Lesson 1 – Managing Quality, Cost & Time

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INTRODUCTION

Working drawings are detailed graphic descriptions that convey to a contractor the architect's design intent. The construction documents, which include the working drawings and specifications, should provide all the information necessary to construct the building—no more and no less. They must be complete, clear, and accurate, arranged in an orderly manner, and without unnecessary repetition. When carefully followed, such documents should result in a project that achieves its objectives relative to quality, cost, and time.

Before preparing the working drawings, the architect should review and analyze the conceptual drawings—schematic design and design development—so that potential problems may be detected and resolved. If a preliminary building elevation, for example, shows glass flush with the exterior wall material, the joint must be detailed not only to achieve that visual result, but to do so in a way that is economical and waterproof. Every such potential problem must be approached analytically and solved during the construction documents phase. The earlier problems are detected, the less costly the solution. This lesson presents some aspects of quality, cost, and time management which lead to successful projects.

QUALITY MANAGEMENT

General Concepts

In recent years, manufacturing companies in the United States have become increasingly aware of the need for strict quality control. Similarly, quality management in the service sector has also improved.

In response to an unacceptable number of errors in building design, documentation, and professional practice, many architects have started to implement *quality control* procedures, which involve carefully checking the work (a contract, a set of drawings, a design sketch) before it is distributed to the user (an owner, a contractor, a drafter). However, quality control identifies errors late in the process, when they are costly to correct.

In response to this limitation, *quality assurance* has been implemented to supplement quality control. Basically, quality assurance requires that in designing, documenting, and constructing a building, the proper resources and scrutiny are applied to each part of the process in order to prevent errors before they are made, or at least to correct errors early, before they are compounded. The limitation of quality assurance is that it is segmented rather than holistic.

Because of this limitation, *total quality management* (TQM) was developed. TQM incorporates quality control and quality assurance, but also includes all aspects of service to achieve the goal of customer satisfaction, where the term *customer* is broadly defined to include the client, the user, the public, and the profession.

Structural Integrity

Vertical Forces

In order to design safe buildings, architects must understand the effects of gravity loads on structures. These loads, which are caused by the weight of a building and its contents, act vertically and are transmitted through the structure to the underlying earth or rock. Usually, a geotechnical engineer determines the pertinent soil characteristics and recommends appropriate design criteria and bearing capacities. However, the architect must verify that the required investigations have been made and the construction documents incorporate the geotechnical engineer's recommendations.

One relevant characteristic is the presence and amount of water in the soil. If the hydrostatic pressure exerted upward on a building exceeds the building's weight, it will tend to float. In this case, either the weight of the building must be increased or the hydrostatic pressure reduced.

Soil characteristics may vary within the area bounded by the perimeter of a building, which could result in differential settlement problems. Although a reasonable amount of uniform settlement may be acceptable, differential settlement can cause structural damage.

When wet soils expand, they exert an upward force on the foundation. The geotechnical engineer may recommend various ways to deal with this situation. Frost may create similar problems, requiring foundations to be located below the frost line in order to avoid upward heaving of the structure.

Winds also create vertical loads on a building. They exert uplift forces on the roof, which may detach the roof from the structure. Winds may have a similar effect on eaves, overhangs, and porch roofs, particularly in parts of the country where hurricanes occur. In those areas, building code provisions require continuous structural connections from foundations to roof.

In summary, consider:

1. Potential differential settlement caused by nonuniform soil conditions.

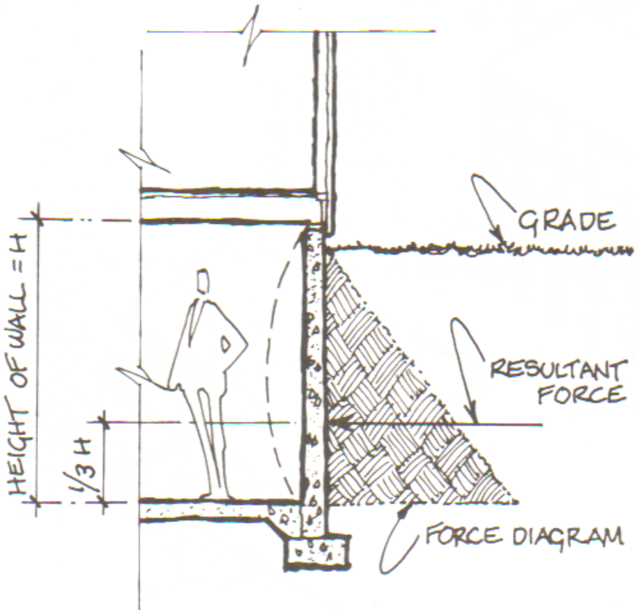
2. Expansive soils, frost action, or a high water table exerting upward pressure on foundations.

3. Wind forces creating uplift on roofs and overhangs.

Lateral Forces

In addition to vertical loads, building structures must also be designed to resist forces acting horizontally, usually called lateral forces. Below the surface of the ground, soils exert lateral pressures on buildings, and subsurface walls must be designed to withstand these pressures. Such walls act like vertical slabs which span between the first floor and the foundation and resist the pressures applied from outside the building. Water in the soil, or the presence of expansive soils, may increase the pressure on subsurface walls. Proper subsurface drainage may alleviate or eliminate the increased horizontal pressures created by water or expansive soils.

