PORTLAND CEMENT
ASSOCIATION

Concrete Floor Systems

GUIDE TO ESTIMATING AND ECONOMIZING

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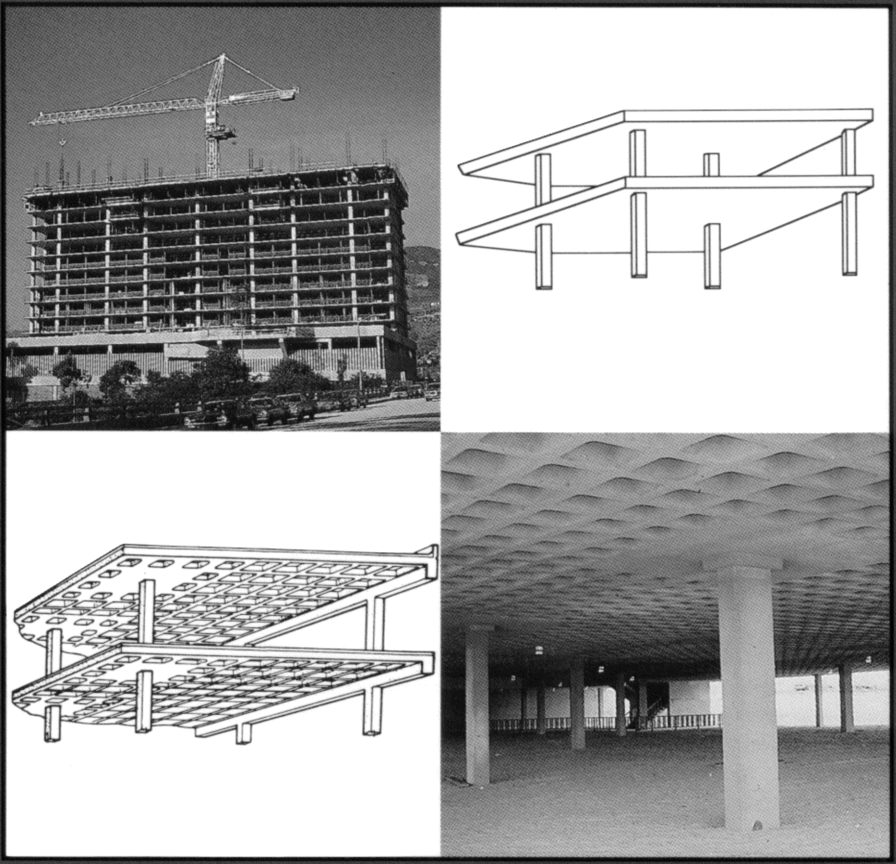


INTRODUCTION

The main objectives of this publication are to:

- Assist in the selection of the most economical cast-in-place concrete floor system for a given plan layout and a given set of loads;
- Provide a preliminary estimate of material quantities for the floor system; and
- Discuss the effect of different variables in the selection process.

Five different floor systems are considered in this publication. These are the flat plate, the flat slab, the one-way joist, the two-way joist or waffle, and the slab supported on beams on all four sides. Material quantity estimates are given for each floor system for various bay sizes.

Pricing Trends

The total cost to construct a building depends on the use for which the structure is designed, the availability of qualified contractors, and the part of the country in which the structure is built. Figure 1 gives cost comparisons for two different types of uses over the past several years. (The data presented in Figures 1 through 5 and Table 1 were obtained from Means Concrete Cost Data, 1990.) The average price per square foot is considerably greater for office buildings than for apartment buildings. Part of the higher cost is because office buildings are designed with more open spaces which in structural terms means costlier, longer clear spans.

