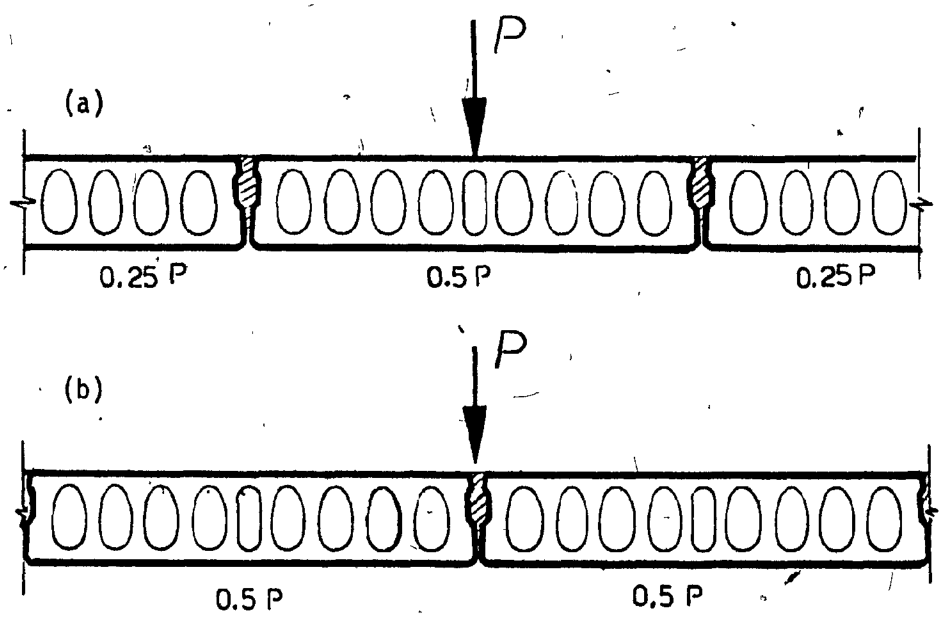


Figure 13. Distribution of the Concentrated Load between Neighbouring Slabs:
(a) Concentrated Load at Mid-Width of Slab,
(b) Load near the joint Between the Slabs.
(Ref. 9).

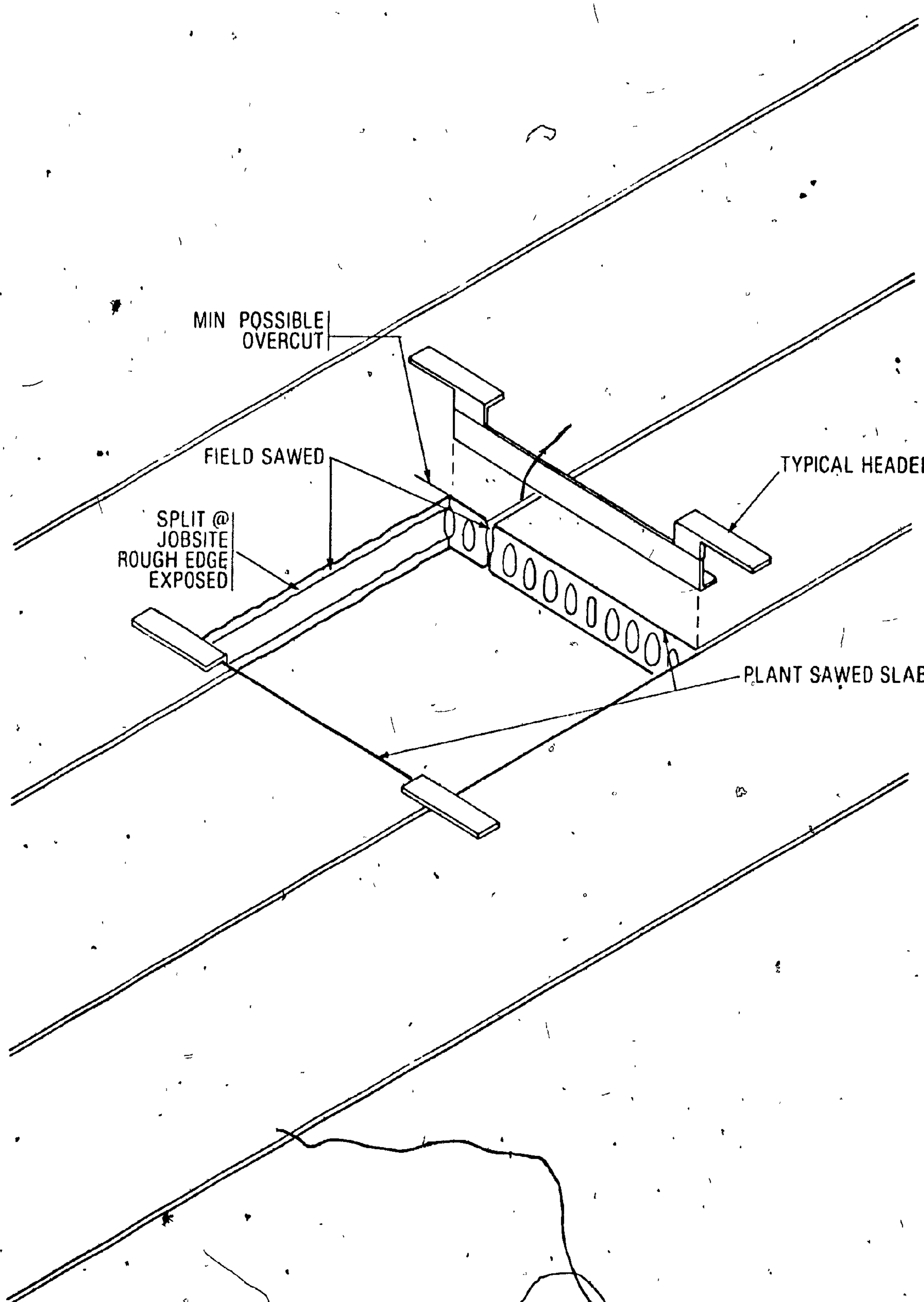


Figure 14. Opening in Hollow-Core Slab Deck.
(Ref. 2)