Structures must also be designed to resist lateral forces acting above the surface of the ground, such as wind or earthquake. Wind forces vary, depending on the building's geographical location as well as its location on a site (surrounded by other structures versus out in the open). The height of a building also affects the intensity of wind forces. Wind may create large overturning moments. However, proper structural design



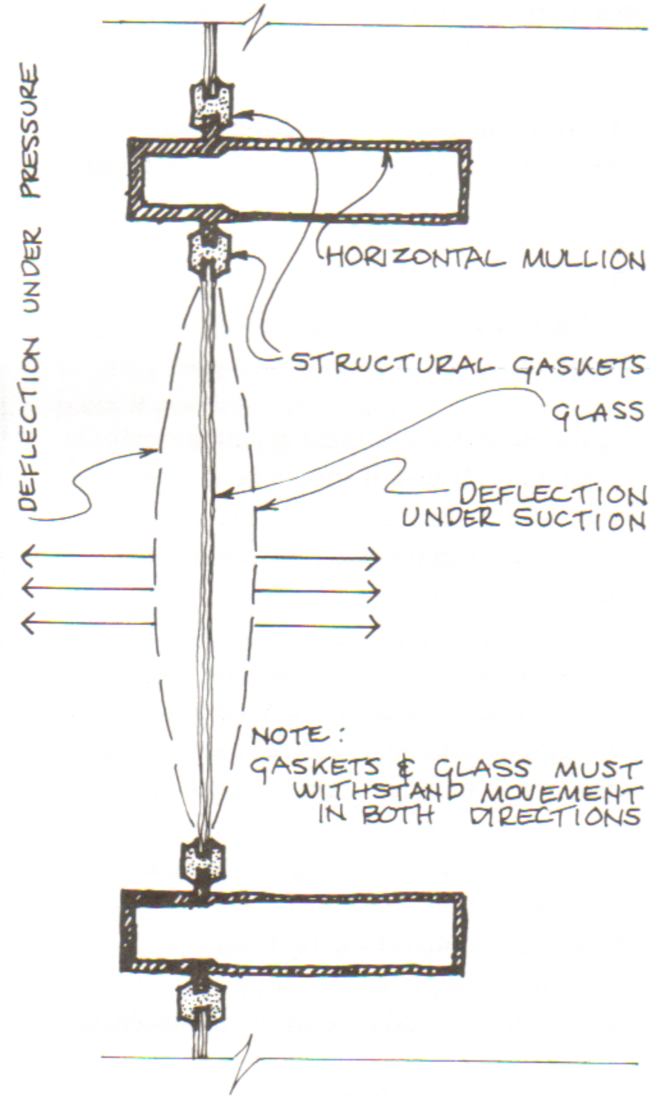
LATERAL FORCE ON SUB-SURFACE WALL

considers such forces and the methods to resist them.

There are both inward and outward pressures on building surfaces exposed to wind, which are not uniform. Thus, the corners of structures must be sufficiently rigid to resist complex racking and twisting forces. Windows and other openings must also be able to resist wind forces. For example, glazing must be detailed to prevent inward pressures from pushing the glass from its frame.

Winds create suction on most roof surfaces and on leeward walls. Proper mechanical anchorage or sufficiently heavy ballast is necessary to hold the roof membrane in place. Window frames must also be capable of holding glass against forces of suction. Furthermore, since the wind direction can change, each wall element must be able to withstand both inward pressure and outward suction.

Earthquakes also create lateral forces in buildings that vary in direction, intensity, and duration. A building's configuration affects its ability to resist seismic (earthquake) forces. Lightweight buildings of regular geometric shape and stiffness tend to perform well. Portions of



FLUCTUATING FORCES ON EXTERIOR ASSEMBLIES structures that are not homogeneous in shape or construction react differently to seismic forces, which can result in stress concentrations. The most careful structural design cannot make an inherently weak building configuration safe from seismic damage. However, even proper configurations contain building design details that must be carefully considered during the preparation of construction documents. It is essential to verify that:

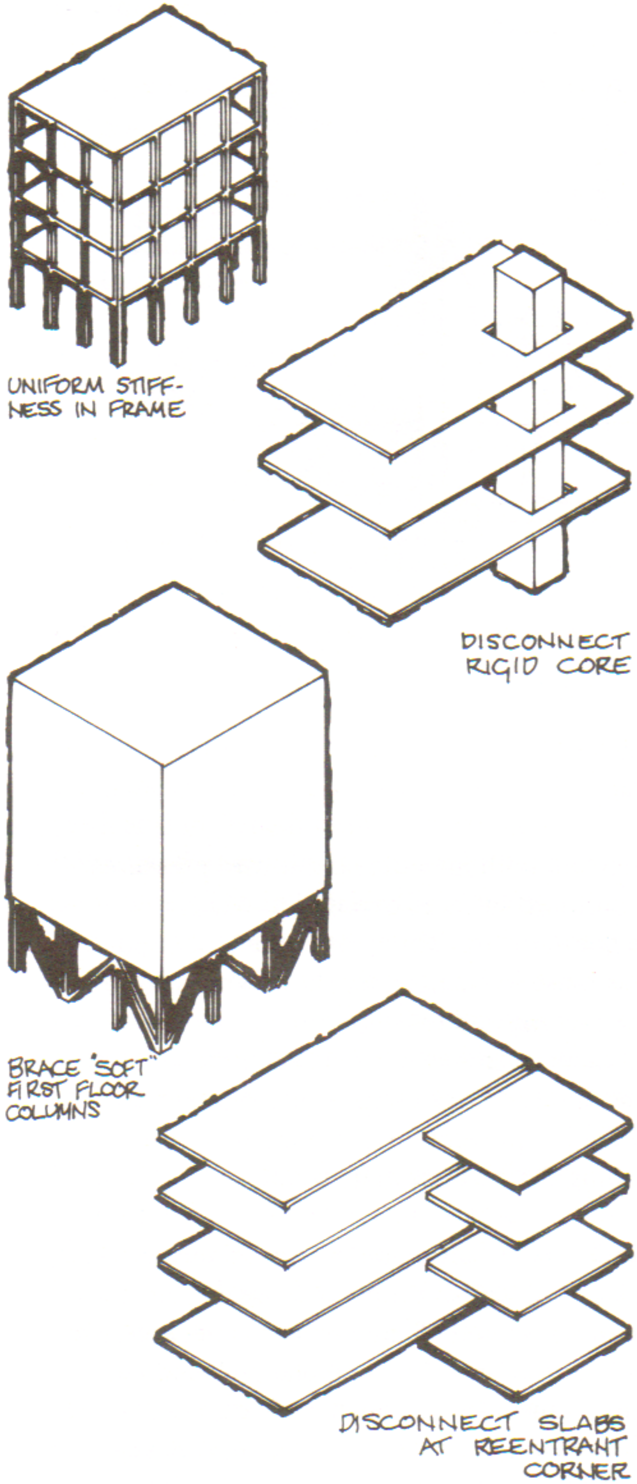
1. There are no extreme variations in the strength or stiffness of the perimeter frame or wall structure. Variations tend to create torsion in a building during earthquakes. Torsion can be alleviated by adding shear walls or stiffening the frame with bracing or additional columns.

