THE DEVELOPMENT OF AN ALTERNATIVE BUILDING SYSTEM
BASED ON THE USE OF AN EXISTING STANDARDIZED COMPONENT:
PRECAST, PRESTRESSED, HOLLOW-CORE CONCRETE SLAB

by

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ABSTRACT

The primary scope of this thesis is a conceptual design implementation for a new building systems approach.

This system is based on a standardized, economically feasible and widely used prefabricated structural component.

The type in question is a precast, prestressed, hollow-core concrete slab, extending its use from its current application in floor and roof decks to load-bearing wall panels.

The system incorporates three additional structural members in order to perform autonomously: continuous prefabricated reinforced concrete beams, high-strength steel bolts and prefabricated reinforced concrete support panels.

Its application, though primarily directed towards the housing industry, can be utilized in the commercial and industrial areas as well.

Thesis Supervisor: Waclaw Zalewski
Title: Professor of Structures
In Commemoration To
My Late Grandmother,
Marija Simovic
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1.0 INTRODUCTION
Since the 1950’s, when prestressed concrete was introduced in the United States, its milieu had developed into what is now a widely acknowledged and accepted method of architectonical construction in the building industry. Its greatest asset is contributed to the economically feasible applications. Prestressed concrete’s attributions have been virtually limitless, encompassing projects in: residential, institutional, commercial and industrial applications. Its relevance to scale has been equally proven to be versatile and flexible.

1.1 STANDARD PRESTRESSED CONCRETE COMPONENTS

There are varieties of standardized prestressed concrete components that are mass produced in today’s market. Each corresponding member pertains specific design applications along with apparent limitations. The following section presents an inventory of prestressed concrete components with brief overviews of prescribed applications and limitations.

1.1.1 Double Tees

Double tees are a basic floor and roof panel member with a span range of 80 feet. They are excellent for long cantilevers. Designed to simplify and speed erection of single and multi-story structures. Double tees create a unique effect when used vertically as exterior wall panels.

1.1.2 Single Tees

Single tees are used for floor and roof structural decks in longer span ranging up to 120 feet, or for especially heavy loading requirements. Normally 8, 10 and 12 feet wide, each unit provides large, and consequently quick, coverage. Single tees are popular for exposed ceilings, where mechanical services can be channeled between stems for easy access. When cantilevered, single tee ends can be custom shaped for architectural treatment.
1.1.3 Hollow-Core Slabs

Hollow-core slabs find major application in residential, commercial, institutional and industrial structures where flat ceilings are desired. The bottom sides acts as the ceilings; the top side as the floor of the room above. Hollow-core slabs provide an effective barrier to airborne and impact sounds, and their voids can be used to carry mechanical services. They are generally designed for use in shorter spans up to 40 feet.

1.1.4 Channel Slabs

Channel slabs provide a very rigid structural member with minimum deflection characteristics. They are ideal where heavy floor and roof loads are encountered in short and medium span ranges.

1.1.5 I-Beams

I-beams find application generally as a long-span beam to support extremely heavy loads. Available in spans to 100 feet, I-beams serve as the main girder in many beam-and-deck-systems.
1.1.6 Box Beams

Box beams are used primarily in bridge construction, and also as girders in heavy-load type structural framing systems. With proper design, the large voids can accommodate various mechanical services.

![Box Beams](image1)

1.1.7 Inverted T Beams

Inverted T beams and ledger beams reduce total structural depth in a building because deck members can be supported on ledges. They are generally used with double tees and hollow core slabs for structural framing.

![Inverted T Beams and Ledger Beams](image2)

1.1.8 Piles and Columns

Piles are used as foundation supports where poor load-bearing conditions exist. They are available in square or octagonal sections, in sizes from 10 to 24 inches; hollow cylindrical piles are available up to 54 inches in diameter. Precast columns are integral component of the precast column-beam-deck system which makes rapid installation possible.

![Piles and Columns](image3)
1.1.9 Wall Panels

Wall panels are used for partial, full-story, or multi-story heights for either curtain wall or load-bearing use. Customized wall panels are available in plain, sculptured, textured or exposed aggregate units of almost any size, shape or color. They also may include insulation materials for improved thermal characteristics.
1.2 MANUFACTURERS OF PRESTRESSED CONCRETE SLABS

There are a number of major manufacturers of prestressed hollow-core concrete slabs throughout the United States, each serving the same function. They are: Flexicore, Spancrete, Spiroll, Dynaspan, Dy-Core and Span Deck. Each manufacturer's product is distinguishable by the different shape of the voids at the center of the slabs, the standard widths in which they are manufactured and the configuration of the profiles.

Flexicore (1'-4 & 2'-0)

Spancrete (3'-4 & 5'-0)

Spiroll (4'-0)

Dynaspan (4'-0 & 8'-0)

Dy-Core (4'-0)

Span Deck (4'-0 & 8'-0)
1.3 DEFINITION OF PRESTRESSED CONCRETE

Prestressed concrete is an architectural and structural material of great strength. Prestressed architectural and structural concrete units are given predetermined, engineered stresses which counteract the stresses that occur when a unit is subjected to loads. This is accomplished by combining two quality materials: high tensile steel strands and high strength concrete. There are two methods of prestressing high tensile steel strands: post-tensioning and pretensioning.

Post-tensioning prestressed concrete means that the steel is tensioned after the concrete is placed and has gained a specific strength.

In pretensioning, high tensile steel strands are stretched between abutements at each end of the casting beds. Concrete is then machine extruded to encase the strands. As the concrete sets, it bonds to the tensioned steel. When the concrete reaches a specified strength, the tensioned strands are released from the abutments. This stresses the concrete, putting it under compression and creating built-in tensile strength.

Most commonly used prestressed concrete utilizes pretensioning due to its adaptability to mass-production in a plant. This manufacturing operation takes place in an all-weather enclosed plants resulting in completely finished prefabricated members for ready delivery to the job site.

1.3.1 Ordinary Concrete Beam

Even without a load, the ordinary concrete beam must carry its own considerable weight - which leaves only a portion of its strength available for added loads.
Under load, the bottom of the beam will develop hairline cracks.

1.3.2 Prestressed Concrete Beam

In a prestressed concrete beam, before it leaves the plant, a slight arch is noticeable. Energy is stored in the unit by the action of the highly tensioned steel which places a high compression in the lower portion of the member. An upward force is hereby created which in effect relieves the beam of having to carry its own weight.

The upward force along the length of the beam counteracts the load applied to the unit.
The fundamental idea of this thesis was initiated by friction connections — commonly associated with steel connections. It is used to service load transmission by friction through physical contact of adjoining surfaces of members after the bolts are pretensioned. (See fig. below). Friction-type connections offer a higher factor of safety against slip and thus is most suitable when stress reversal or cyclical loading may occur.

Prestressed, hollow-core concrete slabs, as acknowledged today, is applied in a horizontal position, primarily for floor and roof decks. This thesis deals with extracting the prestressed concrete slabs from its notorious and existing context to a new and unconventional one: load-bearing wall components, and non load-bearing wall panels.

Chapter 2.0 deals with the description of prestressed concrete slabs and its modifications, along with the additional structural components required to achieve an autonomous building system.

Chapter 3.0 concentrates on major details/solutions regarding connections by means of accomplishing structural integrity of the elements in question.

Chapter 4.0 explains the chronological sequence of assembly of the structural elements with two examples.

Chapter 5.0 addresses the selection of possible finishes for interior/exterior applications.

Chapter 6.0 explores the design periphery of this system accompanied with a typical housing application. Chapter 7.0 deals with the economical issues of this system with comparisons in relation to conventional construction systems.

Chapter 8.0, a conclusion and future research is drawn, based on the analysis of prestressed hollow-core concrete slabs.
2.0 REQUIRED STRUCTURAL COMPONENTS
The essential components of this system consists of five structural elements: prestressed hollow core concrete slabs, prestressed concrete wall panels, prefabricated reinforced concrete beams, prefabricated reinforced concrete support panels and high-strength steel bolts.

2.1 Prestressed Hollow-Core Concrete Slab

A typical cross-section of a prestressed concrete slab that is incorporated into either floor or roof decks is shown in Fig. 1. The holes or voids in the slabs are there to reduce unnecessary weight of the concrete at the neutral axis. There are number of thicknesses available pending on the span and the anticipated service loads. (Note the prestressed tendons at the bottom of the slab).

2.2 Prestressed Concrete Wall Panel

Prior to altering the existing function of prestressed hollow core concrete slabs, three modifications are required to the standardized elements. See Fig. 1. They are: 1) the augmentation of prestressed tendons at the "top" of the slabs when the slabs are casted to secure symmetrical forces in the prestressed tendons (to eliminate any unwarranted camber effects), 2) the elimination of two voids near both ends of the slab to create a solid section to permit maximum compression forces (section where prefabricated beams is attached to member) and 3) holes that are drilled through the members (at the solid sections) to allow installation and permanent positioning of high-strength steel bolts. Holes may either be drilled at the job site or preferably pre-drilled at the manufacturing plant. The diameter of the holes depends on the types of bolts that will be incorporated pending on service loads.

2.2.1 Altered Profile

There may be an optional alteration on the profile of the prestressed concrete elements shown in Fig. 2. This is to insure a weather-tight joint especially at the perimeter walls. And in doing so, the standard form (varies with manufacturers) of the concrete dispatch machine would have to be replaced to the new specification of the desired profile. The new form will cost a considerable amount, however, depending on the amount of members extruded, it could very likely off-set the initial investment. Also, the new profile would only be manufactured once.

2.2.2 Solid Prestressed Concrete Wall Panel

There is a trade-off if solid prestressed concrete wall panels are used versus the hollow core concrete panels: less concrete is required to carry virtually the same load (thinner
wall thickness), and fewer prestressed tendons are required because they can be ideally juxtapositioned in the center of the wall panels. (see Fig. 2).

TYPICAL PRESTRESSED CONCRETE COMPONENTS
Fig. 1
Hole Pre-drilled for Structural Steel Bolt at Top & Bottom
Cont. Neoprene Strip

Eliminate Voids When Casting

Hole Pre-drilled for Structural Steel Bolt

Prestressed Tendons Located Center of Panel

Modified Profile

PRESTRESSED CONCRETE WALL PANEL

SOLID PRESTRESSED CONCRETE WALL PANEL

PRESTRESSED CONCRETE WALL PANELS
Fig. 2
2.2.3 Existing Prestressed Concrete Wall Panels

Spancrete manufacturers have produced a prestressed concrete load-bearing wall panel system deriving from prestressed concrete slab production as shown below.

This system of panels ascertain exactly the same principal or concept of this thesis but it has one inherent restriction: they are limited to one-story height intervals.

The decking system bears directly on top of the wall panels at each floor interval, with the proceeding wall panels positioned on top of the decking system aligning directly over the preceding lower wall panels.

The connection is by exposed reinforcing bars in the joints that is grouted afterwards. This type of connection creates the problem of lateral rigidity after a certain height.

It is interesting to note the various profiles designed in the panels to meet certain conditions including an interlocking system, butt joints and a mitered corner condition.
2.3 Reinforced Concrete Beam

A vital component of this system is the prefabricated concrete beams (shown in Fig. 3) which performs the following functions:

1) Provides a temporary bracing for prestressed concrete wall panels at the initial stages of erection.
2) Aligns prestressed concrete wall panels when positioned in place.
3) Creates a ledge or bearing support for prestressed concrete floor slabs.
4) Increases overall lateral rigidity.

The design parameters for the beams are:

1) The sizes of beams vary as a function of anticipated or prescribed service loads and the required surface area for the appropriate friction connection.
2) Holes are to be drilled through the beams to align with holes in the prestressed concrete wall panels and with countersinking provided for recessing boltheads and nuts in the concrete beams. (Grouted afterwards for waterproofing and to prevent loosening of the connection).
3) Concrete beams are to be continuous to correspond with the width of the total load-bearing wall length. (Beams may have to be segmented due to length restrictions in transportation).
4) The concrete beams may be designed in three structural mediums: reinforced concrete using ordinary rebars, high-strength concrete using prestressed high tensile steel strands, and post-tensioned concrete using high tensile steel cables applied and tensioned after beam is positioned in place.

If the concrete beams are required to be segmented, and depending on the type of structural medium that is decided upon, there are four connections that are valid in order to achieve continuity of the beams, shown in Fig. 4. They are: bolt connection, welded connection with implanted steel anchors (not shown in dia.), connection with steel dowels and post-tensioning method as described above.

2.3.1 Steel Angle

Steel angles may also be used to serve the same function as the concrete beam (see Fig. 3). Listed below are some of the advantages and disadvantages.

Advantages
- Takes up less space.
- Readily available.
- Easily concealed for interior finishes.
- Compatable with corrugated sheet metal and/or steel bar
joists for decking. Elimination of follow-up grouting as in the case of concrete beams to conceal boltheads and nuts.

Disadvantages
Needs Fireproofing.

Fig. 3
CONNECTION OF PREFABRICATED REINFORCED CONCRETE BEAMS

Fig. 4
2.4 Reinforced Concrete Support Panel

The reinforced concrete support panels are required to be prefabricated according to specification requirements with each specific construction application. The height of the panel may vary according to floor heights, thickness may vary depending on the thickness of the prestressed concrete wall panels, and the ledge at the top of the panel may vary according to the height and depth of the concrete beam. See Fig. 5.

The sole function of the prefabricated reinforced concrete support panel is literally a support panel for the continuous concrete beams. It serves consecutively as a tentative and permanent support. It is also the termination member at either end of the prestressed concrete load-bearing wall system.

This component is very crucial in the economy of the system especially during erection in that there is no waiting for cranes to position and hold the concrete beams until they are bolted in place which may take up substantial and valuable time. Also, this component initiates the sequence of erection and is the only member that requires temporary bracing at the onset of construction until the first series of prestressed concrete wall panels and floor slabs are positioned in place and grouted.

The reinforced concrete support panel is positioned perpendicular to the bearing walls and the concrete beams. It is also stacked on top of each other with steel dowels or pins and grouted for alignment.

Normally there are two, three or four support panels required depending on the length of the load-bearing walls.
Steel Dowel for Alignment & Placement of Upper Panel

Hole for Temporary Bolting of Concrete Beam

Width of Adjacent Prestressed Concrete Wall Panels

Width of Concrete Beam

Height of Conc. Beam

Ceiling to Ceiling Height

Female Connection for Support Panel Below

TYPICAL SUPPORT PANEL FOR CONCRETE BEAMS

Fig. 5
2.5 High-Strength Steel Bolts

The final structural component; the key element that makes this building system autonomous, is the high-strength steel bolts. Its only function is to fasten the concrete beams to the prestressed concrete wall panels to create a friction-type connection.

Three types of bolts are applicable to this system: high-strength steel hexagon head bolts, high-strength steel interference-body bolts, and the Huckbolt, (manufactured by the Huck Bolt Company).