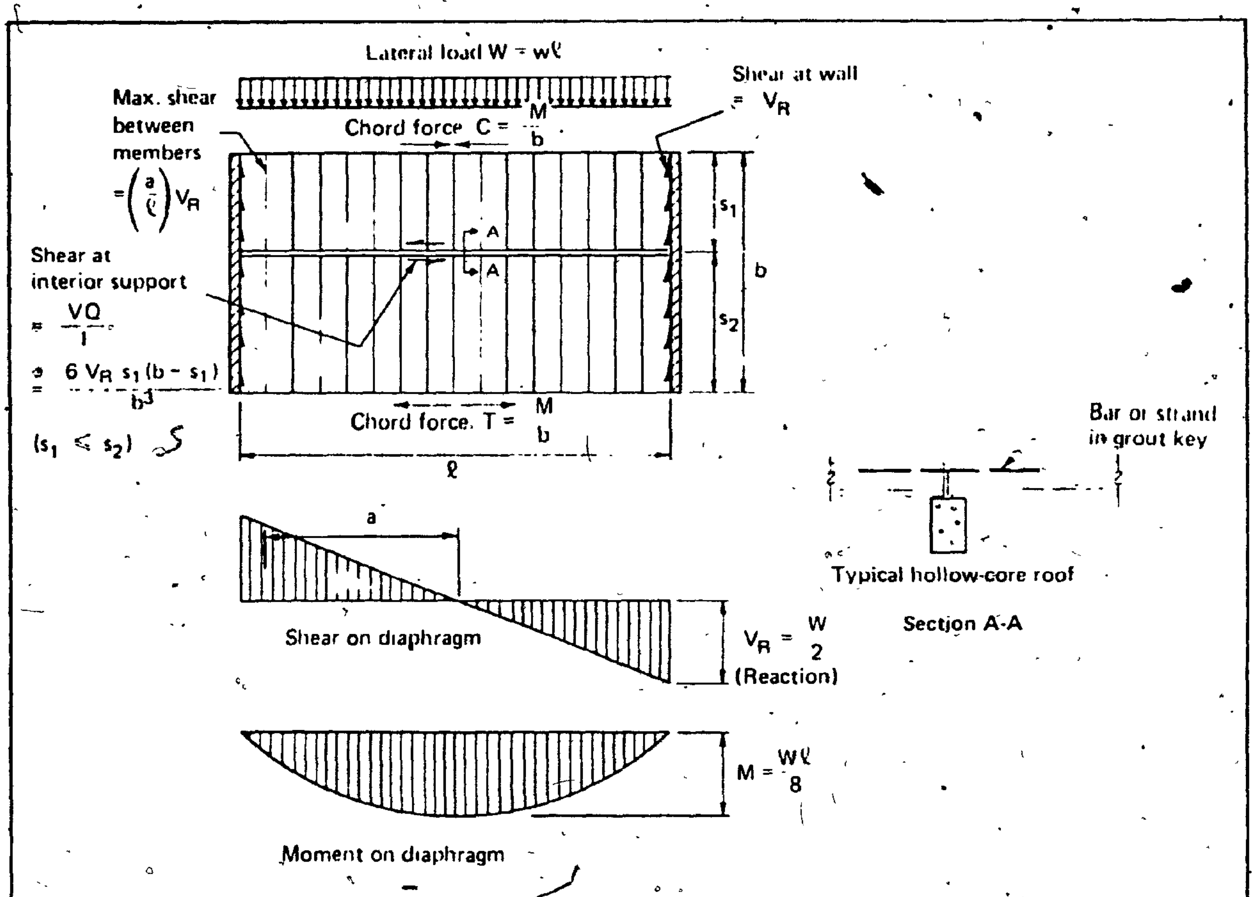


Figure 15. Analogous Beam Design of a Diaphragm (Ref. 5).