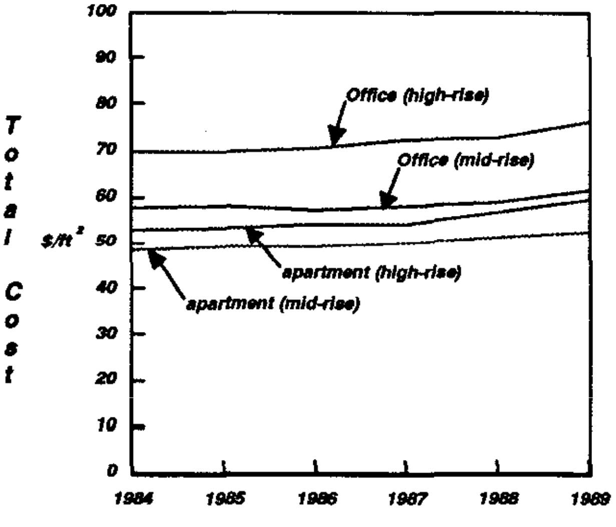


Figure 1 - Price Comparisons for Different Building Types

Table 1 gives cost indices for many major cities in the United States and Canada. The cost index includes both labor and materials, with the value of 100 representing the average cost for 30 major cities. The table shows the wide variation in costs depending on the locale. In Anchorage, Alaska (127.9) or New York City (126.9) the cost of a building can be as much as 60% higher than that of a similar building in Charleston, South Carolina (80.2), Jackson, Mississippi (81) or Sioux Falls, South Dakota (82.2). Figure 2 shows the relative change in costs in current dollars of material and labor over the past 40 years.

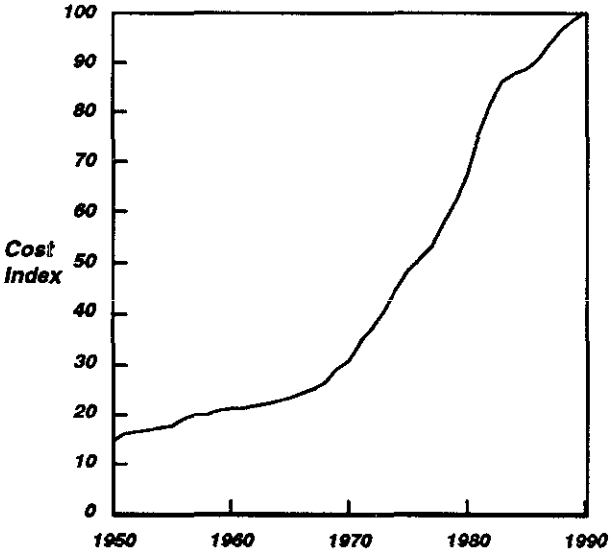


Figure 2 - Annual Construction Cost Comparisons

The majority of the structural cost of a building typically is the cost of the floor system. This is particularly true of low-rise buildings and buildings in low seismic zones. Therefore, it is imperative to select the most economical floor system.

In this publication, estimated quantities are provided for concrete, reinforcing steel and formwork for the five floor systems discussed in the following sections. Prices for labor and material for these items over the past several years are shown in Figures 3 through 5.