2.5.1 Hexagon Head Bolts

The two basic types of high-strength bolts are designed by ASTM as A325 and A490. These bolts are heavy hexagon-head bolts, used with semifinished hexagon nuts. (See Fig. 6 below). A325 bolts are of heat-treated medium carbon steel having an approximate yield strength of 81 to 92 ksi depending on diameter. A490 bolts are also heat-treated but are of alloy steel having an approximate yield strength of 115 to 130 ksi depending also on diameter. Bolting of the nuts can be tightened either by turn-of-the-nut technique or with an impact wrench.

![High-Strength Hexagon Head Bolt](image1)
![High-Strength Interference-Body Bolt](image2)

Fig. 6

2.5.2 Interference-Body Bolts

These bolts have a rounded head and raised ribs that has serrations around the shank as well as parallel to the shank. The actual diameter of a given size of ribbed bolt is slightly larger than the hole into which it is driven. (See Fig. 6). In driving a ribbed bolt, the bolt actually cuts into the edges around the hole producing a relatively tight fit and then bolted as mentioned above. The interference-body bolt is available in A325 and A490 characteristics.
2.5.3 Huckbolt

The Huckbolt, also meeting ASTM Specifications of A325 and A490, are cut to exact final length required by its specific position in the design. One end of the bolt has a formed head; the other end is equipped with two concentric annular coarse and fine grooves, as shown in Fig. 7. The bolts are inserted through the designed holes which have been cased in both of the concrete beams and through the prestressed concrete wall panels. A metal lock collar is inserted by hand over the bolt end and around the finer annular grooves. A specific hydraulic machine tool then tightly clamps around the courser grooves at the end and stresses the bolt to approximately 70 per cent of its ultimate strength. Just before this point of stress is reached, the tool clamps around the collar, swaging this into position on the finer grooves, to hold the stress in the bolt. As soon as the swaging is done, the stress is increased slightly, to break off the bolt end at a deep grooved section formed in the bolt just in front of the swaged lock collar. Installation techniques are shown in Fig. 8.

![Huckbolt](image)

Fig. 7
2.5.4 Washers

Washers are required for any of the bolts mentioned above. They should be oversized to assist transmission of compressive forces from the bolts to the concrete beams or steel angles. They should also have sufficient structural strength and applied on both the nut-side and bolt-side.
3.0 DETAILED CONSIDERATIONS
3.1 Foundation Details

Fig. 9 & 10 are detail connections of wall panels to the foundation wall. They both deal with direct bearing of prestressed concrete wall panels on top of poured-in-place concrete foundation walls with variations of exterior surfaces or finishes. The first detail is exposed concrete wall panels and the second is with an added exterior cladding.

The latter two details (Fig. 11 & 12) involves bearing of wall panels directly on top of the concrete footing, thereby eliminating costly formwork, labor and pouring of transported concrete - a substantial savings both in time and labor.

Note: extra precautions should be taken when grouting joints of all wall members and thorough waterproofing particularly for basement applications.
Poured-in-Place Conc. Slab

Weld Angle 2"x0'4 Cast into Panel

Cont. Weld Plates Anchored to Fndn Wall

3" Min.

2" Rigid Insulation

Prestressed Concrete Wall Panels (Exposed)

1" Grout, Shim & Caulk

1" Max.

Grade

Cont. #5 Rebars at Top & Bottom

Poured-in-Place Conc. Foundation Wall

TYPICAL CONNECTION OF WALL PANELS TO FOUNDATION WALL
(Exposed Wall Panels)
Fig. 9
Poured-in-Place Conc. Slab

Weld Angle 2"x0'-4 Cast into Panel

Cont. Weld Plates Anchored to Fndn Wall

3" Min.

2" Rigid Insulation

Prestressed Concrete Wall Panels

Exterior Cladding

1" Grout, Shim & Caulk

1" Max.

Cont. #5 Rebars at Top & Bottom

Poured-in-Place Conc. Foundation Wall

TYPICAL CONNECTION OF WALL PANELS TO FOUNDATION WALL
(With Exterior Cladding)
Fig. 10
Poured-in-Place Conc. Slab

2" Rigid Insulation

Prestressed Concrete Wall Panel (Exposed)

Grade

Provide Waterproofing

Cont. Groove in Footing
Furnished to Line & Grade

3" Min.

Concrete Footing

Panels Shimmed & Grouted

TYPICAL CONNECTION OF WALL PANELS TO FOOTING
(Slab-on-Grade)

Fig. 11
Grouted Joint
Concrete Topping (Optional)

---

Prestressed Concrete Floor Slab

---

1/8" x 3" Hardboard Brg. Strip

---

Cont. Groove in Footing Furnished to Line & Grade

---

BASEMENT

Provide Waterproofing

#3 Rebar Grouted into Keyways and/or Voids in Panels

---

Panels Shimmed & Grouted

---

Concrete Footing

---

TYPICAL CONNECTION OF WALL PANELS TO FOOTING (With Basement)

Fig. 12
3.2 Wall Details

All of the following details are load-bearing connections of prestressed concrete wall panels with prestressed concrete floor slabs.

The first detail (Fig. 13) deals with continuous wall panels (two to five floor lengths) showing the connection of continuous concrete beams with the floor slabs.

Fig. 14 is a detail showing a non-continuous wall panel connections. This is where vertical continuity is achieved.

Fig. 15 is a typical plumbing chase detail shows how soil stacks, water lines and other mechanical paraphernalia can be integrated feasibly and economically within the system. It can be achieved without unnecessary drilling through the floor slabs by simply eliminating portions of the wall panels between the concrete beams.

The following four details (Fig. 16, 17, 18 & 19) concentrates on exterior wall connections with floor slabs, addressing alternative exterior and interior finishes. (Described in more detail in Chapter 6.)
TYPICAL CONCRETE CONNECTION OF FLOOR SLABS TO LOAD-BEARING WALL PANELS (CONTINUOUS)

Fig. 13

SECTION A-A on Page 91
TYPICAL CONCRETE CONNECTION OF FLOOR SLABS TO LOAD-BEARING
WALL PANELS (NON-CONTINUOUS)

Fig. 14
SECTION B-B on Page 91
TYPICAL PLUMBING CHASE
Fig. 15

- Grouted Joint After Plumbing Installation
- Concrete Topping (Optional)
- Prestressed Conc. Floor Slabs

- 1/8"x3" Hardboard Brg. Strip
- Space for Plumbing Chase
- Cont. Conc. Beam

- Prestressed Conc. Wall Panel Beyond
SECTION C-C on Page 91
TYPICAL CONCRETE CONNECTION OF FLOOR SLABS TO EXPOSED LOAD-BEARING WALL PANELS (CONTINUOUS)
Fig. 16
Metal Studs with Batt Insul.

Textured Plywood (Board on Batten, Beveled Siding, Tongue & Groove Planking, etc.)

Cont. Conc. Beam
Grout Filled

Metal Studs with Batt Insul.

Stucco Finish

SECTION C-C on Page 91
OPTIONAL EXTERIOR FINISH
(Wood, Stucco)
Fig. 17
SECTION C-C on Page 91
OPTIONAL EXTERIOR Finish
(Brick, Concrete Block)
Fig. 18
Exposed Prestressed Conc. Wall Panels

Grout Filled

Metal Studs With Batt Insul.

Gypsum Board Finish

SECTION C-C on Page 91
OPTIONAL EXTERIOR FINISH
(Exposed Concrete)
Fig. 19
3.3 Roof Details

The first detail (Fig. 20) shows a typical parapet condition with an alternative stone or sheet metal coping.

Fig. 21 is a typical roof detail.

The following detail (Fig. 22) shows a typical cantilevered roof.
Alt. Stone Coping

Sheet Metal Coping
Wood Blocking
3/8"x8" Anchor Bolt
Grouted into Keyway

Wood Cant
Built-up Roofing
over Rigid Insul.

Prestressed Conc.
Roof Slabs
1/8"x3" Hardboard
Brg. Strip

Exterior Cladding
Prestressed Conc.
Wall Panels
Rigid Insul.
#3 Rebar Grouted
into Keyways

High-Strength
Steel Bolts
Grout Filled
Cont. Conc. Beam

TYPICAL PARAPET WALL DETAIL
Fig. 20
Built-up Roofing over Rigid Insul.

Sheet Metal
Gravel Stop
Wood Blocking
3/8" x 8" Anchor Bolt
Grouted into Keyway

Rigid Insul.

#3 Rebar Grouted into Keyways
High-Strength Steel Bolts
Grout Filled
Cont. Conc. Beam

Exterior Cladding
Prestressed Conc. Wall Panels

TYPICAL ROOF DETAIL
Fig. 21
3.4 Typical Sections

The first detail (Fig. 23) is a section through the prestressed concrete floor slabs with the prestressed concrete wall panels, continuous concrete beams and bolt connections in elevation.

The next detail (Fig. 24) is a section through the prestressed concrete wall panels looking down towards the prestressed concrete floor slabs and the continuous concrete beams below the floor slabs (dotted line).

The following detail (Fig. 25) is a section through the prestressed concrete wall panels and at the concrete support panel that supports the continuous concrete beam.

Fig. 26 is a section through the prestressed concrete floor slabs and the continuous concrete beams at the corridor looking towards the concrete support panel and at the prestressed concrete wall panels.

Fig. 27 is a transverse section through the corridor showing the prestressed concrete floor slabs, non load-bearing prestressed concrete wall panels and the prefabricated segmented concrete beam used for lateral support.

Fig. 28 is also a transverse section through the corridor showing the prestressed concrete floor slabs, non load-bearing wall panels using typical concrete beam for lateral support.

Fig. 29 is a section through the prestressed concrete wall panel and the concrete support panel at the exterior of the building.
Concrete Topping (Optional)
#3 Rebar Grouted into KEYWAY
Prestressed Concrete Floor Slab
Prestressed Tendons

Cont. Concrete Beam
High-Strength Steel Bolts

SECTION D-D on Page 91
SECTION THROUGH FLOOR SLABS
Fig. 23
Grouted Vert. Keyway

Prestressed Conc. Wall Panel

Prestressed Tendon Grouted Joint

High-Strength Steel Bolt

#3 Rebar Grouted into Keyway

1" Min.

Width of Conc. Beam (Below Slab)

← Prestressed Conc. Floor Slab →

DETAIL E on Page 91
SECTION THROUGH LOAD-BEARING WALL PANELS
Fig. 24
Prestressed Conc. Floor Slab Grouted Joint
#3 Rebar Grouted into Keyway Conc. Topping (*Optional)

1/8"x3" Hardboard Brg. Strip Cont. Conc. Beam

Prestressed Conc. Wall Panels Beyond Conc. Support Panel Beyond

SECTION G-G on Page 91
SECTION THROUGH FLOOR SLABS AT CORRIDOR
Fig. 26
CORRIDOR

Prestressed Conc. Wall Panel
Conc. Topping (Optional)
Prefab. Conc. Beam Bracing
(Resting on Top of Cont. Beam Beyond)
Prestressed Conc. Floor Slab

Butt Joint
Prestressed Conc. Wall Panel Beyond
Post-Tensioned Tendons
Cont. Conc. Beam Beyond

SECTION H-H on Page 91
SECTION THROUGH FLOOR SLABS AT CORRIDOR
(Optional Concrete Beam Bracing)
Fig. 27
CORRIDOR

Prestressed Conc. Wall Panel
Grouted Joint
Conc. Topping (Optional)
Prestressed Conc. Floor Slab
Post-Tensioned Tendons

Butt Joint
Cont. Conc. Beam Beyond
Intermediary Conc. Beam Bracing
High-Strength Steel Bolt

Prestressed Conc. Wall Panel Beyond

SECTION H-H on Page 91
SECTION THROUGH FLOOR SLABS AT CORRIDOR
(Optional Concrete Beam Bracing)
Fig. 28
EXTERIOR

Optional Prestressed
Conc. Wall Panel
(Non Load-Bearing)

--- Prestressed
Grouted Joint
High-Strength
Steel Bolt
1" Min.
Width of Conc.
Beam (Below Slab)

Conc. Support Panel
Grouted Vert. Keyway

Prestressed Tendon
Grouted Joint
High-Strength
Steel Bolt

Prestressed Conc.
Floor Slab
Cont. Conc.
(Below Slab)

Prestressed Conc.
Wall Panel
(Load-Bearing)

DETAIL J on Page 91
SECTION THROUGH LOAD-BEARING WALL AT EXTERIOR WALL
Fig. 29
3.5 Optional Structural Members

Fig. 30 shows an alternative structural medium substituting steel angles for the continuous prestressed reinforced concrete wall panels.

Fig. 31 shows the connection of non-continuous prestressed concrete panels using wide flange beams as a guide and connection of the panels with welded steel angles on either side.

Fig. 32 shows an exterior condition of prestressed concrete wall panels using structural T’s and a steel plate.

The final detail (Fig. 33) shows an alternative prefabricated concrete beam.
SECTION A-A on Page 91
TYPICAL STEEL CONNECTION OF FLOOR SLABS TO LOAD-BEARING WALL PANELS (CONT.)
Fig. 30
Prestressed Conc. Wall Panel
Grouted Joint
\#3 Rebar Grouted into Keyway
Prestressed Conc. Floor Slab
Concrete Topping (Optional)

2 1/2" Min.

1/8"x3" Hardboard Brg. Strip
Cont. Steel Angle Welded to Wide Flange

Cont. Steel Wide Flange

NOTE: Provide Holes for Rebars

SECTION A-A on Page 91
TYPICAL STEEL CONNECTION OF FLOOR SLABS TO LOAD-BEARING WALL PANELS (NON-CONT.)
Fig. 31
Prestressed Conc. Wall Panel
Prestressed Conc Floor Slab
#3 Rebar Grouted into Keyway 2 1/2" Min.
Conc. Topping (Optional)
Grouted Joint
1/8"x3" Hardboard Brg. Strip
Cont. Steel T with Welded Webs

Exterior Cladding
Sq. Steel Plate
High-Strength Steel Bolts

SECTION C-C on Page 91
TYPICAL STEEL CONNECTION OF FLOOR SLABS TO LOAD-BEARING WALL PANELS (CONT.) WITH EXTERIOR CLADDING
Fig. 32
TYPICAL CONCRETE CONNECTION OF FLOOR SLABS TO LOAD-BEARING WALL PANELS (CONT.) WITH EXTERIOR CLADDING

Fig. 33
4.0 SEQUENCE OF ERECTION
There are two methods of assembling the prestressed concrete components of which one is more economically feasible. Both descriptions of assembly procedures will be described starting with the initial development.

For both cases, the assumptions is that the foundation walls, or the footings of the foundation (two options of support for the prestressed concrete wall panels) have been casted and have reached sufficient strength to proceed the sequential erection process of construction.

4.1 Assembly Method #1

This method - the initial development - is applying the concept at a rudimentary basis. The method apparently had some drawbacks which resulted in revamping the order of erection and with an additional structural member, a prefabricated concrete support wall. This is described in more detail in the second method of assembly.

There are four procedures or steps that completes a cycle or one floor height.

Step 1

The setting of prestressed concrete wall panels preferably at length of one story high (for quick, easy handling and bracing) on top of the foundation walls and grouted in a staggered format. Temporary bracing is required for each member.
Step 2

Lifting of prefabricated concrete beams on either side of the prestressed concrete wall panels and held in place until high-strength steel bolts are positioned and bolted. Procedure is the same for each load bearing wall. Note: two cranes are required simultaneously.