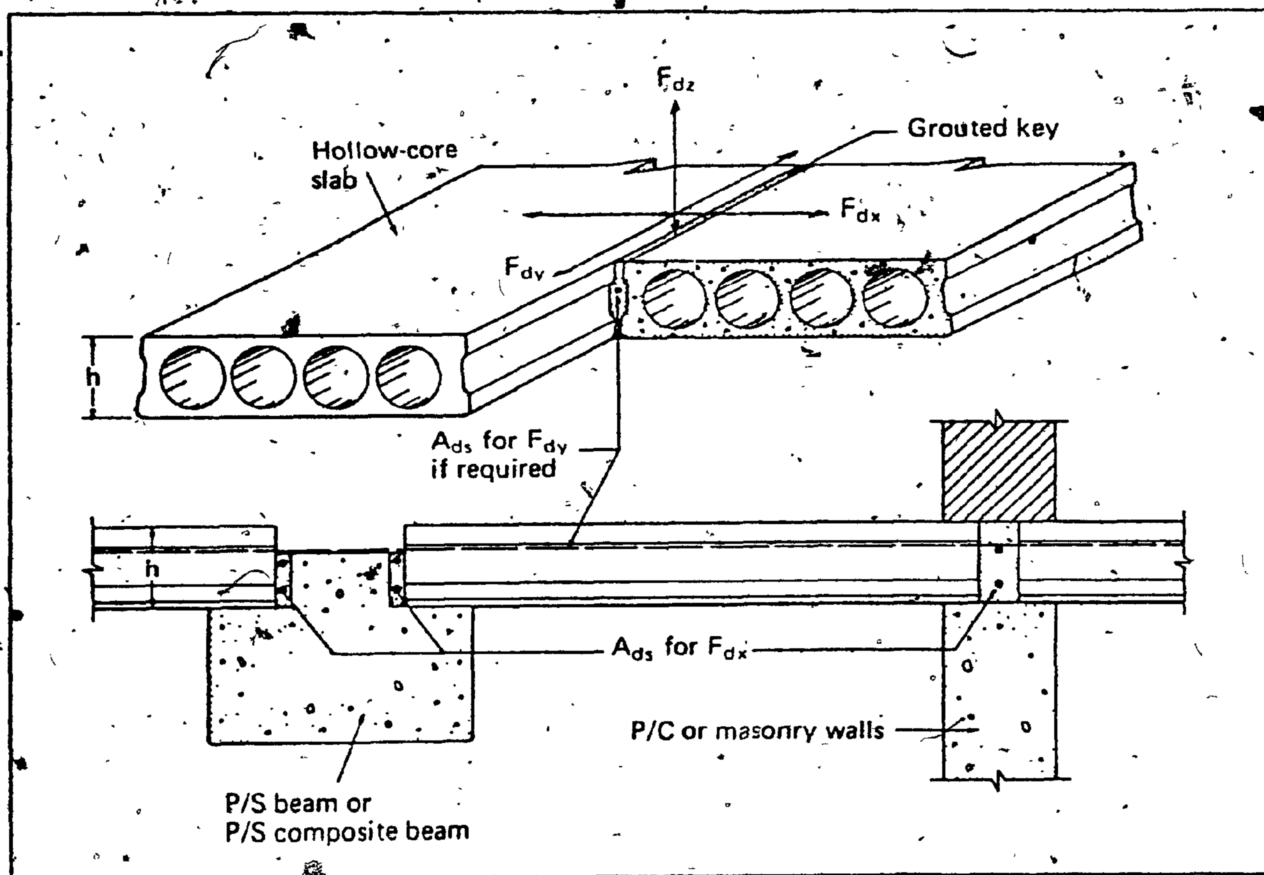


Figure 16. Diaphragm Shear with Grouted Keyways.

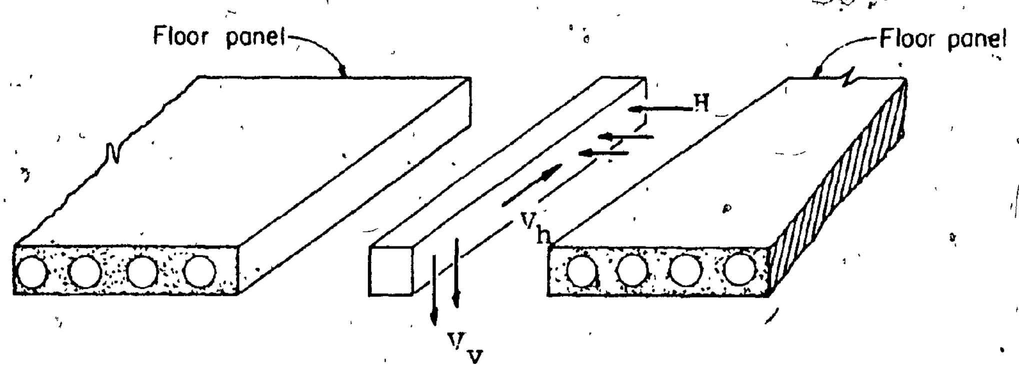


Figure 17. Exploded View of the Horizontal Connection between Floor Panels and the Various Connection Forces.