2. A stiff core is not located asymmetrically in a building. If it is, it should be disconnected from the rest of the structure to prevent it from inducing torsional forces into the structure.

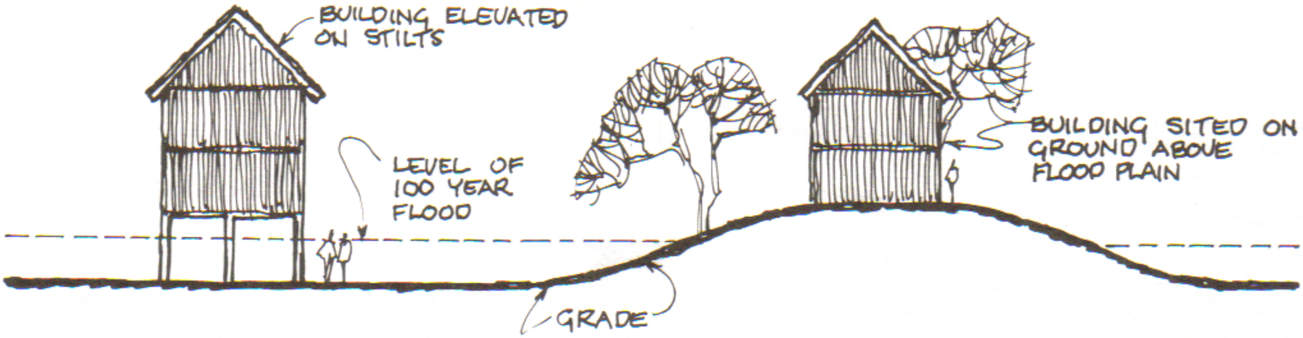
3. There are no notches or reentrant corners to concentrate stresses. If there are, the building should be structurally separated into two or more uniform elements.

4. No *soft story* is created by elevating the structures on *pilotis* at the first story. Bracing columns at the first story or increasing the number of columns to stiffen that level will tend to alleviate the problem.

In general, buildings should be as uniform in configuration and stiffness as possible. Furthermore, connections should allow a structure to act as a unit as much as possible.



SEISMIC DIAGRAMS



FLOODPROOFING

In summary, consider:

1. Providing reinforcing in underground walls to resist lateral forces exerted by soils.

2. Providing drains to prevent or control hydrostatic pressure against underground walls and slabs.

3. Detailing windows and other openings to resist both inward and outward wind pressures.

4. Providing mechanical connections or weight on the roof membrane to resist upward forces created by winds.

5. Shaping buildings uniformly with relatively uniform stiffness and strength to resist seismic forces.

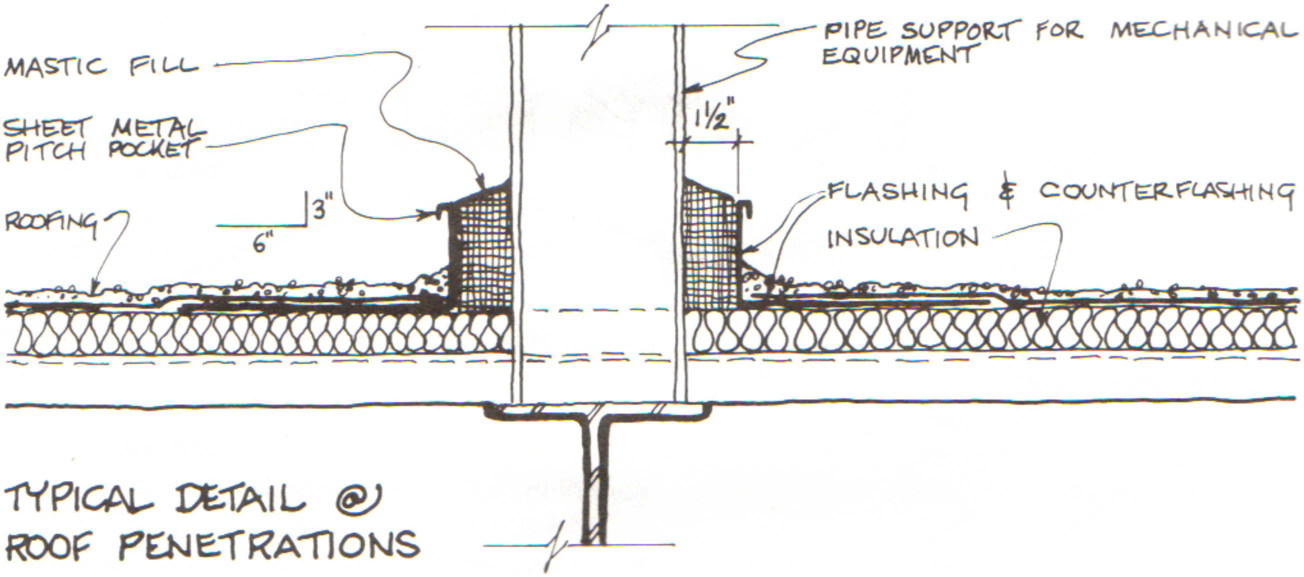
Water and Moisture Control

Buildings are exposed to water from various sources. When water penetrates a building, it may damage building materials, destroy the contents, and inconvenience occupants. Consequently, architectural design and detailing must control the effects of water on buildings.

Floodproofing

Buildings must be protected from floods by locating them outside of the 100-year flood plain if possible. However, if that is impossible, buildings can be floodproofed in other ways.

Buildings can be elevated by placing them on fill or stilts, or a combination of the two, to raise floor levels above anticipated flood levels. Dry and wet methods of floodproofing may also be used. Dry floodproofing methods utilize water resistant materials and sealants to prevent flood waters from entering the building and are thus effective in keeping building interiors dry. Wet floodproofing methods allow water to penetrate buildings. When flood waters recede, standing water is pumped out. This method requires mechanical equipment and other water-sensitive materials to be located above anticipated flood levels. The wet method does not require the structural system to resist the force of flood waters. Both dry and wet methods, however, require building superstructures to be firmly anchored to solid ground.



TYPICAL DETAIL @ ROOF PENETRATIONS

Horizontal Surfaces

Roofs are subject to water and moisture penetration. Sloped roofs, where the pitch is 4:12 or greater, have fewer problems than flat, or slightly sloped, roofs. Shingles, tile, or metal may be applied to sloped roofs to produce attractive and generally leakproof installations, since most water flows down the slope. Critical areas where roof planes form valleys, at penetrations of vents and equipment supports, and intersections between walls and roof surfaces, require flashing to prevent water penetration.

Flat surfaces are more difficult to waterproof. All flat roofs, decks, and other horizontal surfaces should have a minimum slope to drain of 1/4" per foot to avoid standing ponds of water. Details at interruptions or terminations of roof membranes are critical. Particular care is required where roof membranes terminate at parapet walls and roof edges. Details should allow water to run off, incorporating physical barriers, like flashing, to prevent water from penetrating walls. Joints between monolithic roof membranes, as well as penetrations or terminations of the membrane, must be at least as waterproof as the membrane itself. Flashing and mastic are often used for that purpose.

Many manufacturers of roofing systems offer a guarantee, or bond, for a specific time period. They may, however, reserve the right to approve the roofing contractor, and to provide a manufacturer's representative to inspect the installation and provide technical assistance. However, manufacturers may disclaim responsibility for parts of roof systems supplied by others, such as flashing materials. Such disclaimers may result in problems because the integrity of the joint between roof membrane and flashing is sensitive and critical to a successful installation. However, many roof systems include all components, including flashing, enabling architects and owners to benefit from a single source of responsibility.

Costly roof failures can be prevented through the use of proper materials and detailing. The cost of roofing is relatively minor compared to overall project costs. Therefore, it is best to design and specify quality roofing systems.

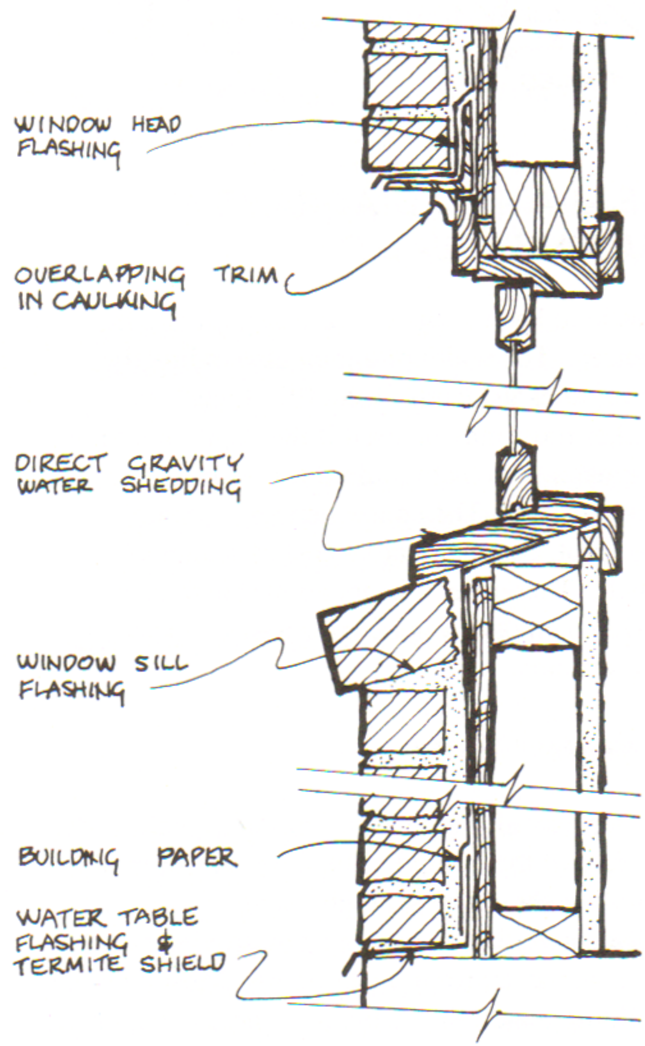
Vertical Surfaces

Exterior walls and openings for windows and doors must also be designed to resist water intrusion. Chemical sealers may be applied to the surface of masonry materials to repel water. Alternatively, impermeable backup materials, such as sheet metal, elastomeric membranes, or building paper, may be used. If moisture does penetrate exterior walls, the backup material will direct it through weep holes back to the exterior. Manufactured window and door assemblies are usually designed to work this way. The component parts resist water penetration and provide positive drainage if water intrudes into the assembly.