STEP 3

Placing of the prestressed concrete floor slabs. Reinforcing steel bars are positioned between every keyway and grouted. Temporary bracing may be removed after grout has reached its subsequent yield strength.
Step 4

Positioning of corresponding prestressed concrete wall panels, also in a staggered format to infill initial voids developed at ground level and to give additional support. Height may vary according to desired lengths (limitations only to conventional transportation restrictions though additional temporary bracing may be required if members are too high). Note: the bolts of the adjacent prestressed concrete wall panels may have to be loosened to allow wall panels to slide between concrete beams. Grouting may proceed at ground level between vertical keyways.

Step 5

Same as step 2
Step 6
Same as step 3

Step 7
Same as step 4
Step 8

Placement of prestressed concrete wall panels (non load-bearing) that are slipped through continuous slots or spacings between prestressed concrete floor slabs to create a sheer wall for lateral rigidity. Grout all vertical keyways. Note: sheer wall is conveniently located on adjacent sides of central corridor.

Step 9

Same as step 2
Step 10

Same as step 3
4.2 Assembly Method #2

This is the subsequent method due to some imperfections of the preceding assembly method. The difference between the two are: an additional structural member (prefabricated continuous concrete support panels) and a switch in the sequential steps of erection.

Step 1

The prefabricated concrete support panels are placed on top of the foundation walls, grouted and temporarily braced. The panels are placed perpendicular to the forthcoming load-bearing panels, at both ends of the anticipated load-bearing walls and at the shear walls as shown. Note: there is a substantial reduction of bracings in this procedure.

Step 2

The prefabricated concrete beam is hoisted on the designed ledges on one side only of the support panels (with the exception of end walls), and bolted through the beams and into the panels.
Note: two cranes are not required and there is a savings in time by having the support panels supporting the concrete beams and eliminating valuable time consumed by holding the beams by the crane as in the first assembly method.

Step 3

The placement of prestressed concrete wall panels in a sequential order on top of the foundation walls (or footings) and grouted. The concrete beam acts as a temporary support for the panels and eventually a permanent connection. The lengths of the panels may be of longer lengths and should vary in one story increments that are staggered at the top ends of the panels to add support and rigidity when construction continues in height at the following stages of erection. Note: No need of staggering the prestressed concrete wall panels, and panels are of longer lengths.

Step 4

The corresponding concrete beam is placed on the opposite side of the prestressed concrete wall panels and onto the ledges of the support panels. The bolting procedures may proceed in a sequential order throughout the length of the load-bearing walls.

Step 5

Placing of prestressed concrete floor slabs. Reinforcing steel
bars are inserted between every keyway and grouted. Concrete beam is introduced to give lateral support.

These are the five procedures or steps that completes a cycle or one floor height.

Step 6
Same as step 2 and 4

Step 7
Same as step 5 with the additional step of placing the prestressed concrete wall panels (non load-bearing) on either side of the central corridor which acts as a shear wall as in the previous assembly procedure.

Step 8
Same as step 2 and 4

Step 9
Placing of the next series of prestressed concrete wall panels between the staggered ends of the panels below, and step 4.

Step 10
Same as step 5.
PROCEDURES OF ASSEMBLY
Step One
Support Panels on Foundation Wall
Step Two
Cont. Conc. Beams Bolted to Support Panels
Step Three
Concrete Wall Panels
Step Four
Cont. Concrete Beams & Bolted
Step Five
Concrete Floor Slabs, Conc. Beam Bracing & Grout
Step Six
Conc. Support Panels, Conc. Beams & Bolt
Step Seven
Conc. Floor Slabs & Non Load-Bearing Conc. Wall Panels
Step Eight
Step Nine
Conc. Wall Panels, Cont. Conc. Beams & Bolt
Step Ten
Concrete Floor Slabs
5.0 FINISHES
5.1 INTERIOR FINISHES

5.1.1 Floors

Floor systems of prestressed concrete slabs readily lend themselves to virtually any available floor finishes. Some types of finishes may require an underlayment of mastic, gypsum concrete or concrete, while others are applied directly to the prestressed concrete slabs with only a minimum amount of surface leveling. Underlayment or concrete topping is required when a resilient floor covering is used. The prestressed concrete slabs should be thoroughly cleaned before application of any underlayment or concrete topping.

Condition of the top surface of the installed deck will vary depending on span, load, openings and other details.

When a concrete topping is desired, it can be designed to act structurally with the prestressed concrete slab as a composite system, or it can be assumed to act only as a fill material. This choice will affect the specification of the topping material and placement.

5.1.2 Concrete Finishes

When concrete is to be used structurally or as a wearing surface, one should specify a minimum of 3000 psi. Color pigments, hardeners or wearing aids may be added. Similar details should prevail for cast-in-place terrazzo. Where practical, align joints with the prestressed concrete slab joints.
5.1.3 Floor Coverings on Underlayment

Underlayment material should be specified similar to the one of the following general types: asphaltic concrete, latex concrete, mastic underlayment. Thickness of underlayment should be only enough to level off construction irregularities.

Similar specifications and procedures should be used for flooring materials which normally require a mortar bed for placing, such as cut stone or precast terrazzo.

![Diagram of Asphalt or Vinyl Tile or Sheet Floor Covering on Underlayment]

5.1.4 Carpeting

For carpeting directly on prestressed concrete slabs, a skim coat of mastic leveling should be applied where irregularities exceed 3/16 in. A minimum of 55 oz. pad should be specified.

![Diagram of Carpeting over Pad on Prestressed Conc. Floor Slab]

75
5.1.5 Exposed Ceiling Slab - Painted

The prestressed concrete slabs have an exceptionally smooth underside surface, obtained because of the thorough vibration of the dense concrete in steel forms in the casting beds. Nicely rounded corners are built into the individual units.

When a paneled ceiling is desired in residential, commercial, school, hospital or similar applications, simply caulking the joints between the slabs and painting is the most economical solution.

The prime coat should be rubber latex paint or a waterproof sealer as is desirable for any other concrete slab. The finish coat may be rubber, oil paint, flat wall finish or an emulsified finish. A distinctive appearance is obtained by stippling the final coat.

5.1.6 Other Ceiling Treatment

Although the most economical ceilings are obtained by simply caulking and painting as outlined above, additional treatments can be applied which produces a variety of results.

Ceiling tiles that are applied directly onto the prestressed concrete slabs.

Spray applied acoustical material when acoustical control is required, mineral fiber or other acoustical material may be sprayed directly on the slab's surface creating a textured finished.

5.1.7 Suspended Ceiling

All conventional hung ceilings may be in conjunction with the prestressed concrete slabs by inserting the hangers in the joints between slabs before grouting.

Alternatively, ceilings may also be hung after slabs are grouted, by drilling underside of the cores and then inserting the hangers in the cores.

Hangers may also be installed from the top of the slab by drilling through the cores, provided topping will be used.

Principal purpose of the suspended ceiling is to conceal ducts, pipes or other mechanical paraphernalia.
Galv. Strap Hanger
Installed Before
Slabs are Grouted

Prestressed Conc.
Floor Slab

Hanger
Toggle Bolt

Suspended Ceiling
5.2 EXTERIOR CLADDING

There are a number of possible materials that can be applied directly to the facade of the exterior prestressed concrete wall panels, bearing directly on the continuous concrete beams. Of course one may simply choose to leave the wall panels exposed which also presents a wide variety of finishes and textures.

5.2.1 Brick/Block

Brick and/or concrete block is compatible with this system. Its construction methodology is similar to brick veneer construction. See Fig. 34. The only difference is that scaffolding is required around the periphery of the building when laying the brick/block on the facade.

5.2.2 Wood/Stucco

Wood and/or stucco finish is another compatible alternative, and is also applied similarly to brick veneer construction. See Fig. 35.

5.2.3 Exposed Concrete

Exposed concrete provides the most flexibility as far as textures, finishes and color variations. The finishes can be applied in most cases when the prestressed concrete wall panels are manufactured - a cost reduction.

The interior side of the prestressed concrete wall panels will need some sort of insulation: rigid or batt insulation. Fig. 36 shows metal studs with batt insulation and a gypsum board finish.

A unique exterior finish can be achieved with a patented Corewall process. A revolving roller screeds and compacts the concrete on the top surface of the panels to create the desired architectural effect (see Fig. 37). By varying the profile and spacing of a number of discs attached to the roller, a wide variety of sculptured finishes is available.

Fig. 38 gives us a sampling of exterior finishes that can be achieved by various means.
SECTION C-C on Page 91
OPTIONAL EXTERIOR FINISH
(Brick, Concrete Block)
Fig. 34
Metal Studs with Batt Insul.

Textured Plywood (Board on Batten, Beveled Siding, Tongue & Groove Planking, etc.)

Cont. Conc. Beam
Grout Filled

Metal Studs with Batt Insul.

Stucco Finish

SECTION C-C on Page 91
OPTIONAL EXTERIOR FINISH
(Wood, Stucco)
Fig. 35
Exposed Prestressed Conc. Wall Panels

Grout Filled

Metal Studs With Batt Insul.

Gypsum Board Finish

SECTION C-C on Page 91
OPTIONAL EXTERIOR FINISH
(Exposed Concrete)
Fig. 36
Fig. 37
Fig. 38
6.1 Modules

Among the prestressed concrete manufacturers mention previously in the introduction, there are alternate width dimensions of hollow-core concrete slabs that varies with each producer. The scope of dimensions are: 1'-4, 2'-0, 3'-4, 4'-0, 5'-0 and 8'-0 widths.

Based on these dimensions, the designer will need to know the nearest location where prestressed concrete members are produced and acknowledge the standard width dimensions associated with the manufacturer. This should serve as the basis for the module system of prestressed concrete hollow-core members incorporated into the design. In large metropolitan areas, there may be two or three manufacturers within a relative close proximity which presents the designer with a more flexible module selection.

Needless to say, the determination of module sizes plays an important role regarding two major criteria: economy, and design flexibility. The larger the width dimension, i.e. larger member, the more economical it becomes simply on the basis of less labor requirements and quicker erection with fewer members. The design flexibility of the project also depends on the module dimensions because of the imposition of integration into the design in order to be efficient, economical, and functional.

The ideal module dimension of prestressed concrete elements is 8'-0 and/or possible combinations of 4'-0 widths (if need be). Both of these sizes are an architectonic dimension in the construction industry.

The modules should be aligned both horizontally and vertically i.e. the wall panels should correspond to the floor slabs. This should prevent any unnecessary cutting of elements. More important, is the allocation of reinforcing bars that is placed in keyways at ends of the prestressed concrete slabs to the adjoining floor slabs or wall panels (if exterior walls). In order to accomplish this, the floor slabs and the wall panels have to align to allow rebars to penetrate through the wall panels.
6.2 Spans/Heights

Floor Spans

There is a definite limitation of maximum span lengths of prestressed concrete floor slabs ranging from 35’ to 40’. Considerations should be given to the allowable service loads, building codes, fire ratings and whether or not concrete topping will be used before span dimensions are determined. These considerations will effect the locations of load-bearing walls, which ultimately effects the functions and space allocations between the walls.

Wall Heights

The maximum lengths for prestressed concrete wall panels is based on the allowable transportation limitations that ranges around 45’. If a typical floor height is 8 plus 10" for the floor slab thickness (8'-10"), then a length of 45' of prestressed concrete wall panel will accommodate 5 floors lengths. An obvious and substantial savings increase in labor costs and construction time with one-time production and handling of one wall member versus five wall panels associated with Spancrete’s load-bearing prestressed concrete wall system mentioned in chapter 2.2.4.

There is substantially more flexibility with ceiling heights than with any other precast wall system. Based on the continuous prestressed concrete wall panel with various lengths, holes that are drilled through the wall panels for the attachment of concrete beams, can be drilled to fluctuate any desired floor intervals e.g. one floor height can be 8′ high, the next can be at 12′ height and the proceeding floor height can be 10′ high without any additional implied constructional costs with the exception of the prefabricated reinforced concrete support panel to correspond to the heights, and the waste of materials. Also, the prestressed concrete wall panels can come in any desired lengths up to 45′ due to the the production methodology of the members.
6.3 Design Restrictions

The design restrictions of this system confronted by the designer is limited to straight load-bearing walls/party walls that extends the length or width (depending on its application) of the building. The walls must be juxtapositioned parallel with each other (for bearing support of decking system). Also, the distance between the continuous straight walls depends on the decking system used and there respective maximum spans.

6.4 Exterior Fenestrations

As far as deciding on what type of exterior fenestrations the designer may want to apply, he or she is only limited to his or her imagination.

6.4.1 Perpendicular to Load-bearing Walls

The exterior walls that are perpendicular to the load-bearing walls are limitless as far as the type of materials desired and the type of wall construction. It can range from a light curtain wall to a solid masonry wall construction with punched openings. The curtain wall construction would be secured onto the longitudinal edge of the prestressed concrete floor slabs. At the same time, the masonry wall can be constructed the full height of the building adjacent the floor slabs, or run intermittently between the floor slabs. This would result in the possibility of emphasizing contrasting materials with a subdivision of horizontality.

Balconies can also be provided by protruding the continuous concrete beams and floor slabs beyond the reinforced concrete support panels. Cantilevering has certain limitations based on the design of the continuous concrete beams. Also, the designer is restricted to extend the length of the cantilever to the full length of the concrete floor slabs unless masonry construction is used.

6.4.2 Parallel to Load-Bearing Walls

The exterior walls running parallel to the load-bearing walls presents more restrictions than walls running perpendicular to it. The designer must consider the structural integrity of the wall system in that there should be a continuity of the prestressed concrete wall panels. A certain amount of wall panels may be deleted for openings of windows and/or doors.

The material selection on these facades also presents a wide spectrum of choices, though its applications are limited in the sense that it should be applied between the continuous concrete beam.
Cantilevering may also be achieved by eliminating the corresponding wall panels, and by extending the prestressed concrete floor slabs (bearing over the continuous concrete beams) beyond the exterior wall plane.

6.5 Applications
This building system may be incorporated in virtually any building type in the construction industry.

6.5.1 Residential
This system is geared to the housing industry primarily of its applicable spans of the prestressed concrete floor and roof slabs.

In apartment building, the central or double-loaded corridor system is considered the most economical. This is to understand when we consider that every square foot of public corridor serves two apartments instead of one.

Each building type has a modifying effect on the apartments placed within its confines. The central corridor type, limits the layout of the apartments minimally. What determines the kind of apartment layout the designer is able to work out is based on the total building length and depth.

In order to be economically feasible the typical floor should contain a maximum number of apartments. Given the minimum room widths determined by the program, just so many apartments can fit into the available building length. The number of apartments in this length can be improved on if each apartment is arranged - keeping the gross area constant - with shorter exterior exposure and increased depth. Naturally, this will put constraints on the apartment. Bedrooms become so narrow that dressers and desks must be placed along the exterior wall, thus eliminating the option of floor-to-ceiling fenestration. The inner ends of the rooms become darker. In spite of all this, buildings with narrow, deep apartments tend to be more economical: using the same gross square foot area, they have smaller perimeters and less exterior wall.