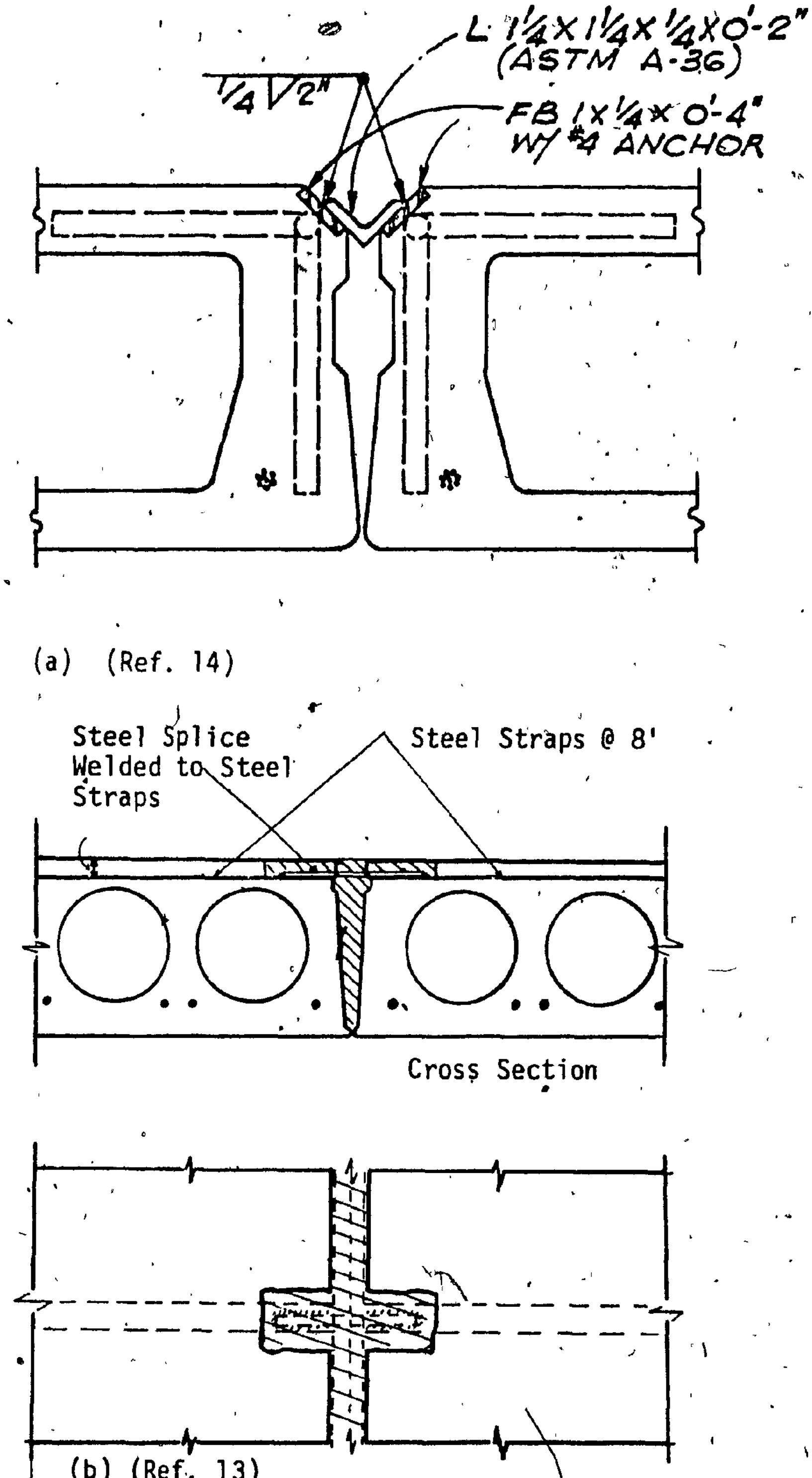
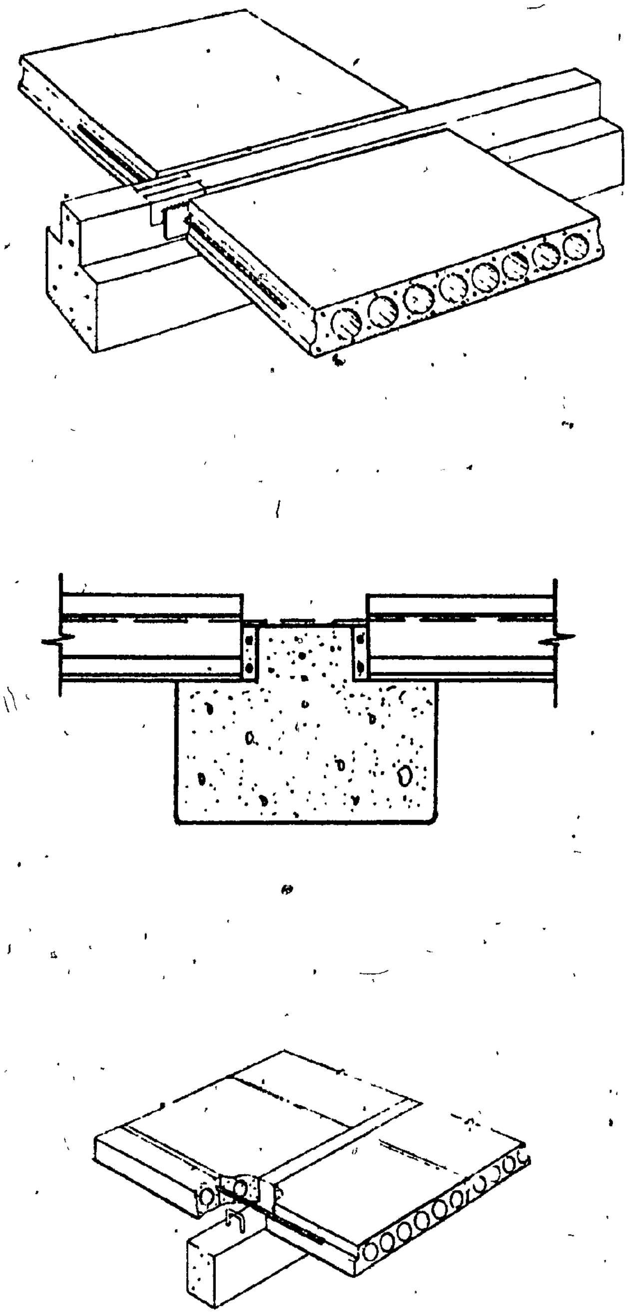


Figure 18. Welded Tie Connections between Adjacent Slabs.



(a)

(b)

(c)

Figure 19. Hollow-Core Slab-To Concre Beam Connections. (Ref. 15).