Table 1—Relative Construction Costs for Reinforced Concrete

ALABAMA (BIRMINGHAM)	84.0	NEW HAMPSHIRE (MANCHESTER)	90.3
ALASKA (ANCHORAGE)	127.9	NEW JERSEY (NEWARK)	104.9
ARIZONA (PHOENIX)	91.9	NEW MEXICO (ALBUQUERQUE)	91.5
ARKANSAS (LITTLE ROCK)	84.5	NEW YORK (NEW YORK)	126.9
CALIFORNIA (LOS ANGELES)	112.0	NEW YORK (ALBANY)	94.5
CALIFORNIA (SAN FRANCISCO)	126.0	NORTH CAROLINA (CHARLOTTE)	80.8
COLORADO (DENVER)	93.5	OHIO (CLEVELAND)	107.3
CONNECTICUT (HARTFORD)	100.1	OHIO (CINCINNATI)	95.3
DELAWARE (WILMINGTON)	100.3	OKLAHOMA (OKLAHOMA CITY)	89.4
WASHINGTON, D.C.	95.4	OREGON (PORTLAND)	101.0
FLORIDA (MIAMI)	89.9	PENNSYLVANIA (PHILADELPHIA)	107.2
GEORGIA (ATLANTA)	89.7	PENNSYLVANIA (PITTSBURGH)	100.6
HAWAII (HONOLULU)	111.1	RHODE ISLAND (PROVIDENCE)	100.8
IDAHO (BOISE)	93.3	SOUTH CAROLINA (CHARLESTON)	80.2
ILLINOIS (CHICAGO)	101.8	SOUTH DAKOTA (SIOUX FALLS)	82.2
INDIANA (INDIANAPOLIS)	97.6	TENNESSEE (MEMPHIS)	87.6
IOWA (DES MOINES)	90.7	TEXAS (DALLAS)	87.8
KANSAS (WICHITA)	86.8	UTAH (SALT LAKE CITY)	91.7
KENTUCKY (LOUISVILLE)	88.3	VERMONT (BURLINGTON)	88.1
LOUISIANA (NEW ORLEANS)	88.6	VIRGINIA (NORFOLK)	83.3
MAINE (PORTLAND)	89.8	WASHINGTON (SEATTLE)	101.6
MARYLAND (BALTIMORE)	96.1	WEST VIRGINIA (CHARLESTON)	97.4
MASSACHUSETTS (BOSTON)	115.6	WISCONSIN (MILWAUKEE)	97.3
MICHIGAN (DETROIT)	106.9	WYOMING (CHEYENNE)	87.4
MINNESOTA (MINNEAPOLIS)	99.4	CANADA (EDMONTON)	100.2
MISSISSIPPI (JACKSON)	81.0	CANADA (MONTREAL)	100.0
MISSOURI (ST. LOUIS)	101.6	CANADA (QUEBEC)	99.0
MONTANA (BILLINGS)	92.1	CANADA (TORONTO)	109.8
NEBRASKA (OMAHA)	88.6	CANADA (VANCOUVER)	105.5
NEVADA (LAS VEGAS)	104.6	CANADA (WINNIPEG)	101.5