The following illustrations show efficiency, one-bedroom, two-bedroom, and three-bedroom apartments with average depth and exterior exposure as well as with increased depth and reduced exterior exposure. They also show the consequences of using some of the apartment space ("borrowing") to accommodate core elements along the central corridor.

It is important to be aware that the apartments are averages reflecting more the marketing conditions than living styles.
6.5.2 Commercial, Industrial, & Institutional

There are applications in commercial, industrial and institutional. There are certain restrictions based only on the maximum spans of the decking systems. In commercial and industrial applications, the perimeter walls may be composed of prestressed concrete wall panels while the interior may be of other means of support, e.g. post and beam system to prevent obstructions otherwise unavoidable if wall panels are used.
LEGEND

- Load-Bearing Prestressed Concrete Wall Panels
- Non Load-Bearing Prestressed Concrete Wall Panels
I. LAYOUT OF PRESTRESSED CONCRETE ELEMENTS

LEGEND

- Load-Bearing Prestressed Concrete Wall Panels
- Non Load-Bearing Prestressed Concrete Wall Panels

1. 8'-0 wide Modules
2. Stairwell
3. Corridor
4. Elev. Shaft
5. Balcony
6. Prestressed Conc. Floor Slabs
7. 4'-0 wide Modules

119x266
Efficiency Apartment

Efficiency Layout

LEGEND

- Load-Bearing Prestressed Concrete Wall Panels
- Non Load-Bearing Prestressed Concrete Wall Panels
One Bedroom Apartment

One Bedroom Layout

LEGEND
- Load-Bearing Prestressed Concrete Wall Panels
- Non Load-Bearing Prestressed Concrete Wall Panels
Two Bedroom Apartment

LEGEND

Load-Bearing Prestressed Concrete Wall Panels
Non Load-Bearing Prestressed Concrete Wall Panels
Two Bedroom Layout

LEGEND

- Load-Bearing Prestressed Concrete Wall Panels
- Non Load-Bearing Prestressed Concrete Wall Panels
Three Bedroom Apartment

LEGEND

Load-Bearing Prestressed Concrete Wall Panels
Non Load-Bearing Prestressed Concrete Wall Panels
Three Bedroom Layout

LEGEND

- Load-Bearing Prestressed Concrete Wall Panels
- Non Load-Bearing Prestressed Concrete Wall Panels

Three Bedroom Apartment
7.0 ECONOMICS OF THE SYSTEM
The use of precast, prestressed concrete units can only be justified if it can be shown to be economically more effective than building with traditional methods.

Section 7.1 addresses the advantages of conventional precast, prestressed concrete that is existing in today's market, while section 7.2 deals more directly with this system as far as economy is concerned.

7.1 The Attributes of Precast, Prestressed Concrete

Less Construction Time

Precast, prestressed concrete components can be uniformly mass produced under controlled manufacturing conditions and environments, allowing for year-round production of components, while excavation and foundation work proceeds at the site. Result: Compressed construction schedule. Components are usually erected directly from the truck to the structure (making it ideal for projects with limited site access or those with on-site material storage space). Total construction time and on-site labor costs are also reduced because components fit readily into place.

Improved Construction Efficiency

With standardized components, smaller and more efficient erection crews can be used, resulting in time and money savings.

Lower Interim Financing Costs

High mortgage rates and cost of interim financing are major concerns of builders, owners and developers who face potential financial risks during construction - from obtaining a construction loan or mortgage, to cost and/or schedule overruns. The reduced construction time of precast, prestressed concrete effectively minimizes these financial risks.

Cost Control

Cost information is monitored from preliminary studies through to contract completion which allows the designer and/or developer to work from a reliable price from the very start of the anticipated project.

Mortgage Companies More Receptive

Mortgage companies are more receptive to the lower project costs and the inherent benefits of precast, prestressed concrete. More accurate predictions of the completion date can be made due to the reduced construction time.
Early Enclosure for Other Construction

Because the structure can be erected so quickly, other trades can start sooner. A working platform is provided for the trades as the structure rises, eliminating the need for scaffolding.

Earlier Occupancy

This is the bottom-line reason why precast, prestressed concrete structures are the economical choice. The faster a building is completed, the sooner it can be put to use by its owner - and precast, prestressed structures save construction time.

Energy Efficiency

Precast, prestressed concrete provides exceptional energy efficiency throughout the life of the building. The use of precast, prestressed concrete provides greater heating and cooling equipment efficiency due to its outside-air infiltration protection, condensation control, temperature stability and thermal storage capabilities.

Earthquake, Fire Resistance

Precast, prestressed concrete provides absolutely reliable fire protection of lives and property without total dependence on sprinkler systems, often resulting in reduced insurance rates. Precast, prestressed components are widely used in areas such as Alaska and California, which are subject to severe earthquakes.

Lower Insurance Costs

Based on the properties of fire and durability of precast, prestressed concrete, insurance companies offer lower insurance rates to owners.

Design Versatility

The design possibilities of precast, prestressed concrete components are virtually limitless and have been applied to nearly every form of structure. In addition to the great variety of standard components, other components can be custom-made in almost infinite number of shapes, sizes and finishes.

High Durability, Low Maintenance

Precast, prestressed concrete components are produced under high-quality factory conditions, resulting in consistently durable products that require minimal future maintenance.
The basic prerequisite for any successful, economical building systems can be simply stated as:

1) Largest possible elements
2) Repetitive elements
3) Minimal or no temporary bracing
4) Safe, simple, proven connections

This type of approach of construction reduces costs in detailing, production and erection. These benefits are most fully realized when the systems approach is introduced in the early design stage.

Precast, prestressed concrete decks reduce cost by reducing building height, and in certain cases, eliminating the need for fireproofing altogether.

The following table is a cost estimation of precast, prestressed hollow-core concrete slabs for roofs and floors (grouted) from the Means Building Construction Cost Data, 1984.

<table>
<thead>
<tr>
<th>SLABS</th>
<th>CREW</th>
<th>DAILY OUTPUT</th>
<th>UNIT</th>
<th>BARE COSTS</th>
<th>TOTAL INCL O&amp;P</th>
</tr>
</thead>
<tbody>
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<td></td>
<td></td>
<td>MAT.</td>
<td>INST.</td>
<td>TOTAL</td>
</tr>
<tr>
<td>6&quot; deep</td>
<td>C-11</td>
<td>4,875 S.F.</td>
<td>2.30</td>
<td>.51</td>
<td>2.81</td>
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<td></td>
<td>5,850</td>
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<td>.43</td>
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<tr>
<td>8&quot; deep</td>
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<td>7,200</td>
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<td>.35</td>
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<td>.28</td>
<td>3.03</td>
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<td>9,500</td>
<td>3.10</td>
<td>.26</td>
<td>3.36</td>
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The following table is a cost estimation of precast, prestressed concrete wall panels for high-rise construction from the same source.

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<th>CREW</th>
<th>DAILY OUTPUT</th>
<th>UNIT</th>
<th>BARE COSTS</th>
<th>TOTAL INCL O&amp;P</th>
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</thead>
<tbody>
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<td></td>
<td></td>
<td></td>
<td>MAT.</td>
<td>INST.</td>
<td>TOTAL</td>
</tr>
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<td>288 S.F.</td>
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<td>15.60</td>
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<td>20' x 10', 6&quot; thick, smooth gray</td>
<td></td>
<td>1,800</td>
<td>8</td>
<td>1.34</td>
<td>9.34</td>
</tr>
<tr>
<td>Exposed aggregate</td>
<td></td>
<td>1,800</td>
<td>8.75</td>
<td>1.34</td>
<td>10.09</td>
</tr>
<tr>
<td>30' x 10', 6&quot; thick, smooth gray</td>
<td></td>
<td>2,100</td>
<td>8</td>
<td>1.15</td>
<td>9.15</td>
</tr>
<tr>
<td>White face</td>
<td></td>
<td>2,100</td>
<td>9.25</td>
<td>1.15</td>
<td>10.40</td>
</tr>
</tbody>
</table>

100
Total bare costs of precast, prestressed concrete wall panels added together equals $18.71, divided by 5 gives us an average cost of $3.74 per sq. ft.

Total overhead and profits, of precast concrete wall panels added together equals $21.56, divided by 5 gives us an average cost of $4.31 per sq. ft.

For a cost estimation of precast concrete wall panels for low-rise construction see table on the previous page and deduct 25% for installation costs.

The total overhead and profits of precast concrete equals $101.70, divided by 8 gives us $12.71 per sq. ft.

If we compare costs that of precast, prestressed concrete slabs and the precast concrete wall panels, we can obviously see a substantial difference.

The average cost of material for precast, prestressed concrete slab is $3.74 per sq. ft. while the precast concrete wall panels cost an average of $10.68 per sq. ft. for low-rise construction versus $11.62 per sq. ft. for high-rise construction.

The average costs for overhead and profits for, precast, prestressed concrete slab is $4.31 per sq. ft. while the precast concrete wall panels cost an average of $12.71 per sq. ft. for low-rise construction versus $13.80 per sq. ft. for high-rise construction.

It should be mentioned that the precast concrete wall panels are used as a curtain wall where an additional structural framing construction (concrete or steel) is required to "hang" the wall panels. Whereas the prestressed concrete slab are also used as an exterior cladding but also incorporates the panels as either non load-bearing walls or load-bearing walls for either interior or exterior applications of the building.

The result of these large price variations is due to the fact that the prestressed concrete slabs are mass produced on 400 to 600° casting beds and can be economically be cut to specified lengths while the precast concrete wall panels are custom designed to designer's specifications with regards to size, color, shape and texture.

Another possible cost reduction can be attributed to the fact that foundation walls can be completely eliminated. The prestressed concrete wall panels can bare directly onto the foundation footings which obviously saves time and money in expensive formwork.
8.0 EVALUATION & CONCLUSION
The research thus accomplished was done at a conceptual level, skimming over the top surface. It is an original idea and development, which could be further developed and refined into a marketable new methodology of construction.

More research would need to be done in the design flexibility of this system. Some of the questions that could be addressed are:

- How high can one build with this system?
- Can one offset the load-bearing walls from a single and straight wall plane?
- How would this system comply with the building codes?
- What calculations would be necessary to determine the structural sizes of the components?

What are the cost analysis of this system that could provide a justification to its applicability in real practice?

What thorough investigation could have looked at regarding various finishes and claddings?

In conclusion, based on this research, this system manifests its vast adaptability in today's construction market context with a substantial savings.
MILESTONES OF EVENTS AND DEVELOPMENTS IN NORTH AMERICAN PRESTRESSED CONCRETE INDUSTRY (1939-1958)

Summarized below is a chronological listing of events influencing the development of the practical use of linear prestressed concrete in the United States and other parts of the western hemisphere.

YEAR   EVENTS

1939  First experimental prestressed concrete piles driven by the Raymond Concrete Pile Corporation in New York Harbor.

1944  Roebling engineers begin study of prestressing steel and research in prestressed concrete.

1946  Prestressed concrete floor slab designed by Roebling is complete in Roebling's Chicago warehouse. First prestressed concrete structure in the United States and first use of Roebling materials specifically developed for prestressed concrete, such as factory-made prestressed cable assemblies consisting of cold-drawn hot-galvanized acid steel wire, and specially designed end terminals.

1946  Tests of three sets of four prestressed concrete beams begin at Tulane University under the direction of Professor Walter Blessey.

1947  Lumberville suspension bridge completed. Floor was prestressed by means of Roebling's 1/2 in. (12.7 mm) diameter high strength rods having threads at their ends for prestressing and anchoring.

1947  Professor Magnel's first visit to the United States (sponsored by the Belgian American Educational Foundation).

1949  Rio Paz suspension bridge, connecting Guatemala to El Salvador, open to highway traffic. It features precast prestressed concrete floor slabs similar to the Lumberville bridge.

1949  Start of fire tests on prestressed concrete elements at Korchamwood, Great Britain by the British Joint Fire Research Organization.

1949  Start of construction of the substructure of the Walnut Lane Bridge and of the manufacture at the site of the full-sized 160 ft. (48.8 m) long test girder. First use of stress-relieved wire, an
American innovation (Roebling).

1949  Start of test to failure of full-sized Walnut Lane test girder (October 25, 1949). Beginning of site casting of actual girders.

1949  Concrete Products Company of America starts production of box girders in America's first pretensioning plant, at Pottstown, Pennsylvania.

1950  Fayetteville, Tennessee Stadium. Use of Roebling galvanized prestressed concrete strands and anchor fittings.

1950  Turkey Creek Bridge, Tennessee. Completion of first American prestressed concrete bridge using concrete blocks and Roebling developed prestressing materials.

1951  Fritz Research Laboratory at Lehigh University, Bethlehem, Pennsylvania, begins tests on box girders. Sponsored jointly by the Department of Highways of Pennsylvania and Roebling. The program was to last more than 20 years, continuously.

1951  Formation of Precompressed Concrete Company Ltd. (PRECO), first Canadian firm entering the prestressed concrete field.

1951  Illinois Cooperative Highway Research program was conducted at the University of Illinois, under the direction of Professor Chester Siess. Questions and answer session at the AASHO Committee meetings on Bridges and Structures and Bureau of Public Roads. It marks the beginning of University of Illinois' research in prestressed concrete.

1951  First United States National MIT sponsored prestressed concrete conference.

1951  First American pretensioned prestressed concrete bridge using non-stress-relieved strands as manufactured by American Steel and Wire Corporation completed in Hershey, Pennsylvania.

1951  Completion of first California prestressed concrete foot bridge using headed wire.

1952  Completion in Mid-West of first buildings using prestressed girders and permanent slabs stressed by headed wires.

1952  Bureau of Public Roads (now Federal Highway
administration) publishes its short "criteria" to be used in the design of post-tensioned prestressed concrete bridges.

1952

The Fritz Laboratories at Lehigh University published their first Progress Report in the program of prestressed concrete research begun in 1951. It was to give the impetus for the construction of the prestressed concrete box girders.

1953

September 10, formation of Prestressed Concrete Development Group of Canada.

1953

Prestressed concrete research programs began on a large scale on a systematic basis at a number of leading American Universities in addition to Lehigh University.

1953

University of Florida, Gainsville, Florida - In cooperation with the Florida State Roads Department: A study concerning plastic flow and shrinkage of prestressed concrete. Fourteen such prestressed concrete girders cast at various Florida bridge construction sites were held under observation for several years.

1953

University of Illinois, Urbana, Illinois, with the Illinois Division of Highways and the U.S. Bureau of Public Roads - As Research Associate Professor of Civil Engineering, Professor Chester Siess was extremely interested in shear strength of prestressed concrete beams. Consequently, a most elaborate program was established. Much of the work was the responsibility of Eugene Zwoyer, then Research Associate in Civil Engineering.

1953

University of California - Beginning with the on site testing of the Arroyo Seco Pedestrian Bridge in 1951, continuing throughout 1952, laboratory tests on prestressed concrete under the stimulus of Professor T.Y. Lin were in full swing by 1953. At that time, full emphasis was on prestressed concrete thin shells and flat plates. Findings were to be the basis for the subsequent design and construction of the cantilever thin shell roof for the Caracas Stadium for which Felix Kulka of T.Y. Lin International was responsible.