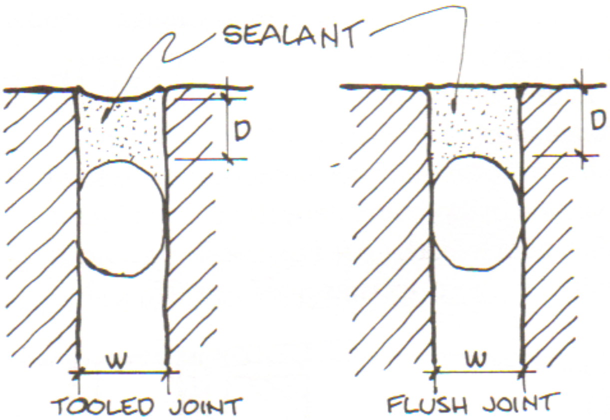
Most problems with vertical surfaces occur at joints where wall materials meet and between walls and window or door assemblies. Water driven by gravity, wind, or capillary action may enter a building at these points. Flashing, overlapping materials and trim, and the application of sealants, are used to prevent such intrusion. Sealants may be used alone or in combination with flashing and overlapped joints to increase the degree of protection.

Sealants

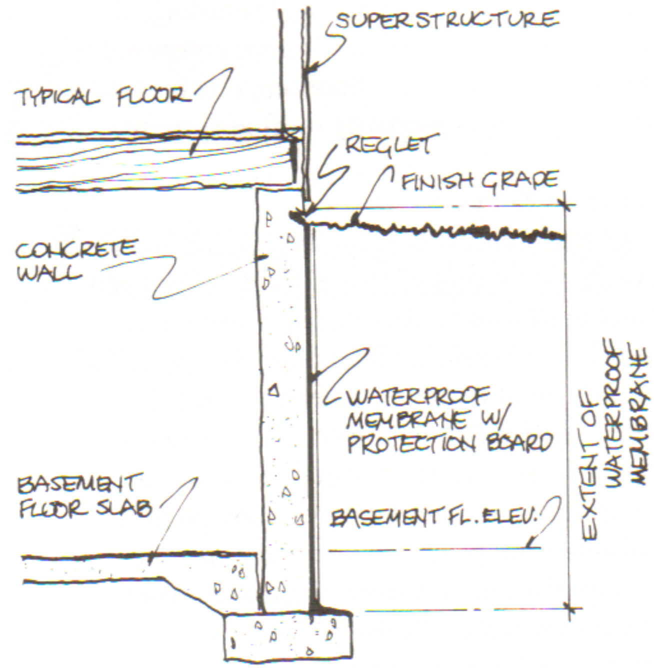
Sealants must be specified for their particular application, and such joints must be carefully detailed. This may include anything from setting a door threshold in two beads of sealant to specifying a sealant for complex joints between exterior materials. In the latter case, the joint width must be adequate to accommodate anticipated movement of the materials. Such movement may occur because of thermal expansion or structural deflection. Initial joint widths help to determine the type of sealant required because sealants must be sufficiently



WATER PROTECTION @ EXTERIOR OPENINGS



SEALANT DIAGRAMS @ MASONRY WALLS



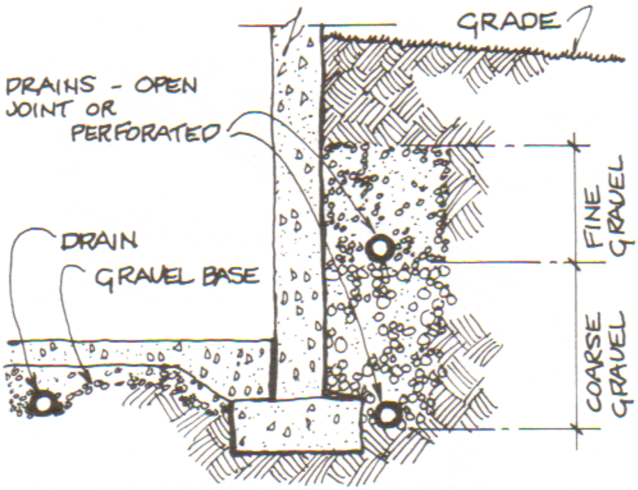
SUB-SURFACE WATERPROOFING

elastic to keep joints sealed under all circumstances. The width of a joint also indirectly determines its depth. Joint fillers, such as backer rods, may be used if the depth of a joint is greater than that required for proper sealant performance. The consequences of joint failures are great, and the relative cost of sealants is small. Therefore, it is not advisable to economize when detailing exterior joints and specifying sealants.