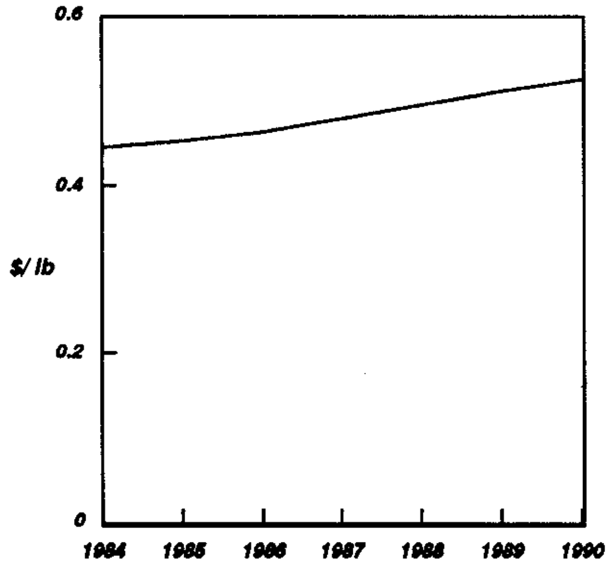


Figure 3 - Cost of Reinforcing Bars in Place

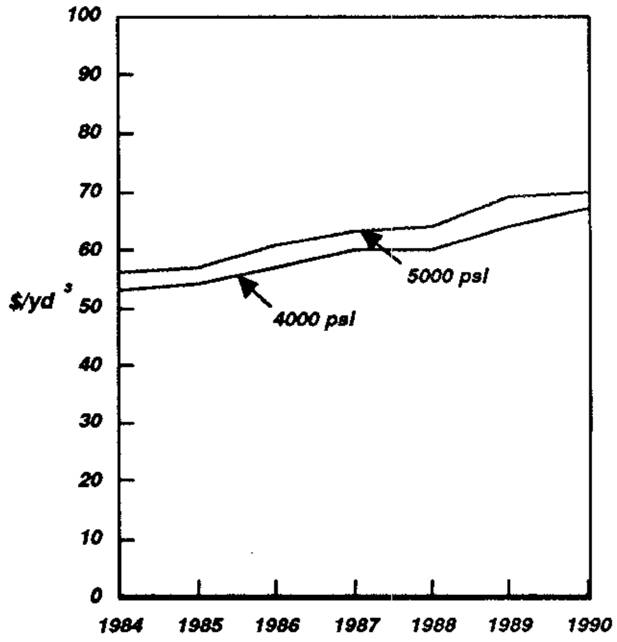


Figure 4 - Cost of Ready-Mixed Concrete

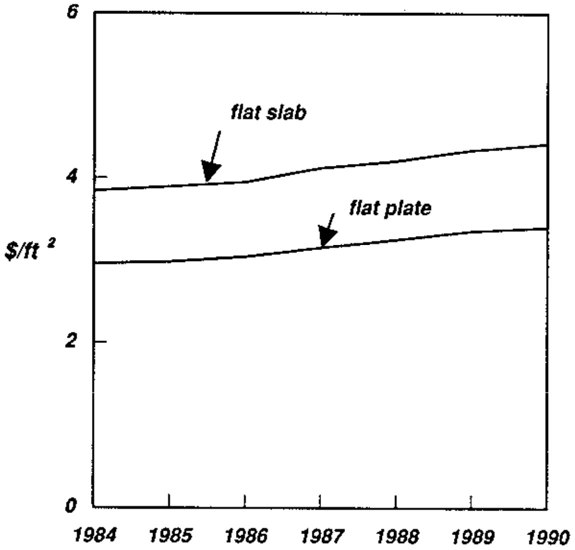


Figure 5 - Cost of Formwork

Presentation of Results

The following pages provide discussion and quantity estimates for the five floor systems. These results were obtained using a five bay by five bay structure. Bay sizes are measured from centerline of column to centerline of column. Floors were designed using ACI 318-89 Building Code Requirements for Reinforced Concrete. Concrete, reinforcing steel and formwork quantities are presented for each of the floor systems. An overview of the floor systems is provided, following the discussion of the floor systems.

Included with each floor system is a discussion of the factors that may affect the estimated quantities. The factors discussed are column dimensions, live loads, and aspect ratios. A cost breakdown is also given in each case. Following the discussion for each individual floor system are several tables and graphs. The graphs show the variation in costs for increased bay size and higher concrete strength. The tables give quantities for various bay sizes.

Fire Resistance of Concrete Floor Systems

Fire resistance rated construction will often be required by the governing building code, or the owner may desire a highly fire resistant structure in order to qualify for the lowest fire insurance rates.

Concrete floor systems offer inherent fire resistance. Therefore, when the floor system is completed, no additional protective measures are necessary in order to achieve code required fire resistance ratings.

On the other hand, for steel floor systems for instance, additional protection must be provided by special acoustical ceilings, or fireproofing sprayed on the underside of the steel deck and/or beams. In addition, when an acoustical ceiling is an integral part of a rated floor/ceiling assembly, special ceiling suspension systems, and special protective devices at penetrations for light fixtures and HVAC diffusers are required.

These additional costs associated with protecting the structural framing members must be added to the cost of the structural frame to produce an accurate cost estimate. If this is not done, the actual cost of the competing floor system is understated, making a valid comparison with a concrete floor system difficult, if not impossible.

Fire resistance rating requirements vary from zero to four hours, with two hours typically being required for high rise buildings. Before selecting the floor system, the designer should determine the fire resistance rating required by the applicable building code. Except for one-way and two-way joist systems, the minimum slab thickness necessary to satisfy structural requirements (usually 5 in.) will normally provide a floor system that has at least a two hour fire resistance rating.

Table 2 shows minimum slab thicknesses necessary to provide fire resistance ratings from one to four hours, for different types of aggregate. If the thickness necessary to satisfy fire resistance requirements exceeds that required for structural purposes, consideration should be given to using a different type of aggregate that provides higher fire resistance for the same thickness. For example, a one-way joist system may require a 3 in. thick slab to satisfy structural requirements. However, if a two hour fire resistance rating is desired, a 5 in. thick slab will be required if siliceous aggregate normal weight concrete is used. By using lightweight aggregate concrete, the slab thickness can be reduced to 3.6 in. This 28% reduction in thickness translates into approximately a 45% reduction in dead load.