1953

Portland Cement Association Research and Development Laboratories, Skokie, Illinois - At PCA's laboratories, consideration was being given to commence large research programs to include full size girders, all under leadership of Dr. Alan
Bates, Dr. Eivind Honestad and Dr. Alan Mattack. Reports of many tests were published by PCA.

1954 January 28, 1954 Canadian Conference on Prestressed Concrete at University of Toronto. Professor Magnel attended as did many Canadian and American engineers. Particularly valuable were the tests on full-sized beams reported by Cleveland's Austin Company.

1954 Use of the first time in Canada of 5000 psi ready-mix concrete.

1954 Publication by the Bureau of Public Roads of the revised and expanded "Criteria For Prestressed Concrete Bridges" for both pretensioned and post-tensioned concrete.

1954 Founding of Prestressed Concrete Institute.

1954 Prestressed Concrete Institute published the first edition of the Tentative Specifications for Pretensioned Prestressed Concrete.

1955 Bureau of Public Roads, Highway Research Board and others complete arrangements for construction of $12 million (increased before completion of Project to $27-million) road test project of AASHO, in Ottawa, Illinois. Project included prestressed concrete bridges. In 1962, AASHO revealed results in an extensive three-volume report. At least three sets of data influenced subsequent prestressed concrete bridge design in that tensile stresses would be allowed in concrete prestressed with strands. (Up to then no bottom tensile stresses were allowed at midspan of girders.)

1957 First World Conference of Prestressed Concrete at San Francisco sponsored by the PCI with the cooperation of National Professional Societies.

1958 Publication by the ACI-ASCE Joint Committee 323 of the Tentative Recommendations for Prestressed Concrete.
PROPERTIES PECULIAR TO PRESTRESSED CONCRETE

Shrinkage

Shrinkage of concrete is a process known to everyone familiar with reinforced concrete. As concrete cures, its total volume decreases slightly and it tends to shrink in all three dimensions.

When the tension in pretensioned strands is transferred from external anchorages to the concrete members, the compressive force created in the concrete closes all the existing shrinkage cracks and both the concrete member and the strands shorten an amount equal to the sum of the widths of the shrinkage cracks. Although the rate of shrinkage is greatest when the member is first cast, it continues for some time after the prestressing operation. Since the continuing shrinkage cannot cause cracks in the concrete which is now in compression, it causes additional shortening. In the final analysis, the pretensioned strands shorten an amount equal to the total shrinkage. This shortening causes a reduction of the tensile stress in the strands.

Elastic Compression

Elastic compression of the concrete member takes place as the prestressing force is applied. As in any elastic material its magnitude is a function of the modulus of elasticity of the concrete and the intensity of the compressive stress.

Since the pretensioned is under initial tension when the concrete member under zero stress is bonded to it, the strand shortens an amount from the anchorages to the concrete member.

Creep

Creep of concrete, often referred to as plastic flow, is inelastic shortening which takes place over a period of time. It is caused by a constant compressive stress, and its magnitude is a function of the intensity of that stress. Pretensioned tendons shorten an amount equal to the entire creep.

Relaxation

Relaxation of prestressing tendons is the fourth cause of stress loss. Since these tendons are used at an initial tension of 65 to 70 percent of their ultimate strength, they, too, undergo a creep or plastic flow to the constant high stress. Conditions, however, are somewhat different from those in the concrete. If a weight were hung on a tendon to create a stress equal to 70 percent of its ultimate strength, the tendon would slowly elongate or creep as the concrete member
shortens. In an actual structure the tendon is not held at a constant load; it is not even held at a constant length. As the concrete member shortens from the factors mentioned above, the tendons shortens too. There is a certain amount of plastic flow within the tendon which, since it cannot cause a reduction in stress is called "relaxation."
MATERIALS OF CONCRETE

Properties

In reinforced concrete structures the usable concrete strength is limited by the behavior of the member. When the tensile stress in the reinforcing steel exceeds 18,000 or 20,000 psi, the member begins to show excessive cracks and deflection. Since 3,000-psi concrete is strong enough to develop these stresses in the reinforcing, higher strengths are seldom specified.

The concrete used in prestressed concrete, although made of the same basic ingredients, is much stronger, since its full strength can be utilized. In this case the governing factor is economical fabrication. A majority of members are made of 5,000-psi concrete, although some fabricators are appreciably higher strengths and most specifications permit a minimum of 4,000 psi.

High-strength concrete has several advantages:

1. A smaller cross-section area can be used to carry a given load. This means less dead weight and in many instances shallower members, giving more clearance.

2. Its higher modulus of elasticity decreases camber, which is frequently a problem in prestressed concrete because of the relatively high negative moment that exits under the dead-load condition. The high modulus of elasticity also reduces deflection and in pretensioned members cuts down the stress loss due to elastic shortening.

\[ E_c = 33 \left( \frac{w}{F_c} \right)^{2/3} \]

- $E_c$: Elastic Modulus (ksi)
- $w$: Unit weight (pcf)
- $F_c$: Compressive Strength (ksi)

Unit weight $w$ pcf

\[ E_c = 6500 \text{ psi} \]

\[ E_c = 5000 \text{ psi} \]

\[ E_c = 3750 \text{ psi} \]

\[ E_c = 2500 \text{ psi} \]

\[ E_c = 2000 \text{ psi} \]
3. Members can be prestressed and equipment released for the next pour in minimum time because the required compressive strength of concrete at time of initial prestress is reached sooner. In some cases fabricators of pretensioned members use a mix which gives a higher compressive strength of concrete at time of initial prestress in time to maintain pouring schedule.

4. In bridges and other members exposed to freezing or salt spray the combination of high strength and density plus freedom from cracks makes prestressed concrete virtually maintenance-free.

Placing

Prestressed concrete fabricators employ several aids for handling the high-strength low-slump concrete to achieve satisfactory placement and rapid curing.

Vibrators are standard equipment for all work of this type. Vibrating screeds are frequently used on area-type members such as double T's and channels.

Air entraining cement and admixtures such as Plastiment are employed to increase the workability while maintaining the water-cement ratio and ultimate strength is avoided because the extra cement paste in the rich mix is a source of additional shrinkage.

Curing

Rapid curing to permit frequent reuse of equipment is an important factor in the economical production of prestressed concrete and especially of the pretensioned type. Figure 39 illustrates the curing speed obtained by steam curing on a typical circulating hot oil through pipes located under and beside the curing concrete. Many use high-early-strength cement.

Calcium chloride is not used to accelerate curing because existing test data indicate that its action is damaging to the properties of high strength tendons.
PROCEDURE
1. Delay steam 4 to 6 hr
2. Raise steam 1° per min to 145° F
3. Hold steam at 145° for 18 hr

MIX
Cement 658 lb
Sand 1,195 lb
Stone 1,908 lb
Water 34.7 Gal
Plastiment 21 to 28 oz

Fig. 39
Lightweight Concrete

Prestressed concrete members that are pretensioned can be fabricated satisfactorily from light-weight concrete.

The chief differences between regular-weight concrete and lightweight concrete of the same ultimate strength are in the elastic properties.

Shortening of lightweight concrete due to creep plus shrinkage is usually greater than the shortening of regular-weight concrete under similar conditions, but with properly designed mixes it is not excessive and can be provided for in the design.

Properties of many lightweight aggregates are such that it is difficult to measure their water content, thus making it difficult to know how much water to add to the mix. A slump test is sometimes used as a check. In order to obtain a uniform product it is often desirable to use regular sand as the fine aggregate even though it does increase the weight of the finished product.

Producers of lightweight aggregates know their own products. They can recommend mixes and handling methods to give concrete with the design properties. They should also have test reports to indicate what creep and shrinkage can be expected in concretes made from their product.

Prestressed concrete members made of lightweight concrete have a longer fire endurance than identical members made of regular-weight concrete. One possible exception is thin slabs (less than 3 in.) in which fire rating is determined by heat transfer through the slab.
TENDONS

General Properties

The need for high-strength tendons to minimize the drop in prestressing force due to stress losses. Satisfactory tendons are made from wire or combinations of wires and from high-strength bars, all of which are fabricated with special prestressed concrete properties. These tendons differ from most other steels in several ways in order to meet the particular requirements of prestressed concrete.

Uniform elongation to initial tension is essential in obtaining an accurate prestressing force. Fig 40 is the stress-strain curve of a 0.196-in.-diameter uncoated stress-relieved prestressed concrete wire. (Its general shape is typical of all types of prestressed concrete tendons.)

For all practical purposes, this curve is a straight line to a point above the initial tension of 165,000 to 175,000 psi normally used for 0.196-in. wire. Tendons do not have a yield point like that of ordinary steel where elongation continues without increase of stress. They do reach a point where the ratio of strain to stress increases rapidly and remains large until the tendon fails. This change in slope of the curve is also a necessary property. When a beam is overloaded and the stress in the tendon approaches ultimate, the tendon elongates, causing a visible deflection which warns impending failure.

In addition to high strength and special elastic properties, a tendon must have a low coefficient of relaxation at the high stresses used.
Prestressed concrete wire is made by drawing a high-carbon hot-rolled round steel rod through several conical dies. As the rod passes through each die, its diameter is decreased and its length is correspondingly increased. In the process, the crystals that made up the rod are drawn out into long parallel fibers which give wire its extremely high tensile strength.

Cold drawn wire does not have the uniform plastic properties needed in the prestressed concrete. As the crystals elongate into fibers, they develop stresses in excess of their yield point. The resulting wire is made up of fibers which are full if internal stresses. When a tensile load is applied to the wire, each fiber elongates the same amount. The stress due to this elongation is added to the internal stress, and soon the fiber with the highest internal stress reaches the point where its ratio of strain to stress increases rapidly. From here on this fiber will elongate with the others, but its stress will not increase so rapidly. Since the internal stresses in the various fibers are not uniform, first one fiber, then another, then another will reach the yield point. The resulting load-elongation curve of the wire is not uniform.

The internal stresses in the cold drawn wire are eliminated by subjecting it to a stress-relieving process in which it is raised to a moderate temperature (750° to 850° F) for a short period of time (15 to 30 sec.). This is not heat-treated and does not change the ultimate strength of the wire to any noticable degree. It does create a wire which has the desired uniform elastic properties because it is free of internal stresses.

At stress up to 70 per cent of its ultimate strength, the modulus of elasticity of uncoated stress-relieved prestressed concrete wire is approximately 29,000,000 psi. While this value is sufficiently accurate for design calculations, it is recommended that the steel fabricator's load-elongation curve for the particular wire be used in computing the elongation required in jacking wires to a specific tension.

Seven-Wire Strand

Seven-wire uncoated stress-relieved concrete strands conforming to ASTM Designation A 416 are the tendons normally used in pretensioned bonded members. Fig 41 is a photograph of a seven-wire strand and Fig 42 is the load-elongation curve.

Each strand is made up of seven cold drawn wires. The center
wire is straight, and the six outside wires are laid helically around it. All six outside wires are the same diameter, and the center wire is slightly larger. The difference in diameter is sufficient to guarantee that each of the outside wires will bear on and grip the center wire. This is an important detail in members where the tension in the strand is developed through bond. The six outer wires are bonded to the concrete both by adhesive bond and by mechanical bond of the concrete in the valleys between the wires. Under tension each of the outer wires bears on the center wire, and the resulting friction makes the center wire elongate with the outer wires. If the center wire were too small, the outer wires would bear against each other to form a pipe through which the center wire would slip without carrying any load.

After the seven wires are formed into a strand, the strand is subjected to a stress-relieving process. The result is a strand with ideal elastic properties and free of internal stresses. Stress-relieving the individual wires before stranding does not produce a satisfactory strand because the outer wires are subjected to severe twisting in the stranding operation, which creates internal stresses. These are removed only when the stress-relieving operation follows the stranding operation.

![Fig. 41](image1)

![Fig. 42](image2)

- Nominal diameter - \( \frac{3}{8} \) in.
- Guaranteed minimum ultimate - 20,000 lb
- Nominal area - 0.0799 sq in.
- Elongation in 10 ft at recommended prestressing load (14,000 lb) - 0.750 in.
ACoustical Properties

General

The basic purpose of architectural acoustics is to provide a satisfactory environment in which desired sounds are clearly heard by the intended listeners and unwanted sounds (noise) are isolated or adsorbed.

Under most conditions, the architect/engineer can determine the acoustical needs of the space and then design the building to satisfy those needs. Good acoustical design utilizes both absorptive and reflective surfaces, sound barriers and vibration isolators. Some surfaces must reflect sound so that the loudness will be adequate in all areas where listeners are located. Other surfaces absorb sound to avoid echoes, sound distortion and long reverberation times. Sound is isolated where it is not wanted by selecting wall and floor-ceiling constructions. Vibrations generated by mechanical equipment must be isolated from the structural frame of the building.

The problems of sound insulation are usually considerably more complicated than those of sound absorption. The former involves reductions of sound level, which are of greater orders of magnitude than can be achieved by absorption. These large reductions of sound level from space to space can be achieved only by continuous, impervious barriers. If the problem also involves structure borne sound, it may be necessary to introduce resilient layers or discontinuities into the barriers.

Sound absorbing materials and sound insulating materials are used for different purposes. There is not much sound absorption from an 8 in. concrete wall; similarly, high sound insulation is not available from porous, lightweight material that may be applied to room surfaces. It is important to recognize that the basic mechanisms of sound absorption and sound insulation are quite different.

Sound Transmission Loss

Sound transmission loss measurements are made at 16 frequencies at one-third intervals covering the range from 125 to 4000 Hz. To simplify specification of desired performance characteristics the single number Sound Transmission Class (STC) was developed.

Airborne sound reaching a wall, floor or ceiling produces vibrations in the element and is radiated with reduced intensity on the other side. Airborne sound transmission loss of walls and floor-ceiling assemblies is a function of their weight, stiffness and vibration damping characteristics.
Weight is concrete's greatest asset when it is used as a sound insulator. For sections of similar design, but different weights, the STC increases approximately 6 units for each doubling of weight as shown in Fig. 43.

The acoustical test results of both airborne sound transmission loss and impact insulation of 6 and 8 in. hollow-core slabs are shown in Fig. 44.

Table 1 presents the ratings for precast concrete walls and floor-ceiling assemblies. The effects of various assembly treatments are shown in Table 2. The improvements are additive, but in some cases the total effect may be slightly less than the sum.

Absorption of Sound

The sound absorption coefficient can be specified at individual frequencies or as an average of absorption coefficients (NRC).

A dense non-porous concrete surface typically absorbs 1 to 2 percent of incident of sound and has an NRC of 0.015. There are specially fabricated units with porous concrete surfaces which provide greater absorption. In the case where additional sound absorption of precast concrete is desired, a coating of acoustical material can be spray applied, acoustical tile can be applied with adhesive, or an acoustical ceiling can be suspended. Most of the spray applied fire retardant materials used to increase the fire resistance of precast concrete and other floor-ceiling systems can also be used to absorb sound. The NRC of the sprayed fiber range from 0.25 to 0.75. Most cementitious types have an NRC from 0.25 to 0.50.