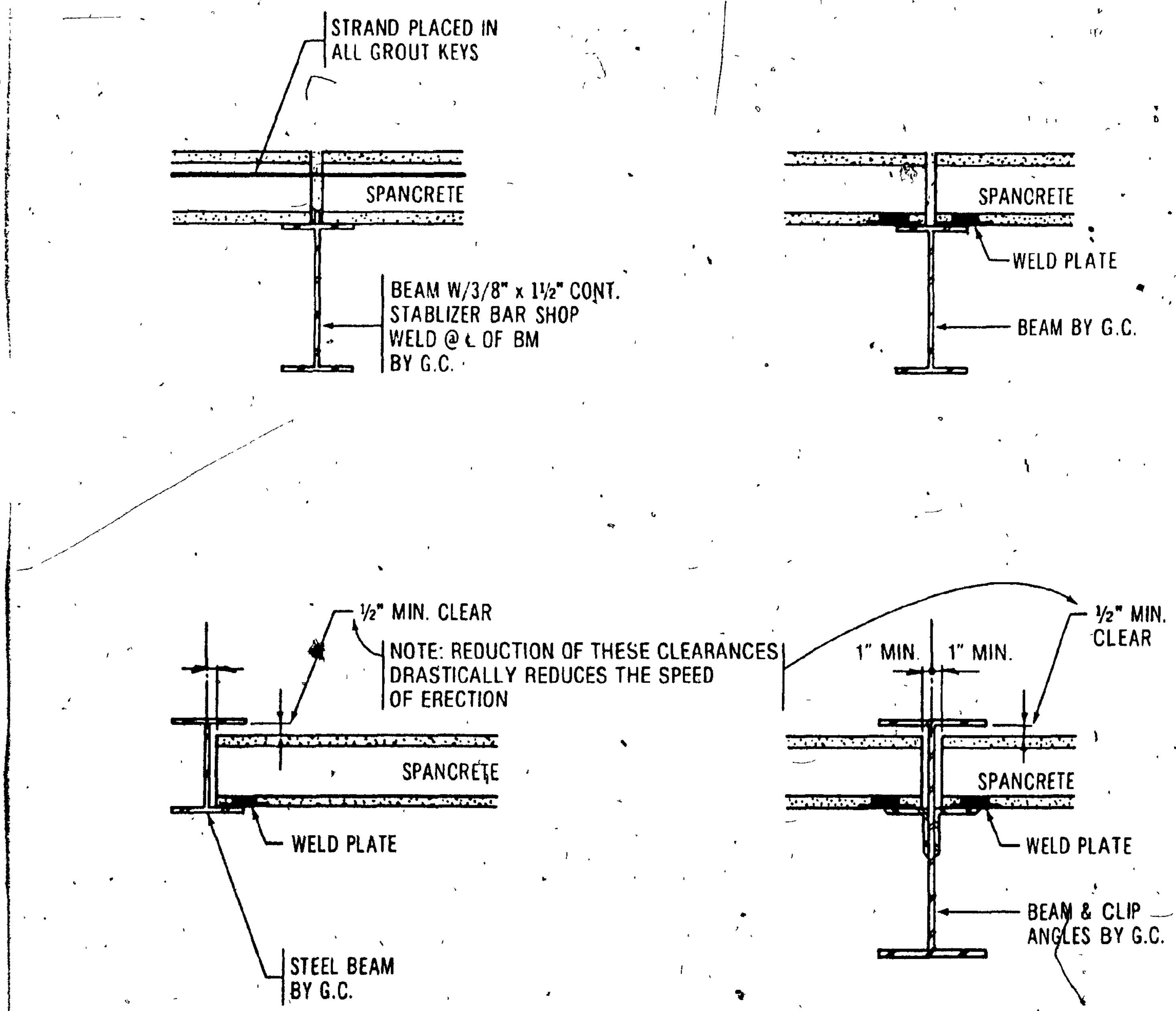
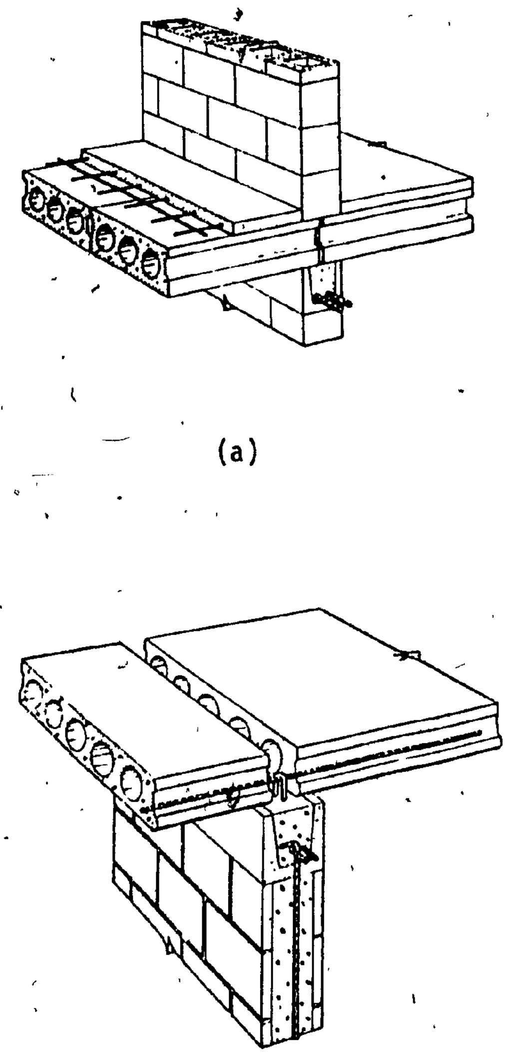


Figure 20. Connection Details of Hollow-Core Slabs on Steel Beam (Ref. 2)



(a)

(b)

Figure 21. Hollow-Core Slab-To-Masonry Wall Connections. (Ref. 15).