Table 2—Minimum Slab Thickness for Fire Resistance Rating

Floor Construction Material	Minimum slab thickness (in.) for fire-resistance rating			
	1 hr	2 hr	3 hr	4 hr
Siliceous Aggregate Concrete	3.5	5.0	6.2	7.0
Carbonate Aggregate Concrete	3.2	4.6	5.7	6.6
Sand-lightweight Concrete	2.7	3.8	4.6	5.4
Lightweight Concrete	2.5	3.6	4.4	5.1

Adequate cover must be provided to keep reinforcing steel temperatures within code prescribed limits. The amount of cover depends on the element considered (i.e., slab, joist or beam), and whether the element is restrained against thermal expansion. All elements of cast-in-place concrete framing systems are considered to be restrained.

For positive moment reinforcement in beams spaced at 4 ft or less on center, and in joists and slabs, regardless of the type of concrete aggregate used, the minimum cover required by ACI 318 is adequate for ratings of up to four hours. For beams spaced at more than 4 ft on center, the cover must not be less than the values given in Table 3.

Table 3—Cover Thickness for Fire Resistance Rating for Beams Spaced More than 4 ft on Center

Beam Width (in.)	Cover thickness (in.) for fire-resistance rating			
	1 hr	2 hr	3 hr	4 hr
5	¾	¾	1	1¼
7	¾	¾	¾	¾
≥ 10	¾	¾	¾	¾

The cover for an individual bar is the minimum cover between the surface of the bar and the fire-exposed surface of the structural member. When more than one bar is used, the cover is assumed to be the average of the minimum cover to each bar, where the cover for corner bars used in the calculation is one-half the actual value. The actual cover for an individual bar must be not less than one-half the value shown in Table 3, nor less than ¾ in. For beam widths between tabulated values, use direct interpolation to determine minimum cover.

The foregoing is intended to give a brief overview of the subject of fire resistance of concrete floor systems. While the information cited is consistent with the three model building codes in use in the United States, the legally adopted building code governing the specific project should be consulted.

OVERVIEW

General Discussion

This section provides overall comparisons of the economics of the various floor systems discussed in this publication. It provides a summary of the factors that may influence the costs of cast-in-place concrete floor systems. These factors include column dimensions, live loads, aspect ratios and proper detailing. A few other aspects that have an influence on economy are also discussed.

Overall Comparisons

Four figures that compare the economics of the different structural floor systems considered are provided at the end of this publication. The figures clearly show that the optimality of the slab system depends on two major factors: the span in the long direction, and the intensity of superimposed dead and live loads. For a given set of loads, the slab system that is optimal for short spans, is not necessarily optimal for longer spans. For a given span, the slab system that is optimal for light superimposed loads, is not necessarily optimal for heavier loads. The four figures should facilitate the section of a structural floor system most appropriate for a certain application.

Column Dimensions

Analysis shows that the height between floors has very little influence on the material quantities for the floor system. Column cross-sectional properties determine the clear span length and the shear capacity of the slab. The column cross-sectional dimensions used in this publication were representative of 10- to 20-story buildings. Increasing or decreasing the column dimensions by 2 in. did not affect the concrete quantities and changed the steel reinforcing quantities by less than 1%.

Live Loads

The material quantities for the floor system are typically controlled by deflections rather then stresses. Increasing the live load from 50 psf to 100 psf only resulted in a 4% to 10% increase in the floor system cost.

Aspect Ratio

Square bays usually represent the most economical floor layout, since deflection control requirements can be exactly met in both directions. A rectangular bay with an aspect ratio of 1.5 ranges between 4% to 10% more in cost than a bay with an aspect ratio of 1.0 and the same floor area. This, however, is not the case for one-way joist systems. This type of floor system should have the joists span in the short direction, and is almost unaffected by aspect ratios of up to 1.5.

Concrete Strengths

Concrete strengths of 4000 psi, 5000 psi, and 6000 psi were used in this publication. Cost analysis shows that for gravity loads, 4000 psi concrete is more economical than higher concrete strengths.

Cost Breakdown

The formwork for the floor systems will absorb from 50% to 58% of the costs. Concrete material, placing and finishing account for 21% to 30%. The material and placing costs of the reinforcing steel amount to between 17% and 25% of the cost.

Repetition

A cost efficient design utilizes repetition. Changes should be minimized from floor to floor. Changing column locations, joist spacing, or the type of floor system increases the cost of formwork, time of construction and the chance of field mistakes, and therefore should be avoided.