Acceptable Noise Criteria

As a rule, a certain amount of continuous sound can be tolerated before it becomes noise. An "acceptable" level neither disturbs room occupants nor interferes with the communication of wanted sound.

The most generally accepted and commonly used noise criteria today are expressed as the Preferred Noise Criteria (PNC) curves, Fig 45. These values are the result of extensive studies based on the human response to both sound pressure level and frequency and take into account the requirements for speech intelligibility. The figures in Table ... represent general acoustical goals. They can also be compared with anticipated noise levels in specific rooms to assist in evaluating noise reduction problems.

Undesirable sounds may be from an exterior source such as automobiles or aircraft, or they may be generated as speech in an adjacent classroom or music in an adjacent apartment. They
(a) Sound Transmission Class (STC)

<table>
<thead>
<tr>
<th>Type and Overall Thickness</th>
<th>Inside Light</th>
<th>Construction Space</th>
<th>Outside Light</th>
<th>STC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/8&quot; Plate or float</td>
<td>—</td>
<td>—</td>
<td>1/8&quot;</td>
<td>23</td>
</tr>
<tr>
<td>1/4&quot; Plate or float</td>
<td>—</td>
<td>—</td>
<td>1/4&quot;</td>
<td>28</td>
</tr>
<tr>
<td>1/2&quot; Plate or float</td>
<td>—</td>
<td>—</td>
<td>1/2&quot;</td>
<td>31</td>
</tr>
<tr>
<td>1&quot; Insulated glass</td>
<td>1/4&quot;</td>
<td>1/2&quot; Air Space</td>
<td>1/4&quot;</td>
<td>31</td>
</tr>
<tr>
<td>1/4&quot; Laminated</td>
<td>1/8&quot;</td>
<td>.030 Vinyl</td>
<td>1/8&quot;</td>
<td>34</td>
</tr>
<tr>
<td>1 1/2&quot; Insulated glass</td>
<td>1/4&quot;</td>
<td>1&quot; Air Space</td>
<td>1/4&quot;</td>
<td>35</td>
</tr>
<tr>
<td>3/4&quot; Plate or float</td>
<td>—</td>
<td>—</td>
<td>3/4&quot;</td>
<td>36</td>
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<td>1/4&quot;</td>
<td>1/2&quot; Air Space</td>
<td>1/4&quot;</td>
<td>38</td>
</tr>
<tr>
<td>1&quot; Plate or Float</td>
<td>—</td>
<td>—</td>
<td>1&quot;</td>
<td>37</td>
</tr>
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<td>2 3/4&quot; Insulated glass</td>
<td>1/4&quot;</td>
<td>2&quot; Air Space</td>
<td>1/2&quot;</td>
<td>39</td>
</tr>
<tr>
<td>4 3/4&quot; Insulated glass</td>
<td>1/4&quot;</td>
<td>4&quot; Air Space</td>
<td>1/2&quot;</td>
<td>40</td>
</tr>
<tr>
<td>6 3/4&quot; Insulated glass</td>
<td>1/4&quot;</td>
<td>6&quot; Air Space</td>
<td>1/4&quot;</td>
<td>42</td>
</tr>
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</table>

(b) Transmission Loss (dB)

<table>
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<tr>
<th>Frequency (Hz)</th>
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<th>160</th>
<th>200</th>
<th>250</th>
<th>315</th>
<th>400</th>
<th>500</th>
<th>630</th>
<th>800</th>
<th>1000</th>
<th>1250</th>
<th>1600</th>
<th>2000</th>
<th>2500</th>
<th>3150</th>
<th>4000</th>
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<tbody>
<tr>
<td>1/4 inch plate glass — 28 STC</td>
<td>24</td>
<td>22</td>
<td>24</td>
<td>24</td>
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<td>26</td>
<td>27</td>
<td>33</td>
<td>36</td>
<td>37</td>
<td>39</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>1 inch insulating glass with 1/2 inch air space — 31 STC</td>
<td>25</td>
<td>25</td>
<td>22</td>
<td>20</td>
<td>24</td>
<td>27</td>
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<td>33</td>
<td>35</td>
<td>34</td>
<td>29</td>
<td>31</td>
<td>33</td>
<td></td>
</tr>
<tr>
<td>1 inch insulating glass laminated with 1/2 inch air space — 38 STC</td>
<td>30</td>
<td>29</td>
<td>26</td>
<td>28</td>
<td>31</td>
<td>34</td>
<td>35</td>
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<td>40</td>
<td>41</td>
<td>40</td>
<td>41</td>
<td></td>
</tr>
</tbody>
</table>

Table 2

Fig. 43

STC = 0.1304 W + 43.48
statistical tolerance = ±2.5 STC
<table>
<thead>
<tr>
<th>Assembly No.</th>
<th>Wall Systems</th>
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<th>IIC</th>
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<tbody>
<tr>
<td>1</td>
<td>4 in. flat panel, 54 psf</td>
<td>49</td>
<td>—</td>
</tr>
<tr>
<td>2</td>
<td>6 in. flat panel, 75 psf</td>
<td>55</td>
<td>—</td>
</tr>
<tr>
<td>3</td>
<td>Assembly 2 with wood furring, 3/4 in. insulation and 1/2 in. gypsum board</td>
<td>58*</td>
<td>—</td>
</tr>
<tr>
<td>4</td>
<td>Assembly 2 with 1/2 in. space, 1 5/8 in. metal stud row, 1 1/2 in. insulation and 1/2 in. gypsum board</td>
<td>63*</td>
<td>—</td>
</tr>
<tr>
<td>5</td>
<td>8 in. flat panel, 95 psf</td>
<td>58</td>
<td>—</td>
</tr>
<tr>
<td>6</td>
<td>14 in. prestressed tees with 4 in. flange, 75 psf</td>
<td>54</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Assembly 7 with 1/2 in. space, 1 5/8 in. metal stud row, 1 1/2 in. insulation and 1/2 in. gypsum board</td>
<td>59</td>
<td>51</td>
</tr>
<tr>
<td>8</td>
<td>Assembly 7 with resiliently suspended acoustical ceiling with 1 1/2 in. mineral fiber blanket above, 77 psf</td>
<td>59</td>
<td>82</td>
</tr>
<tr>
<td>9</td>
<td>Assembly 7 with carpet and pad, 76 psf</td>
<td>54</td>
<td>72</td>
</tr>
<tr>
<td>10</td>
<td>Assembly 9 with carpet and pad, 78 psf</td>
<td>54</td>
<td>72</td>
</tr>
<tr>
<td>11</td>
<td>8 in. hollow-core prestressed units, 57 psf</td>
<td>50</td>
<td>28</td>
</tr>
<tr>
<td>12</td>
<td>Assembly 11 with carpet and pad, 58 psf</td>
<td>50</td>
<td>73</td>
</tr>
<tr>
<td>13</td>
<td>8 in. hollow-core prestressed units with 1/2 in. wood block flooring adhered directly, 58 psf</td>
<td>51</td>
<td>47</td>
</tr>
<tr>
<td>14</td>
<td>Assembly 13 except 1/2 in. wood block flooring adhered to 1/2 in. sound-deadening board underlayment adhered to concrete, 60 psf</td>
<td>52</td>
<td>55</td>
</tr>
<tr>
<td>15</td>
<td>Assembly 14 with acoustical ceiling, 62 psf</td>
<td>59</td>
<td>61</td>
</tr>
<tr>
<td>16</td>
<td>4 in. flat slabs, 54 psf</td>
<td>49</td>
<td>25</td>
</tr>
<tr>
<td>17</td>
<td>5 in. flat slabs, 60 psf</td>
<td>52*</td>
<td>24</td>
</tr>
<tr>
<td>18</td>
<td>6 in. flat slabs, 75 psf</td>
<td>55</td>
<td>34</td>
</tr>
<tr>
<td>19</td>
<td>8 in. flat slabs, 95 psf</td>
<td>58</td>
<td>34*</td>
</tr>
<tr>
<td>20</td>
<td>10 in. flat slabs, 120 psf</td>
<td>59*</td>
<td>31</td>
</tr>
<tr>
<td>21</td>
<td>5 in. flat slab concrete with carpet and pad, 61 psf</td>
<td>52*</td>
<td>68</td>
</tr>
<tr>
<td>22</td>
<td>10 in. flat slab concrete with carpet and pad, 121 psf</td>
<td>59*</td>
<td>74</td>
</tr>
</tbody>
</table>

*Estimated values

Table 1
also may be direct impact-induced sound such as foot-falls on the floor above, rain impact on a lightweight roof construction or vibrating mechanical equipment.

Thus, the designer must always be ready to accept the task of analyzing the many potential sources of intruding sound as related to their frequency characteristics and the rates at which they occur. The level of toleration that is to be expected by those who will occupy the space must be established. Fig. 46 gives the spectral characteristics of common exterior noise sources. Fig. 47 provides similar data on common interior noise sources.

Establishment of Noise Insulation Objectives

Often acoustical control is specified as to the minimum insulation values of the dividing partition system. Municipal building codes, lending institutions and the Department of Housing and Urban Development (HUD) list both airborne STC values and impact IIC values for different living environments. As an example, "HUD Minimum Property Standard - Multiple Housing" has the following requirements:

<table>
<thead>
<tr>
<th>Location of Partition</th>
<th>STC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between living units</td>
<td>45</td>
</tr>
<tr>
<td>Between living units and public space</td>
<td>50</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Location of Floor-Ceiling</th>
<th>STC</th>
<th>IIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between living units</td>
<td>45</td>
<td>45</td>
</tr>
<tr>
<td>Between living units and public space</td>
<td>50</td>
<td>50</td>
</tr>
</tbody>
</table>

Once the objectives are established, the designer then should refer to available data, e.g., Fig 43 or Table 1., and select the system which best meets these requirements. In this respects, concrete systems have superior properties and can with minimal effort comply with these criteria.

Composite Wall Considerations

Doors and windows are often the weak link in an otherwise effective sound barrier. Minimal effects on sound transmission loss will be achieved in most cases by a proper selection of glass, Table 2. Mounting of the glass in its frame should be done with care to eliminate noise leaks and to reduce the glass plate vibrations.

Sound transmission loss of a door depends on its material and construction, and the sealing between the door and the frame. There is a mass law dependence of STC on weight (psf) for both wood and steel doors. The approximate relationships are:

For steel doors: \( STC = 15 + 27 \log W \)

For wood doors: \( STC = 12 + 32 \log W \) where \( W \) = weight of the
Fig. 46

Fig. 47
These relationships are purely empirical and a large deviation can be expected for any given door.

Fig 48 can be used to calculate the effective acoustic isolation of a wall system which contains a composite of elements, each with known individual transmission loss data.

Leaks and Flanking

The performance of a building section with an otherwise adequate STC can be seriously reduced by a relatively small hole or any other path which allows sound to bypass the acoustical barrier. All noise which reaches a space by paths other than through the primary barrier is called flanking. Common flanking paths are openings around doors or windows, at electrical outlets, telephone and television connections, and pipe and duct penetrations.

Although not easily quantified, an inverse relationship exists between the performance of an element as a primary barrier and its propensity to transmit flanking sound. In other words, the probability of existing flanking paths in a concrete structure is much less than in the one of steel or wood frame.

Vibration Isolation

The isolation of vibrations produced by equipment with unbalanced operation of starting forces can frequently be accomplished by mounting the equipment on a heavy concrete slab placed on resilient supports. A slab of this type is called an inertia block.

Inertia blocks can provide a desirable low center of gravity and compensate for the thrusts such as those generated by large fans. For equipment with less unbalanced weight, a "house keeping" slab is sometimes used below the resilient mounts to provide a rigid support for the mounts and to keep them above the floor where they remain cleaner and easier to inspect. This slab may also be mounted on pads of precompressed glass fiber or neoprene.

If static deflection of the floor is more than a small fraction of the static deflection of the resilient mounts, there is a danger that the floor will act as part of the vibrating system. Prestressed concrete floors supporting such
equipment can be built stiff to avoid this effect. A deflection much less than the otherwise satisfactory 1/360 of the span, away from its center, also reduces static deflection.

![Diagram](image)

**Fig. 48**
THERMAL PROPERTIES

General

Thermal codes and standards prescribe in many ways the heat transmission requirements for buildings. Therefore, it is important to have basic knowledge about the heat loss and heat gain of many materials. Some of the fundamentals and design aids that are needed to analyze and compare the heat losses and heat gains through building envelopes.

Precast and prestressed concrete construction have a unique advantage with their thermal inertia and thermal storage properties. This advantage is recognized in some codes, however, procedures to account for the benefits of heavier materials are not usually given.

The trend is toward more insulation with little regard given to its total impact on the energy saved. Before assuming that thick insulation is needed, mass effects, less glass area, reduced infiltration and controlled ventilation should be considered. Further considerations may include building orientation, exterior color, shading or reflections from adjacent structures, surrounding surfaces or vegetation, building aspect ratio, number of stories, and wind direction and speed.

Except where noted the information and design criteria that follow are taken from or derived from ASHRAE "Handbook of Fundamentals", also known as the ASHRAE Handbook, and from the ASHRAE Standard 90-75, "energy Conservation in New Building Design", also known as the ASHRAE Standard.

Thermal Properties of Materials, Surfaces and Air Spaces

The thermal properties of materials and air spaces are based on steady state tests. The tests established the number of British thermal units (Btu) that pass from the warm side to the cool side per sq ft per hr per degree temperature difference either side of the item being tested. The results of the tests determine the conductivity, $k$, per inch thickness for homogeneous sections. For non-homogeneous compound sections and air spaces the tests determine the conductance, $C$, for the total thickness. The values $k$ and $C$ do not include surface conductances. The inside surface conductance, $f_i$, and the outside surface conductance $f_o$ are considered separately.

The resistance method is used to determine the overall thermal effectiveness of wall, floor and roof sections. Therefore, the resistance, $R$, i.e., the reciprocal of $k$, $C$, $f_i$, and $f_o$ must be known. The $R$-values of construction materials are not influenced by the direction of heat flow. On the other hand the $R$ of the surfaces and air spaces differs depending on
orientation, that is whether they are vertical, sloping or horizontal. Also the R-values of surfaces are affected by the velocity of air at the surfaces and by their reflective properties.

Tables 3. and 4. give the thermal resistances of surfaces and 3 1/2 in. air spaces. Values in Table 4. can be used for all air space thickness with very little change in the overall R of the section, with one exception. Where heat flow direction is down, the procedure given in footnote 1, Table 4. should be used.

Table 5. gives the thermal properties of most commonly used building materials. For glass, only u-values are given since the glass alone has almost no thermal resistance. The resistances of the surfaces of the glass contribute mostly to the U-value.

Table 6. gives the thermal properties of various weight concrete, including insulating concretes. It also gives R-values of some of the commonly used prestressed concrete floor, roof and wall units.