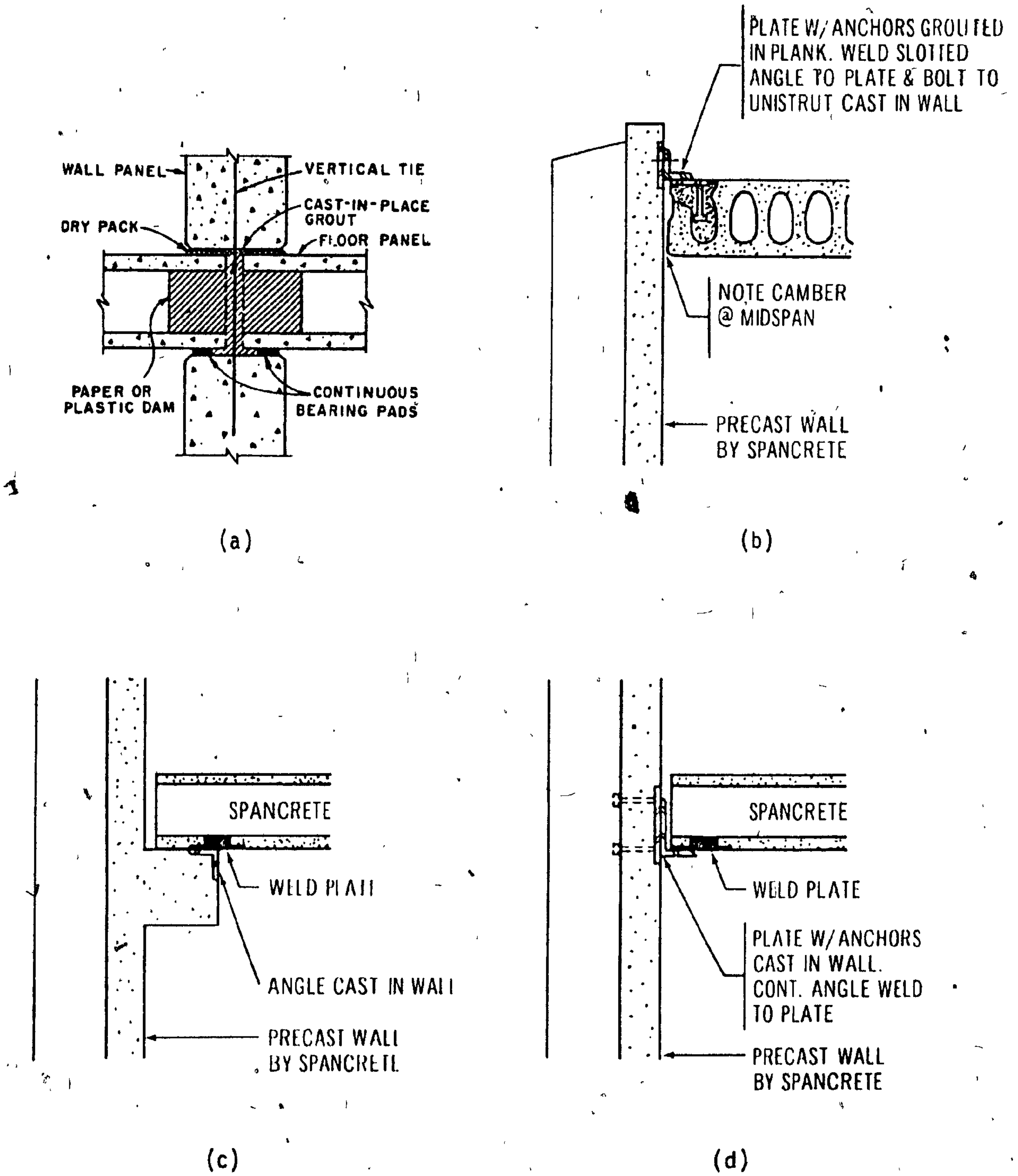


Figure 22. Connection Details of Hollow-Core Slab on Precast Concrete Bearing Wall.
(Ref. 2).

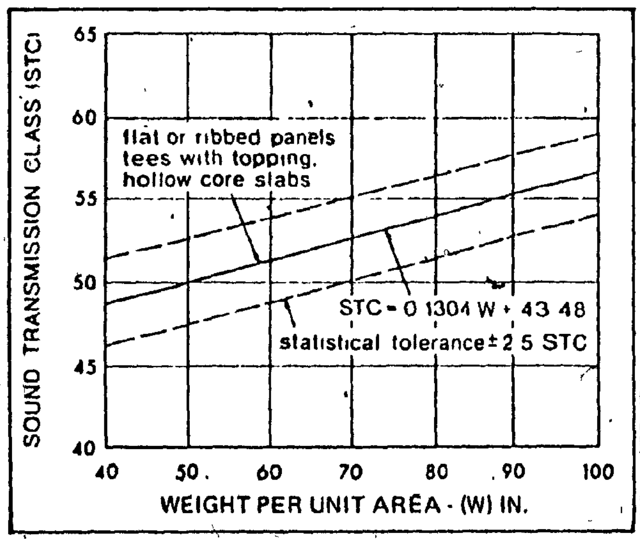


Figure 23. Sound Transmission Class as a Function of Weight of Floor or Wall.
(Ref. 25).

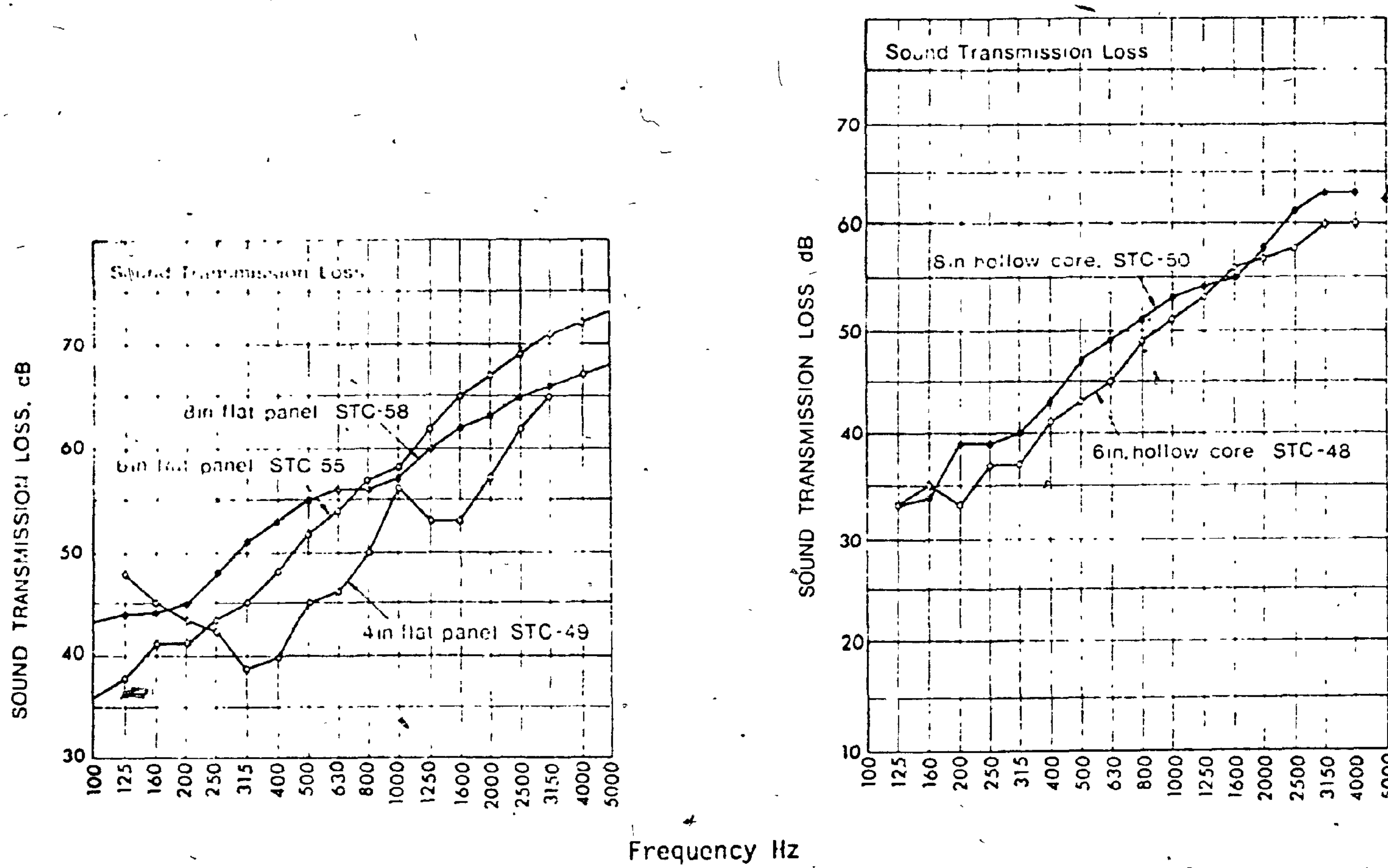


Figure 24. Sound Transmission Loss Data of (a) Solid Flat and (b) Hollow-Core, Concrete Panels, of Normal Weight Concrete. (Ref. 5).