Column-Beam Intersections

The beams that frame into columns should be at least as wide as the columns. If the beams are narrower than the columns, the beam forms will require costly field labor to pass the formwork around the columns.

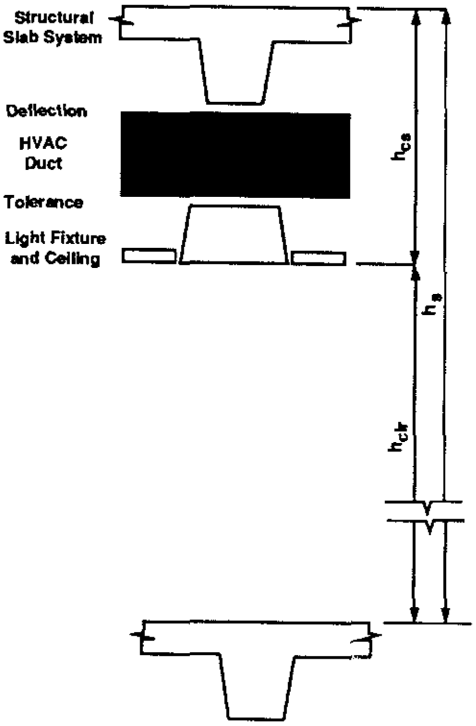
Standard Dimensions

Standard available sizes should be used for structural forming. For instance, joist formwork pans are available in various web depths of 20 in. and from 8 in. to 16 in. in 2 in. increments. Specifying a depth different from these sizes will require the fabrication of costly special formwork. When detailing drop panels or other changes in the floor system depth, actual lumber dimensions should be taken into account.

Depth of the Ceiling Sandwich

This publication has addressed the economy of the structural slab system only. However, the structural engineer usually has to look beyond. The structural slab system is part of the so-called ceiling sandwich which also includes the mechanical system (HVAC ducts), the lighting fixtures, and the ceiling itself.

The floor-to-floor height of a building is the total depth of the ceiling sandwich plus the clear floor-to-ceiling height. Any variation in the depth of the ceiling sandwich will have an impact on the total height of: the shearwalls and columns, the mechanical, electrical and plumbing risers, the stairs and interior architectural finishes, and the exterior cladding. It will also have an impact on the total heating, cooling and ventilation volume. To minimize the depth of the ceiling sandwich is very often the goal of the structural engineer. This becomes particularly important in cities like Washington, D.C. that impose a height limit on buildings. Optimization of the ceiling sandwich depth may translate into an extra story or two accommodated within the prescribed height limit.