Subsurface Water

Water may also enter buildings at, or below, the surface of the ground. The floor elevation of a building should be set high enough so that the adjacent grade can be sloped to provide positive drainage away from the building. Most common building materials, including concrete, which are used below grade are permeable. Consequently, a waterproof membrane must be applied to the outside of a wall below the surface of the ground to prevent water penetration. Membranes must be continuous and penetrations by pipes at footings and other junctures may require mechanical waterstops. In any case, membranes should extend below the level of the lowest floor of a building.

Foundation drains may be required to alleviate hydrostatic pressure created by ground water and to minimize the potential for water penetration. They are made of perforated pipe and are placed in gravel fill areas outside foundation walls. Drains should be placed at the perimeter of a building to collect ground water and carry it away. The gravel fill helps keep pipes free of silt and facilitates water flow to them. If the water table is high, a full gravel base may be required under a basement floor, with drain pipes appropriately spaced. The gravel base course not only aids the flow of



SUB-SURFACE DRAINS

water to drains, but it also prevents capillary action against slabs.

Condensation

Moisture that originates within a building must also be considered. Water vapor passing through an interior surface of a wall or ceiling will condense to liquid upon contact with a sufficiently cold exterior wall or roof surface. The resulting condensation may drip onto ceilings or along the inside of walls, damaging interior finishes, blistering paint, and causing decay.

A vapor barrier on the warm (interior) side of a wall or roof space usually prevents condensation, since it stops water vapor before it comes in contact with a cold surface or space. Mechanical or natural ventilation, particularly in attic spaces, is used to evaporate moisture that may occur in roof areas.

In summary, consider:

1. Floodproofing by siting structures outside of flood plains, elevating buildings, or using methods of dry or wet floodproofing.

2. Providing proper flashing details at all roof penetrations, junctions, and terminations.

3. Using sealants or backing materials at junctions of vertical surfaces.

4. Using flashing, overlapping materials, and sealants at openings in vertical surfaces.

5. Selecting appropriate sealants with proper width-to-depth ratios at joints.

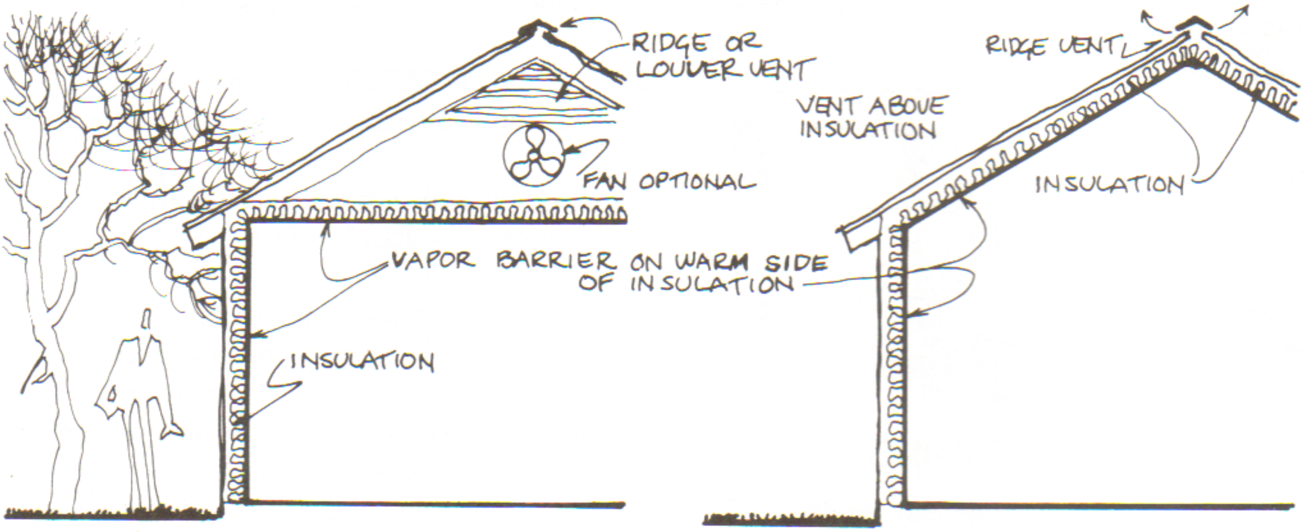
6. Sloping ground surfaces away from buildings for positive drainage.

7. Providing waterproof membranes and subsurface drains at building perimeters and, in some cases, under floor slabs.

8. Providing vapor barriers on the warm side of walls and roofs, combined with adequate ventilation to control condensation.

Environmental Considerations

Architects must select materials which are resistant to decay and corrosion. For example, redwood, cedar, and concrete are naturally resistant to decay and may be left untreated. Most other materials, however, are not naturally resistant to decay or corrosion and must be treated. Many materials are painted, although there are alternative treatments available. For example, wood may be chemically treated under pressure, or Cor-Ten steel, which weathers or corrodes to a point where it effectively protects itself, may be used. Most alloys,



VAPOR BARRIERS

plastics, and fluorocarbon coatings also resist decay and corrosion.

Corrosion may occur where flashing meets other building materials. Electrolysis, also known as galvanic action, occurs when two reactive materials, such as aluminum and steel, come into contact with each other, which may lead to corrosion. It is critical to avoid electrolytic action and corrosion because flashings are vital to making a building watertight. Corrosion may occur even where materials do not touch. Where water passes over one material onto another, electrolysis may occur. Therefore, reactive materials should be separated by mastic, building paper, or other material, to prevent water from creating a galvanic connection between materials.

Insects, particularly termites, present an additional hazard. Termites attack the wood parts of structures. Metal shields are installed to block termites trying to reach those parts. These termite shields must create a continuous barrier to the movement of insects in order to be effective. Added protection may be provided by introducing poison into the soil at the perimeter of a building, under floor slabs, in crawl spaces, and in voids within concrete masonry units. Since termites prefer warm, damp, poorly ventilated spaces, they may be controlled by minimizing such conditions.