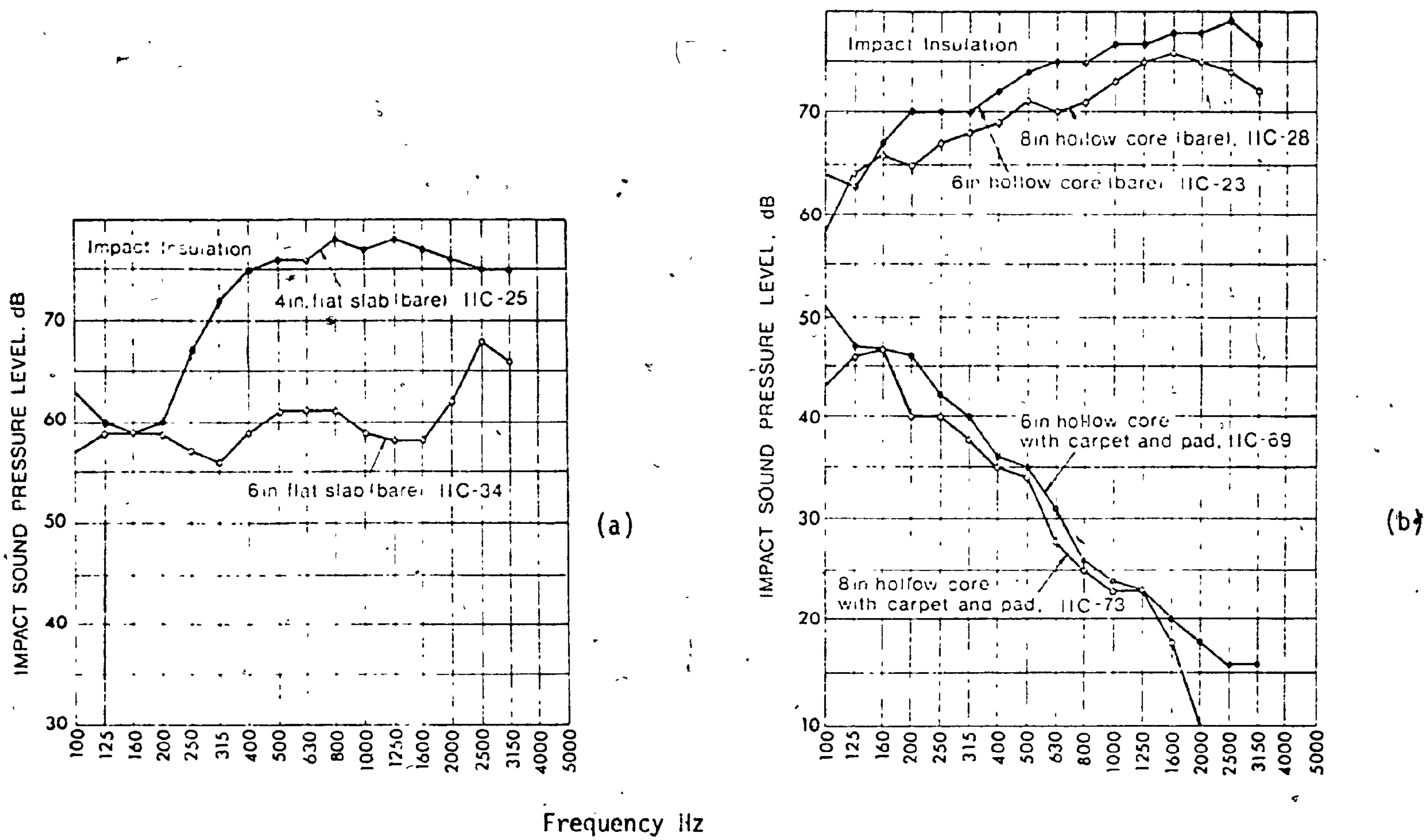


Figure 25. Impact Insulation Data of (a) Solid Flat and (b) Hollow-Core Concrete Panels, of Normal Weight Concrete. (Ref. 5).

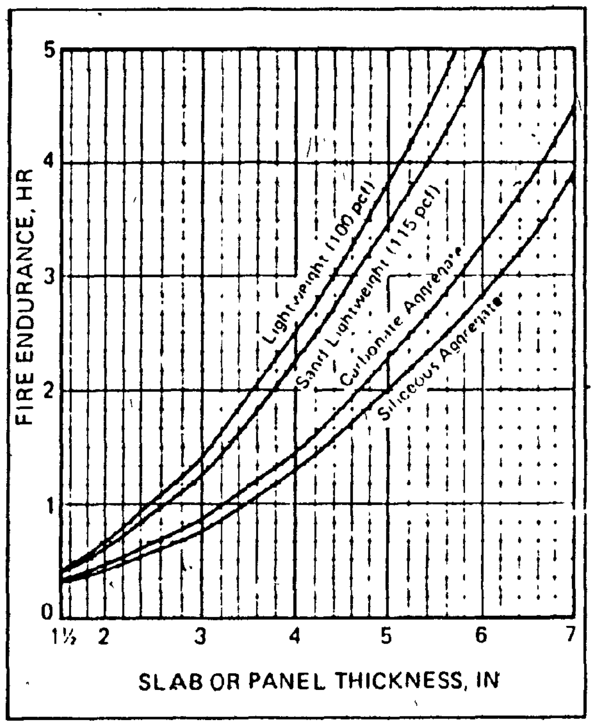


Figure 26. Fire Endurance (Heat Transmission) of Concrete Slabs. (Ref. 5).