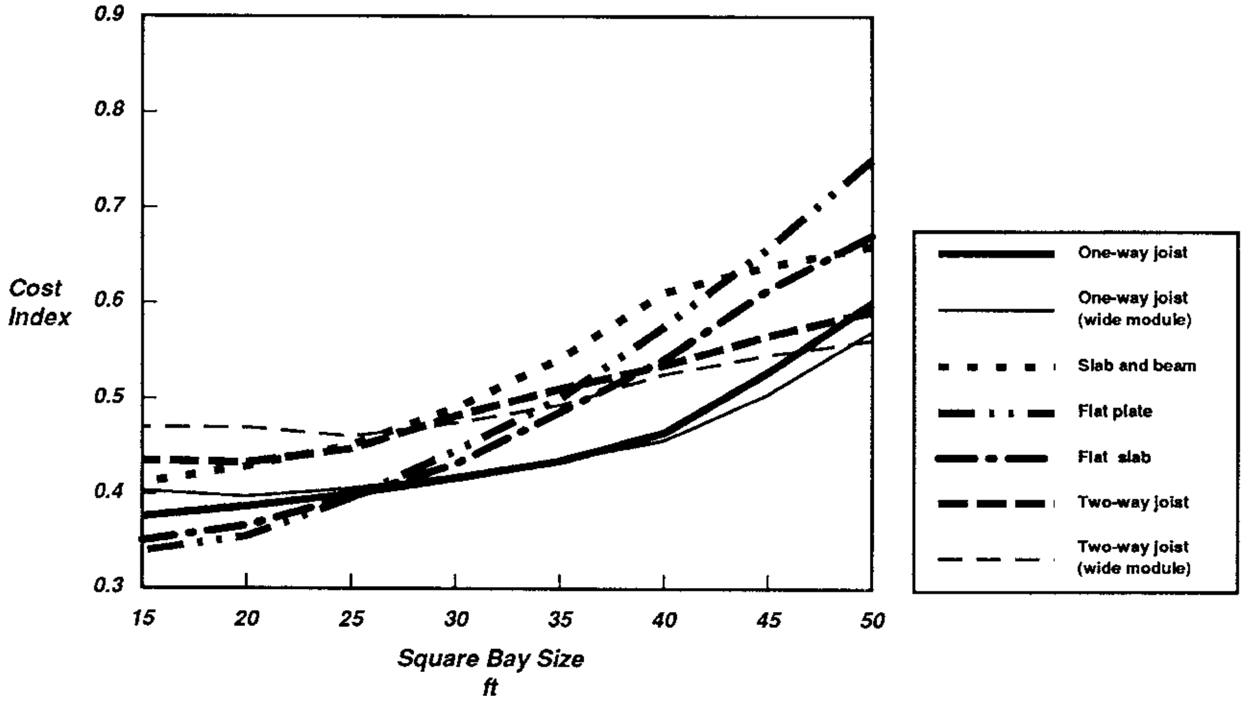
A number of details have been attempted in the past to accomplish a reduced depth of the ceiling sandwich. The HVAC ducts can pass through the webs of joists or beams. This will reduce the floor-to-floor height, but will increase formwork and field labor costs. Another alternative is to cut notches at the bottom of the joist or beam to allow passage of the upper portions of the HVAC ducts. This alternative also requires additional forming costs. Further, special detailing would be needed to meet the structural integrity requirements of the ACI 318-89 Code. More importantly, however, such practices take flexibility away from accommodating future changes in the use of the floor space. Such flexibility is becoming more important in view of the shifting emphasis towards consciously designing buildings for a long service life.

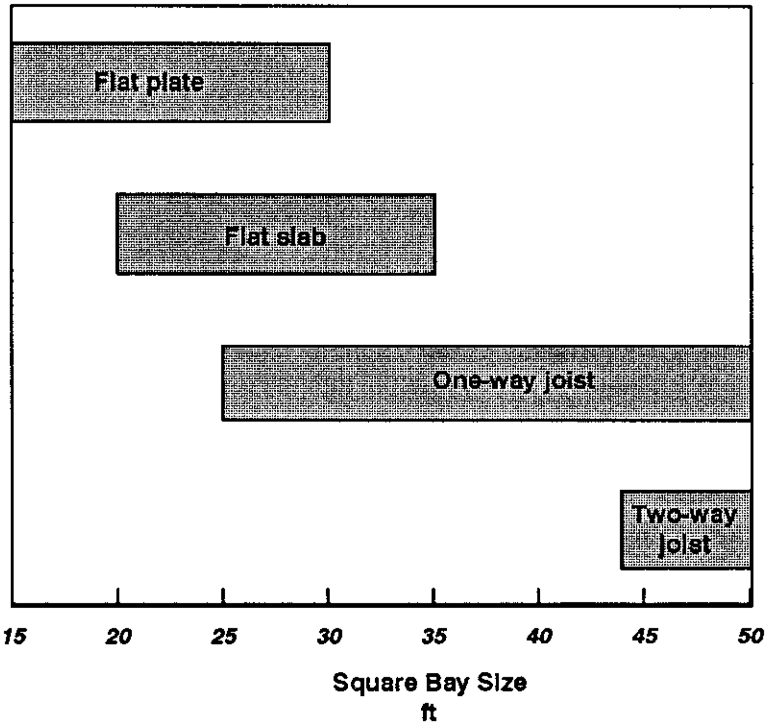
OVERVIEW

Live Load = 50 psf

Superimposed Dead Load = 20 psf

$f_c' = 4000$ psi





OVERVIEW

Live Load = 100 psf

Superimposed Dead Load = 20 psf

f'_c = 4000 psi