Certain materials used in building products have been identified as hazardous. These include asbestos (used in fireproofing and pipe insulation), volatile organic compounds (VOCs, used in coatings), PCBs (used in electrical transformers), lead (used in coatings), coal tar (used in roofing), and other toxic substances. Architects should certainly not specify products composed of these materials.

Moreover, the AIA Owner-Architect Agreement (Document B141), Paragraph 9.8, states in part that the architect *shall have no responsibility for the discovery, presence, handling, removal or disposal of …hazardous materials.* Professional liability insurance excludes coverage for services performed related to these materials.

The phrase *sick building syndrome* is now used primarily to describe poor indoor air quality. This phenomenon can result from inadequate mechanical ventilation, germ-breeding filters and stagnant condensate reservoirs, off-gassing from fabrics, coatings and backing materials, tobacco smoke, and other toxic substances. Some regulations exist, while others are being developed, to remedy this situation.

In addition, architects are placing greater emphasis on conservation when specifying building materials. Products made from renewable resources, recycled and recyclable materials, and products which require less energy to manufacture, are being specified in response to environmental awareness.

Thermal and Acoustical Control

Thermal Control

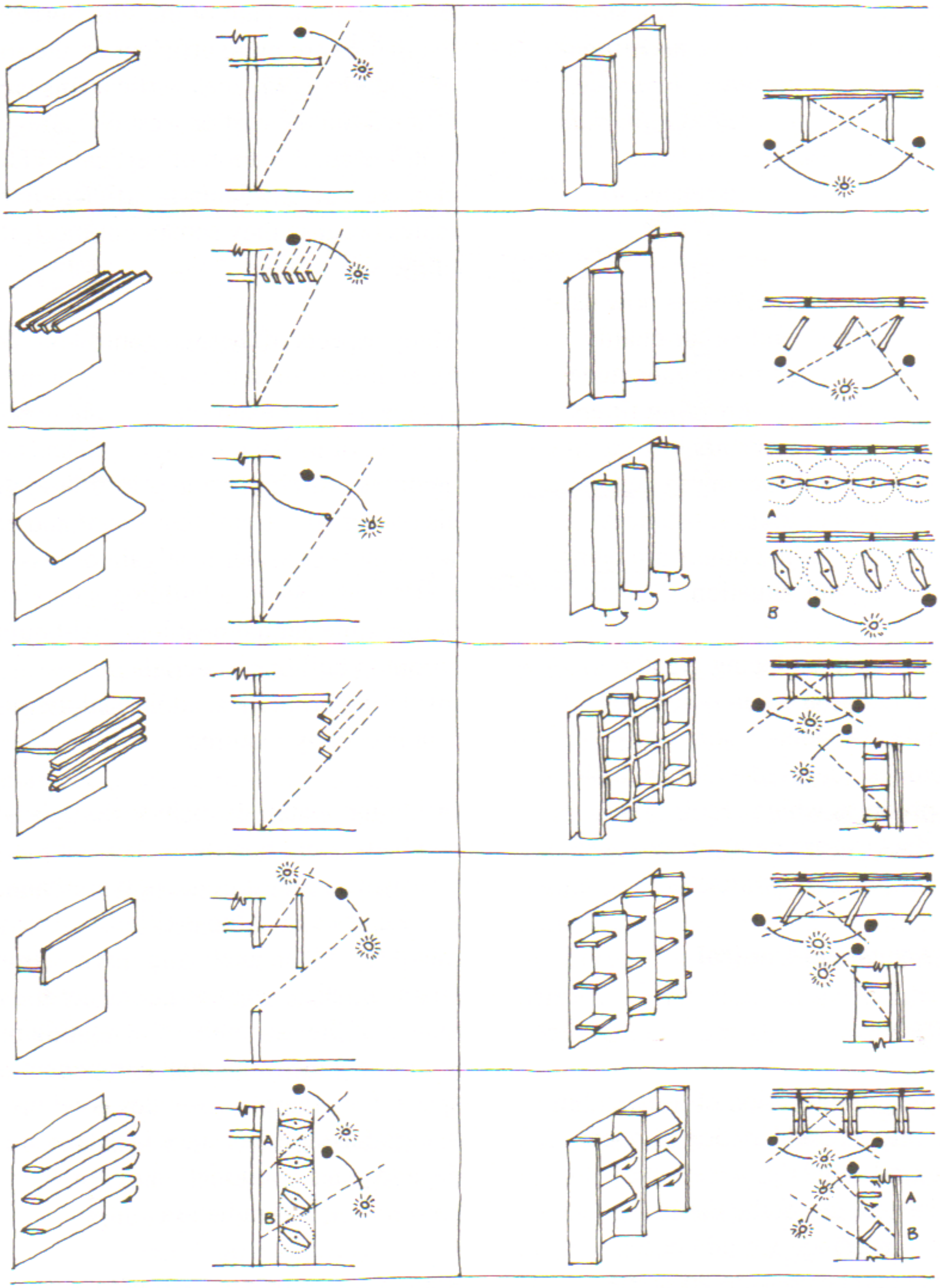
Siting, landscaping, the location of uses within a structure, the amount and location of openings in exterior walls, and the selection of building materials, all affect the thermal performance of a building. Certain basic design elements must be considered in the preparation of construction documents.

For example, there are various applications of sunshades to control heat gain from the sun. Because of the path of the sun, horizontal overhangs are more efficient on the south side of a building, whereas vertical fins are more efficient on the east or west elevations. Egg-crates, a combination of vertical and horizontal elements, are particularly efficient in hot climates because they screen out most, if not all, of the sun's rays.