Thermal conductances and resistances are usually determined and reported for building materials in their oven dry condition. Conductances and resistances for concrete are often reported in its normally dry condition as well as its oven dry condition. Normally dry is the condition of concrete containing an equilibrium amount of free water after extended exposure to warm air at 35 to 50% relative humidity. Values given in the tables are based on concrete that is considered normally dry.

It should be noted that normally dry concrete in combination with insulation generally provides about the same R-value as equally insulated oven dry concrete. It should also be noted that normally dry concrete, because of its moisture content, has the ability to store a greater amount of heat than oven dry concretes, a property somewhat beneficial when considering dynamic thermal response of concrete.

Thermal Storage Effects

For some time it has been known that walls and roofs of concrete or any massive material react to temperature variations slowly and therefore reduce heating and cooling loads, however, engineering application of this concept has been limited to only estimating mass effects. Computers now make it possible to better account for mass effects with hour by hour calculations for 24 hours, a week, a month, or a year. Some 24-hour peak load computer studies show that as the weight of walls increases the heat flow rates and peak loads decrease. Fig 49. compares the heat gain through two roofs having different weights but with equal U-values and exposed
Thermal resistances, $R_f$, of surfaces

<table>
<thead>
<tr>
<th>Position of Surface</th>
<th>Direction of Heat Flow</th>
<th>Still air, $R_n$</th>
<th>Moving air, $R_{nt}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Non-reflective Surface</td>
<td>Reflective Surface</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A (1)</td>
<td>B (2)</td>
</tr>
<tr>
<td>Vertical</td>
<td>Horizontal</td>
<td>0.68</td>
<td>1.35</td>
</tr>
<tr>
<td>Horizontal</td>
<td>Up</td>
<td>0.61</td>
<td>1.10</td>
</tr>
<tr>
<td></td>
<td>Down</td>
<td>0.92</td>
<td>2.70</td>
</tr>
</tbody>
</table>

(1) Aluminum painted paper
(2) Bright aluminum foil
(3) Winter design
(4) Summer design

Table 3

Thermal resistances, $R_s$, of air spaces (1)

<table>
<thead>
<tr>
<th>Position of Air Space</th>
<th>Direction of Heat Flow</th>
<th>Air Space</th>
<th>Non-reflective Surfaces</th>
<th>Reflective Surfaces</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>One Side (2)</td>
</tr>
<tr>
<td></td>
<td>Horizontal (walls)</td>
<td>Winter</td>
<td>50 10 1.01</td>
<td>2.32</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Summer</td>
<td>90 10 0.85</td>
<td>2.15</td>
</tr>
<tr>
<td></td>
<td>Vertical</td>
<td>Winter</td>
<td>50 10 0.93</td>
<td>1.95</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Winter</td>
<td>50 30 0.84</td>
<td>1.58</td>
</tr>
<tr>
<td></td>
<td>Down (floors)</td>
<td>Summer</td>
<td>50 1.23 3.97 8.72 10.37</td>
<td>3.41</td>
</tr>
<tr>
<td></td>
<td>Down (floORS)</td>
<td>Summer</td>
<td>90</td>
<td>1.00</td>
</tr>
</tbody>
</table>

(1) For 3 1/2 in. air space thickness. The values with the exception of those for reflective surfaces, heat flow down, will differ about 10% for air space thickness of 3/4 in. to 16 in.

(2) Aluminum painted paper
(3) Bright aluminum foil

Table 4
### Thermal properties of various building materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Unit Weight, pcf</th>
<th>Resistance Per inch of thickness, 1/k</th>
<th>For thickness shown, R</th>
<th>Transmittance, U</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insulation, rigid</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cellular glass</td>
<td>8.5</td>
<td>2.63</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fiberglass</td>
<td>4 to 9</td>
<td>4.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mineral fiber, resin binder</td>
<td>15</td>
<td>3.45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mineral fiberboard, wet felted, roof insulation</td>
<td>16-17</td>
<td>2.94</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wood, shredded, cemented in preformed slabs</td>
<td>22</td>
<td>1.67</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polystyrene - cut cell surface</td>
<td>1.8</td>
<td>4.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polystyrene - smooth skin surface</td>
<td>3.5</td>
<td>5.26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polystyrene - molded bead</td>
<td>1.0</td>
<td>3.57</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polyurethane</td>
<td>1.5</td>
<td>6.25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Miscellaneous</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acoustical tile</td>
<td>18</td>
<td>2.50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carpet, fibrous pad</td>
<td></td>
<td>2.08</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carpet, rubber pad</td>
<td></td>
<td>1.23</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Floor tile, asphalt, rubber, vinyl</td>
<td></td>
<td>0.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gypsum board</td>
<td>50</td>
<td>0.90</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Particle board</td>
<td>50</td>
<td>1.06</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plaster</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>cement, sand agg. gyp, L.W. agg.</td>
<td>116</td>
<td>0.20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>gyp, sand agg.</td>
<td>45</td>
<td>0.63</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roofing, 3/8 in. built-up</td>
<td>105</td>
<td>0.17</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wood hard</td>
<td>70</td>
<td>0.33</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wood soft</td>
<td>45</td>
<td>0.91</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wood plywood</td>
<td>32</td>
<td>1.25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glass doors &amp; windows</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single, winter</td>
<td></td>
<td>1.13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single, summer</td>
<td></td>
<td>1.06</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Double, winter</td>
<td></td>
<td>0.65</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Double, summer</td>
<td></td>
<td>0.61</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Doors, metal</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Insulated, winter</td>
<td></td>
<td>0.19</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Insulated, summer</td>
<td></td>
<td>0.18</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(1) See Table 6. for all concretes, including insulating concrete for roof fill.
(2) 1/4" air space.

Table 5
Thermal properties of concrete\(^{(1)}\)

<table>
<thead>
<tr>
<th>Description</th>
<th>Concrete Weight, pcf</th>
<th>Thickness, in.</th>
<th>Resistance, R Per Inch of thickness, (1/k)</th>
<th>For thickness shown, 1/C</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Concretes including normal weight, lightweight</strong> and lightweight insulating concretes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>145</td>
<td>0.075</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>140</td>
<td>0.083</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>130</td>
<td>0.11</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>120</td>
<td>0.14</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>110</td>
<td>0.19</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>0.24</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>90</td>
<td>0.30</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>80</td>
<td>0.37</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>70</td>
<td>0.45</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>0.52</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>0.67</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>0.83</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>1.43</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Normal weight tees(^{(2)}) and solid slabs</strong></td>
<td>145</td>
<td>2</td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>0.23</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>0.30</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>5</td>
<td>0.38</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>6</td>
<td>0.45</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>8</td>
<td>0.60</td>
<td></td>
</tr>
<tr>
<td><strong>Normal weight hollow core slabs</strong></td>
<td>145</td>
<td>6</td>
<td>1.07</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>8</td>
<td>1.34</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>10</td>
<td>1.73</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>12</td>
<td>1.91</td>
<td></td>
</tr>
<tr>
<td><strong>Structural lightweight tees(^{(2)}) and solid slabs</strong></td>
<td>110</td>
<td>2</td>
<td>0.38</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>0.57</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>0.76</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>5</td>
<td>0.95</td>
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<td>1.14</td>
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<td>8</td>
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<tr>
<td><strong>Structural lightweight hollow core slabs</strong></td>
<td>110</td>
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<td>2.00</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>12</td>
<td>2.59</td>
<td></td>
</tr>
</tbody>
</table>

\(^{(1)}\) 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 6
to identical summer simulated temperatures.

Heating Loads

The ASHRAE Handbook recognizes the effects of mass on a building's ability to retain heat, however it does not offer a way to account for the effect. Computer studies of ten wall types each exposed to ten different weather conditions show that as weight of walls increases, the heat flow outward decreases. As a result, the steady-state U-values can be modified to account for mass effects on walls and roofs. The modifications change as the number of heating degree days changes. The modification M-factors are given in Fig. 50.

Cooling Loads

The effects of mass on cooling loads are reflected in the designs by the use of equivalent temperature differences, TDeq, as given in Tables 7 and 8. The TDeqw (walls) and TDeqr (roofs) decrease as the weight of the sections increases.

Building Envelope Performance and Trade-Off Considerations

The ASHRAE Standard and some codes permit component trade-offs. That is, the stated overall Uo-value of any one assembly, such as roof/ceiling, wall or floor, may be increased and the Uo-value for other components decreased, provided the overall heat transmission for the entire building envelope does not exceed the total allowed by the criteria. For buildings where the floors are not exposed to the outdoors the allowed overall envelope hourly loss is:

\[
\text{Floss} = \frac{\Delta T \cdot A_w \cdot U_w + \Delta T \cdot A_r \cdot U_r}{U_o}
\]

where:
- \( \Delta T \) = temperature difference, indoor to outdoor, \( ^\circ F \)
- \( A_w \) = overall area of walls, \( \text{sq ft} \)
- \( A_r \) = overall area of roof, \( \text{sq ft} \)
- \( U_w \) = overall heat transmission value of walls, \( \text{Btu/hr ft}^2 \text{F} \)
- \( U_r \) = overall heat transmission value of roof, \( \text{Btu/hr ft}^2 \text{F} \)

All values in the brackets of the equation can be altered from those given in the code or standard providing the summation of the values is not increased.

The trade-off concept is useful particularly for altering wall, floor or roof criteria without exceeding the total loss allowed for the envelope. The concept also permits different Uw-values on, for example, north and south exposures. Component trade-offs coupled with trade-off of elements of components, such as opaque vs. glass, permit a great deal of freedom in building envelope design. Also, with fewer prescriptive requirements, more efficient building design are possible.
Heat gain comparison for light and heavy roofs

![Graph showing heat gain comparison](image)

**Table 7**

<table>
<thead>
<tr>
<th>Weight of Wall (lb/ft²)</th>
<th>TD_{eqw} °F</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 25</td>
<td>44</td>
</tr>
<tr>
<td>26 - 40</td>
<td>37</td>
</tr>
<tr>
<td>41 - 70</td>
<td>30</td>
</tr>
<tr>
<td>71 &amp; above</td>
<td>23</td>
</tr>
</tbody>
</table>

**Table 8**

<table>
<thead>
<tr>
<th>Weight of Roof (lb/ft²)</th>
<th>TD_{eqr} °F</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 10</td>
<td>70</td>
</tr>
<tr>
<td>11 - 50</td>
<td>50</td>
</tr>
<tr>
<td>51 &amp; above</td>
<td>40</td>
</tr>
</tbody>
</table>

Modification factor, M, for heating designs (for use in modifying steady state U-values)

![Modification factor graph](image)

**Fig. 49**

Wall temperature difference, TD_{eqw}

Roof temperature difference, TD_{eqr}
Condensation Control

Moisture which condenses on the interior of a building is unsightly and can cause damage to the building or its contents. Even more undesirable is the condensation of moisture within a building wall or ceiling assembly where it is not readily noticed until damage has occurred. All air in buildings contains some water with warm air carrying more moisture than cold air. In many buildings moisture is added to the air by industrial processes, cooking, laundering, or humidifiers. If the inside surface temperature of a wall, floor or ceiling is too cold, the air contacting this surface will be cooled below its dew point temperature and leave its excess water on its surface. Condensation occurs on the surface with the lowest temperature.

Once condensation occurs, the relative humidity of the interior space of a building cannot be increased since any additional water vapor will simply condense on the cold surface. In effect, then, the inside temperature of an assembly limits the relative humidity which may be contained in an interior space. Fig 51 gives U-values for any combination of outside temperatures and inside relative humidities above which condensation will occur on the interior surfaces.
Relative humidity at which visible condensation occurs on inside surfaces. Inside temperature, 70°F.
FIRE RESISTANCE

Introduction

Precast prestressed concrete members can be provided with any degree of fire resistance that may be required by building codes, insurance companies, and other authorities. The fire resistance of building assemblies is determined from standard fire tests defined by the American Society for Testing and Materials.

To insure that fire resistance requirements are satisfied, the engineer can use tabulated information provided by various authoritative bodies, such as Underwriters Laboratories, Inc., the American Insurance Association and model building codes. This information is based on the results of standard fire tests of assemblies that may include ceilings and other building components. The 1978 edition of the UL "Fire Resistance Directory" alone provides information on more than 120 assemblies, incorporating precast prestressed concrete members.

In the absence of tabulated data, the fire resistance of precast prestressed concrete members and assemblies can be determined in most cases by calculation. These calculations are based on engineering principals 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.

Standard Fire Tests of Prestressed Concrete Assemblies

The fire test of a prestressed concrete assembly in America was conducted in 1953 at the National Bureau of Standards. Since that time, more than 150 prestressed concrete assemblies have been subjected to standard fire tests in America. Although many of the tests were conducted for the purpose of serving specific fire ratings, most of the tests were performed in conjunction with broad research studies whose objectives have been to understand the behavior of prestressed concrete subjected to fire. The knowledge gained from these tests has resulted in the development of (1) lists of fire resistive prestressed concrete components, and (2) procedures for determining the fire endurance by calculation.

Many different types of prestressed concrete elements have been fire tested. These elements include joists, double tees, mono-wing tees, single tees, solid slabs, hollow-core slabs, rectangular beams, ledger beams, and I-shape beams. In addition, roofs with thermal insulation and loadbearing wall panels have also been tested. Nearly all of these elements
have been exposed directly to fire, but a few tests have been conducted on specimens that received additional protection from the fire by spray-applied coatings, ceilings, etc.

Fire Tests of Flexural Elements

Tests have shown that the structural fire endurance of a flexural precast prestressed concrete element depends on several factors, the most important of which is the method of support, i.e., restrained or unrestrained. Other factors include size and shape of the element, thickness of cover (or more precisely, the distance between the centers of the prestressing tendons and the nearest fire-exposed surface), aggregate type, and load intensity. The fire endurance as determined by the criteria for temperature rise of the unexposed surface (heat transmission) depends primarily on the concrete thickness and aggregate type.

Single Course Slabs

For concrete slabs, the temperature rise of the unexposed surface depends mainly on the thickness and aggregate type of the concrete. Other less important factors include unit weight, moisture condition, air content, and maximum aggregate size. Within the usual ranges, water-cement ratio, strength, and age have only insignificant effects.

Fig 52 shows the fire endurance (heat transmission) of concrete slabs as influenced by aggregate type and thickness. For a hollow-core slab, this thickness may be obtained by dividing the net cross sectional area by its width. The curves represent air-entrained concrete made with air-dry aggregates having a nominal maximum size of 3/4 in. and fire tested when the concrete was at the standard moisture condition. On the graph, concrete aggregates are designed as lightweight, sand-lightweight, carbonate, or siliceous.

Fire endurance generally increases with a decrease in unit weight, but for structural concretes, the influence of aggregate type may overshadow the effect of the unit weight.

For normal weight concrete, fire endurance is improved by decreasing the maximum aggregate size. The reason for this is that the cement paste content increases with a decrease in aggregate size.

Members Restrained Against Thermal Expansion

If a fire occurs beneath an interior portion of a large reinforced concrete slab, the heated portion will tend to expand and push against the surrounding part of the slab. In turn, the unheated part of the slab exerts compressive forces on the heated portion. The compressive force, or thrust, acts near the bottom of the slab when the fire test occurs but, as
the fire progresses, the line of action of the thrust rises as the mechanical properties of the heated concrete change. This thrust is generally great enough to increase the fire endurance significantly.