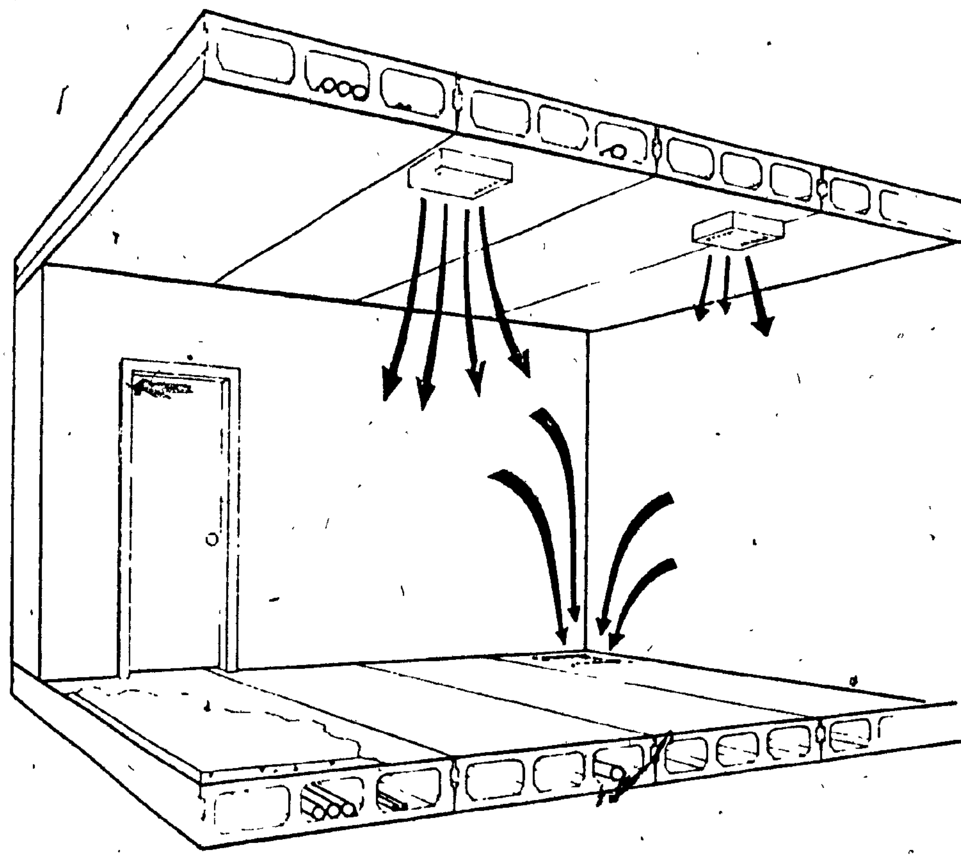
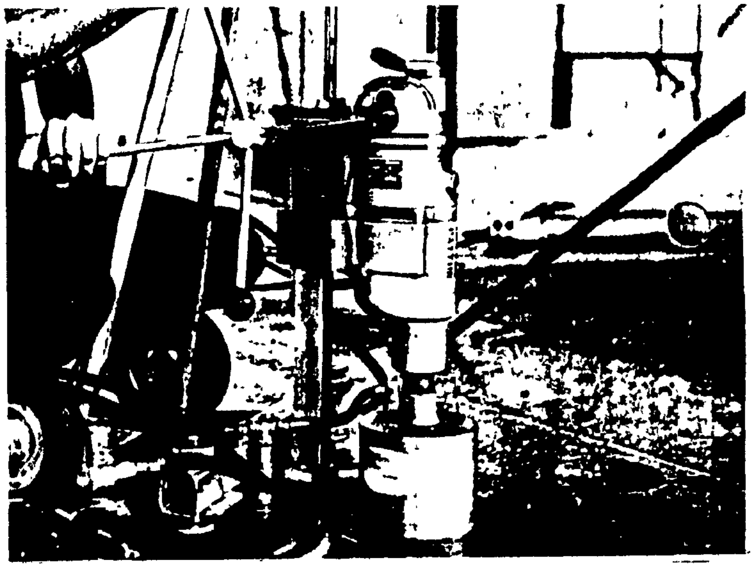
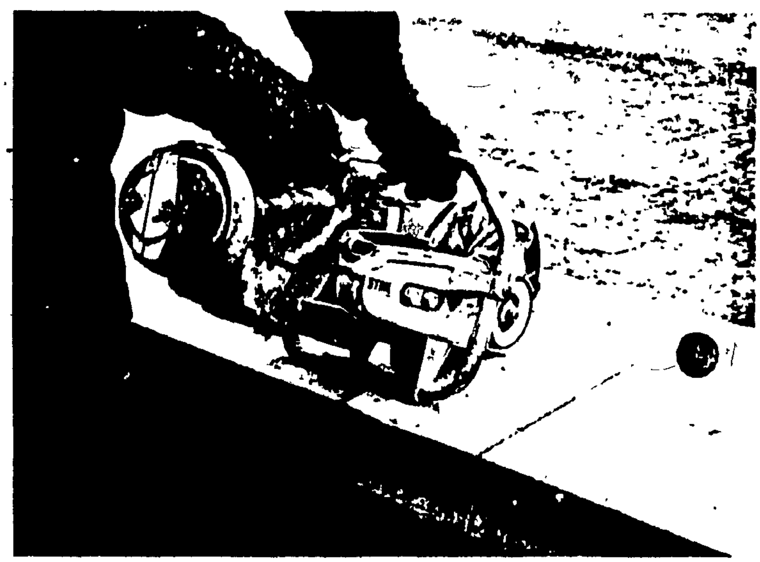


Figure 27. Integration of Mechanical and Electrical Systems in Hollow-Core Slab Floors. (Ref. 14).



(a)



(b)

Figure 28. Field (a) Drilling and (b) Saming, of Hollow-Core Slabs.
(Ref. 20).

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