The effects of restraint to thermal expansion can be characterized as shown in Fig. 53. The thermal thrust acts in a manner similar to an external prestressing force, which increases the positive moment capacity.

The increase in bending moment capacity is similar to the effect of added reinforcement located along the line of action of the thrust. It can be assumed that the added reinforcement has yield strength (force) equal to the thrust. By this approach, it is possible to determine the magnitude and location of the required thrust to provide a given fire endurance.

Code and Economic Considerations

An important aspect of dealing with fire resistance is to understand what the benefits are to the owner of a building in the proper selection of materials incorporated in his structure. These benefits fall into two areas, code and economics.

Building codes are laws that must be satisfied regardless of any other considerations. The designer, representing the owner, has no option in the code regulations. Only in the materials and assemblies that meet these regulations.

Economic benefits are often overlooked by the designer/owner team at the time decisions are made on the structural system. Proper consideration of fire resistive construction through life-cycle cost analysis will provide the owner economic benefits over other types of construction in many areas, e.g. lower insurance costs, larger allowable gross areas under certain types of building construction, fewer stairwells and exits, increased value for loan purposes, longer mortgage terms, and better resale value. To ensure an owner of the best return on his investment, a life-cycle cost analysis using fire resistive construction must be prepared.

Beyond the theoretical considerations is the history of excellent performance of prestressed concrete in actual fires. Structural integrity has been provided, fires are contained in the area of origin, and, in many instances, repairs consist of "cosmetic" treatment only leading to early re-occupancy of structure.
Fire endurance (heat transmission) of concrete slabs

Fig. 52

Axially restrained beam during fire exposure

Fig. 53

(curved due to deflection of beam)
COORDINATION WITH MECHANICAL, ELECTRICAL AND OTHER SUB-SYSTEMS

Introduction

Prestressed concrete is used in a wide variety of buildings with lighting, mechanical, plumbing and other services is of importance to the designer. Because of increased environmental demands, the ratio of costs for mechanical and electrical installations to total building has increased substantially in recent years. This section is intended to provide the designer with the necessary perspective to economically satisfy mechanical and electrical requirements, and to describe some of the installation of other sub-systems.

Lighting and Power Distribution

For many applications, the designer can take advantage of fire resistance, reflective qualities and appearance of prestressed concrete by leaving the columns, beams and ceiling structure exposed. By using reflective paint and properly spaced high output fluorescent lamps installed in a continuous strip, the designer can achieve a high level of illumination at a minimum cost. By using reflective paints, these precast concrete lighting channels can be made as efficient as conventional fluorescent fixtures.

Electrical Floors

The increasing use of business machines, and other communication systems stresses the need for adequate and flexible means of supplying electricity and communication service. Since a cast-in-place topping is usually placed on prestressed floor members, conduit runs and floor outlets can be readily buried within this topping. With shallow height electrical systems, a comprehensive system can be provided in a reasonably thin topping. The total height of conduits for these comprehensive electrical systems is as little as 1-3/8 in. Most systems can easily be included in a 2 to 4 inch thick slab. Voids in prestressed slabs can be used as electrical raceways as shown in Fig 54.

When the system is placed in a structural composite slab, the effect of ducts and conduits must be carefully examined and their location coordinated with reinforced steel. Tests on slabs with burried ductwork have shown that structural strength is not normally impaired by the voids.

Because of the high load-carrying capacity of prestressed concrete members, it is possible to locate high-voltage substations, with heavy transformers, near the areas of consumption with little or no expense.
Ductwork

The designer may also utilize the space within the holes inside prestressed hollow-core concrete slabs for distribution ducts for heating, air-conditioning, or exhaust systems. These members have oval, round or rectangular voids of varying size which can provide ducts or raceways for the various systems. Openings in cores drilled in the field can provide access and distribution. The voids in the slabs are aligned and connected to provide continuity of the system.

Other Sub-Systems

Suspended ceilings, crane rails, and other sub-systems can be easily accommodated with standard manufactured hardware items and embedded plates as shown in Fig 55.

Systems Building

As more and more systems buildings are built with precast and prestressed concrete, and as interest in this method of construction increases, we can expect that more of the building sub-systems will be prefabricated and pre-coordinated with the structure.

This leads to the conclusion that those parts of the structure that require the most labor skills should logically be prefabricated prior to installation in the field. The prefabricated components can be preassemblies of basic plumbing systems or electrical/mechanical. To reduce on-site labor, prefabricated bathroom units or combination bathroom/kitchen modules have been developed as shown in Fig 56. Such units include bathroom fixtures, kitchen cabinets and sinks, as well as wall, ceiling, and floor surfaces. Plumbing units are often connected and assembled prior to delivery to the job sites. These bathroom/kitchen modules can be molded plastic units or fabricated from drywall components. To eliminate a double floor, the module can be plant built on the structural member or the walls of the unit can be designed strong enough for all fixtures to be wall hung. In the latter case, the units are placed directly on a precast floor and in multi-story construction are located in a stack fashion with one bathroom directly over the one below. A block-out for a chase is provided in the precast floor and connections are made from each unit to the next to provide a vertical plumbing stack. Prefabricated wet-wall plumbing systems, as shown in Fig 57, incorporate preassembled piping systems using snap-on or no-hub connections made up of a variety of materials. These units only require a block-out in the prestressed flooring units and are also arranged in a stack fashion. Best economy results when bathrooms are backed up to each other, since a common vertical run can service two bathrooms.

Some core modules not only feature bath and kitchen
components, but also HVAC components all packaged in one unit. These modules can also be easily accommodated in prestressed structural systems by placing them directly on the prestressed members with shimming and grouting as required.

Fig. 55
Kitchen/bathroom modules can be pre-assembled on precast prestressed slabs ready for installation in systems buildings
Prefabricated wet-wall plumbing systems incorporate pre-assembled piping

Fig. 57
STRUCTURAL FASTENER

High-Strength Bolts

The two basic types of high-strength bolts are designed by ASTM as A325 and A490. These bolts are heavy hexagon-head bolts, used with heavy semifinished hexagon nuts, as shown in Fig 58. The threaded portion is shorter than for bolts in nonstructural applications, and may be cut or rolled. A325 bolts are of heat-treated medium carbon steel having an approximate yield strength of 81 to 92 ksi depending on diameter. A490 bolts are also heat-treated but are of alloy steel having an approximate yield strength of 115 to 130 ksi depending also on diameter.

High-strength bolts range in diameter from 1/2 to 11/2 in. The most common diameters used in building construction are 3/4 in. and 7/8 in., whereas the most common sizes in bridge design are 3/4 in. and 1 in.

High-strength bolts are tightened to develop tensile stress in them which results in a predictable clamping force on the joint. The actual transfer of service loads through a joint is therefore, due to the friction developed in the pieces being joined. Joints containing high-strength bolts are designed either as friction type, where slip is the basis for ultimate strength; or as bearing type, where bearing of the bolt shank against the hole is the basis for ultimate strength.

Installation of these bolts may be either with calibrated torque wrenches, or more commonly with any ordinary wrench using the "turn-of-the-nut" method. The latter method involves making an additional angular turn of the nut starting from the snug position.

Ribbed Bolts

These bolts of ordinary rivet steel which have a rounded head and raised ribs parallel to the shank were used for many years as an alternative to rivets. The actual diameter of a given size of ribbed bolt is slightly larger than the hole into which it is driven. In driving a ribbed bolt, the bolt actually cuts into the edges around the hole producing a relatively tight fit. This type of bolt was particularly useful in bearing connections and in connections which had stress reversals.

A modern variation of the ribbed bolt is the interference-body bolt shown in Fig 58 which is of A325 bolt steel and instead of longitudinal ribs has serrations around the shank as well as parallel to the shank. Because of the serrations around the shank through the ribs, this bolt is often called an
interrupted-rib bolt. Ribbed bolts are used when tight fit of the bolt in the hole is desired and it permits tightening by means of turning the nut without the simultaneous holding of the bolt head as may be required with smooth loose fitting ordinary A325 bolts.

Types of High-Strength Bolts

At the present time the two basic types of high strength bolts are the A325 bolt, for most common situations, and the A490, for use on higher strength steels where an excessive number of A325 bolts might otherwise be required. The A325 bolt is identified by three radial lines spaced 120 degrees apart on the head. Both types of bolts have heavy hexagon heads and come with heavy semifinished hexagon nuts. Another characteristic of both the A325 and A490 bolts is their shorter thread lengths, the shorter thread lengths making it easier to exclude the threads from the shearing plane. Figure 59 and Table 9 show the control dimensions for A325 and A490 bolts and the methods of identification.

Occasionally, ASTM A490 bolts are substituted for A325 bolts when a longer thread dimension is required, the A490 bolts having the same hexagon head and thread length as standard A307 bolts but having the same strength as A325 bolts.

A variation of the standard A325 and A490 used for bearing connections is the interference-body bolt. These bolts have a button head and may be used with the standard high-strength nuts or with self-locking nuts. The interference-body type bolts have particular applications where high bearing capacity is desired together with stress reversals or vibratory loads.

Installation Techniques

There are two general methods of developing the required pretension indicated in Table ... One is called the calibrated wrench method and the other the turn-of-the-nut method.

The calibrated wrench method includes the use of manual torque wrenches and power wrenches adjusted to stall at a specific torque value. Early studies of controlling the amount of pretension by torque measurements were performed by many investigators including Stewart and Maney. Maney reported that variations in tensile stresses produced by a given torque were as high as +/- 30 percent with an average of +/- 10 percent. Due to this variation, which was also confirmed by field experience, the Research Council on Riveted and Bolted Structural Joints has recommended that torque or calibrated wrenches be set to produce a bolt tension 5 to 10 percent in excess of the value indicated in Table...

Beginning in the early 1950's and continuing into the 1960's the turn-of-the-nut method was developed whereby the
High-strength hexagon head bolt

High-strength interference-body bolt

Fig. 58

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Heavy Hex Structural Bolts</td>
<td>Heavy Hex Nuts</td>
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<tr>
<td></td>
<td>Width across flats $B$</td>
<td>Height, $H$</td>
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<tr>
<td></td>
<td>Width across flats $W$</td>
<td>Height, $H$</td>
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<td>$\frac{3}{8}$</td>
<td>$\frac{1}{4}$</td>
<td>$\frac{3}{8}$</td>
</tr>
</tbody>
</table>

Fig. 59

AISC-1.23.5

<table>
<thead>
<tr>
<th>Bolt Size, Inches</th>
<th>Minimum Bolt Tension, 1 Kips</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A325 and A440 Bolts</td>
</tr>
<tr>
<td>$\frac{1}{8}$</td>
<td>12</td>
</tr>
<tr>
<td>$\frac{5}{32}$</td>
<td>15</td>
</tr>
<tr>
<td>$\frac{1}{4}$</td>
<td>28</td>
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<tr>
<td>$\frac{3}{8}$</td>
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<td>$\frac{1}{2}$</td>
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<td>$\frac{3}{8}$</td>
<td>56</td>
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<td>$\frac{1}{2}$</td>
<td>71</td>
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<tr>
<td>$\frac{5}{8}$</td>
<td>85</td>
</tr>
<tr>
<td>$\frac{3}{4}$</td>
<td>103</td>
</tr>
<tr>
<td>Over $\frac{3}{4}$</td>
<td>0.7 x T.S.</td>
</tr>
</tbody>
</table>

1 Equal to 70 percent of specified minimum tensile strengths of bolts, rounded off to the nearest kip.

Table 9
pretensioning force in the bolt is obtained by a specified rotation of the nut from an initially snug position which causes a specific amount of strain in the bolt. According to the Research council on Riveted and Bolted Structural Joints, nut is considered to be snug when impacting first begins as it is being tightened by an impact wrench. Although snugness or initial tightness can vary due to the condition of the surfaces being tightened, this variation is not significant.

One may wonder whether there is danger of having inadequate reserve strength if the pretension exceeds the proof load; i.e., when it approaches 90 percent of the ultimate strength. Figure 60 shows the effect of various turns of the nut with the margin of safety indicated. If the calibrated wrench method is used strength is the critical factor, with the typical safety margin shown in Fig 60. The possibility of overtorquing the bolts with power wrenches is not considered a problem since such overtorquing usually fractures the bolts and they are replaced during installation. In the turn-of-the-nut method, deformation is the critical factor with the typical safety margin shown in Fig 60. For either installation process one can expect a minimum of 21/4 turns from snug to fracture. When the turn-of-the-nut used and bolts are tensioned using 1/8 turn increments, frequently as many as four turns may be obtained from snug to fracture. The turn-of-the-nut method is the cheapest, is more reliable, and is generally the preferred method.

The method requirements, as approved by AISC-1.23.5, are given by the Research Council 1966 specifications. The approved nut rotations are indicated in Table 61.

Friction-Type and Bearing-Type Connections

AISC 1969 provides for two categories of high-strength bolted joints, the friction-type and the bearing-type. Bolts in either type of joint are installed by the same process so that the same pretension is provided. Performance of the bolted joints under service loads is identical; service load transmission is by friction. The difference between the friction-type and bearing-type connection lies entirely in the factor of safety provided against slip under overloads.

The friction-type is so called because it has the higher factor of safety against slip and thus suitable when stress reversal or cyclical loading may occur. The higher factor of safety provides good fatigue resistance.

The bearing-type joint is so named for use when it is not deemed critical if slip occurs under occasional overload to bring the bolt shank into contact with the side of the hole. For any subsequent loading, the stress is transferred by friction in combination with bearing on the plate. As long as the loading is static such slip will occur only once;
thereafter the bolt is already bearing against the material at the side of the hole.

Fig. 60

Nut Rotation* from Snug Tight Condition (from Ref. 7)

<table>
<thead>
<tr>
<th>Disposition of Outer Faces of Bolted Parts</th>
<th>Both faces normal to bolt axis, or one face normal to axis and other face sloped not more than 1 : 20 (bevel washer not used)</th>
<th>Both faces sloped not more than 1 : 20 from normal to bolt axis (bevel washers not used)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Both faces normal to bolt axis, or one face normal to axis and other face sloped not more than 1 : 20 (bevel washer not used)</td>
<td>Bolt length * not exceeding 8 diameters or 8 inches</td>
<td>Bolt length * exceeding 8 diameters or 8 inches</td>
</tr>
<tr>
<td>For all length of bolts</td>
<td>1/4 turn</td>
<td>1/4 turn</td>
</tr>
</tbody>
</table>

*Nut rotation is rotation relative to bolt regardless of the element (nut or bolt) being turned. Tolerance on rotation: 30° over or under. For coarse thread heavy hex structural bolts of all sizes and length and heavy hex semi-finished nuts.

* Bolt length is measured from underside of head to extreme end of point.

Fig. 61
Billig, Prestressed Reinforced Concrete, Knapp, Drewett & Sons, Ltd., 1944.


Evans and Bennett, Prestressed Concrete, Chapman and Hall, Inc., 1958.


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