Many aspects of thermal control are determined by architects in collaboration with mechanical engineers. For example, glass may be selected because of its heat and light transmission qualities. Similarly, the selection of the materials comprising a building's roof and exterior walls must consider heat gain or loss. Building codes may specify a building's maximum permissible annual heat loss. Although many common building materials possess good insulating properties, additional thermal insulation is usually required.

Insulation materials include fiberglass blankets and batts, rigid boards made from thermoplastics such as polystyrene, polyurethane, or isocyanurate, and loose fill of perlite or vermiculite. When analyzing thermal transmission characteristics, one must consider the performance of the assembly of insulating materials, not merely the individual component parts. Air space, for example, provides good insulation in material assemblies since heat transmission depends on a combination of conduction, convection, and radiation.

Some insulating materials are combustible. For example, certain rigid insulation boards may create a fire hazard if they are exposed to air. Others may be more flammable installed



HORIZONTAL

VERTICAL + COMBINED

WINDOW SHADING DEVICES

horizontally than vertically. The selection of insulating materials must consider fire resistance, as well as resistance to heat transmission.

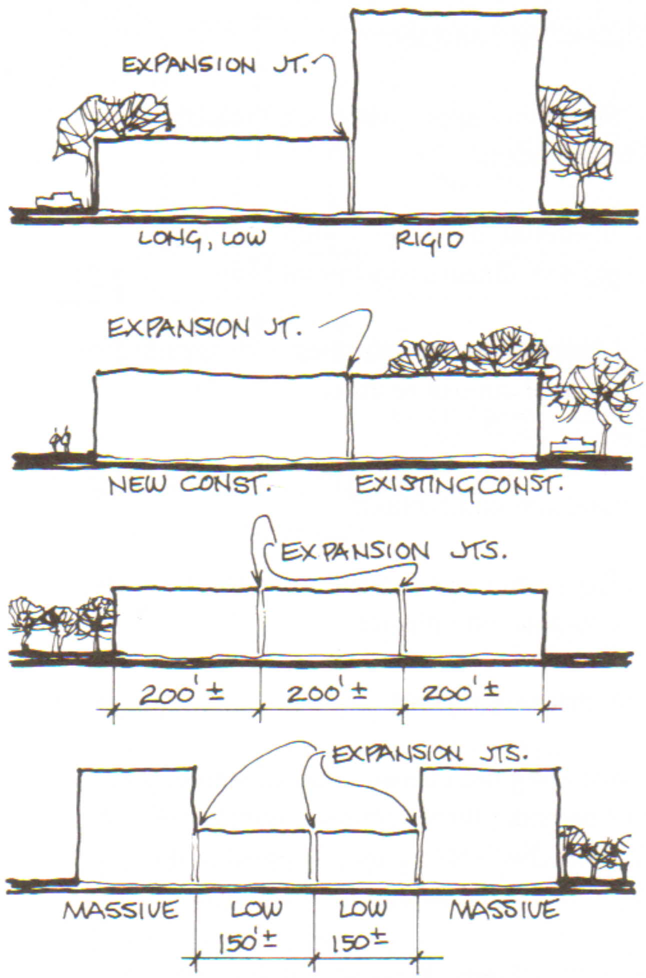
The thermal transmission characteristics of manufactured assemblies must also be considered. For example, certain metal windows may allow heat and cold to be conducted through their frames. Some assemblies are not sufficiently weather-stripped to prevent air infiltration. Most metal window today, however, are manufactured with thermal breaks in the frames to prevent conduction of heat and cold and with weather-strips to inhibit air infiltration.

Thermal expansion and contraction cause building materials to move. The amount of thermal expansion depends on the material. For example, aluminum expands at approximately four times the rate of masonry and twice that of concrete. Metals may buckle or separate from anchors if details do not allow for movement. Loose metal results in poor appearance and may allow water to penetrate a building.

Roofs usually absorb more heat than walls, tending to expand and to exert horizontal forces against walls. Walls must be designed and detailed to accommodate these forces.

Movements caused by temperature changes may induce tensile forces which result in cracking, especially in materials which have low tensile strength, such as masonry and concrete. Such cracking can be controlled by using steel reinforcing, and by providing expansion and control joints at the appropriate locations.

Expansion joints allow masonry to move independently of a structural steel or concrete frame, while control joints relieve forces that may build up within individual masonry elements. Expansion joints should be located at regular intervals along walls, at major changes in wall height or thickness, at columns and pilasters, at wall openings, near wall intersections, and near junctions of walls in L-, T-, or U-shaped buildings. Masonry must remain structurally stable and watertight at control and expansion joints.



LOCATING MASONRY EXPANSION JOINTS

Concrete and plaster are similar to masonry and react in much the same way. Some cracking will inevitably occur, most of which does not affect the building's structural integrity. However, cracks are unsightly and may allow water to enter the building. Therefore, architects attempt to control cracking by providing weakened joints (control joints) in which the cracks are likely to occur, in preference to the random cracking that would otherwise take place.

In summary, consider:

1. Sunshades appropriate to a building's solar orientation.

2. Insulating materials which are integral parts of construction assemblies.

3. Manufactured assemblies with appropriate thermal control features.

4. Details that accommodate thermal expansion and contraction.

5. Expansion and control joints for masonry, concrete, and plaster.

Acoustical Control

In analyzing the transmission of sound, we must consider three factors: source, path, and receiver. Each factor may be modified or controlled in the design of buildings.

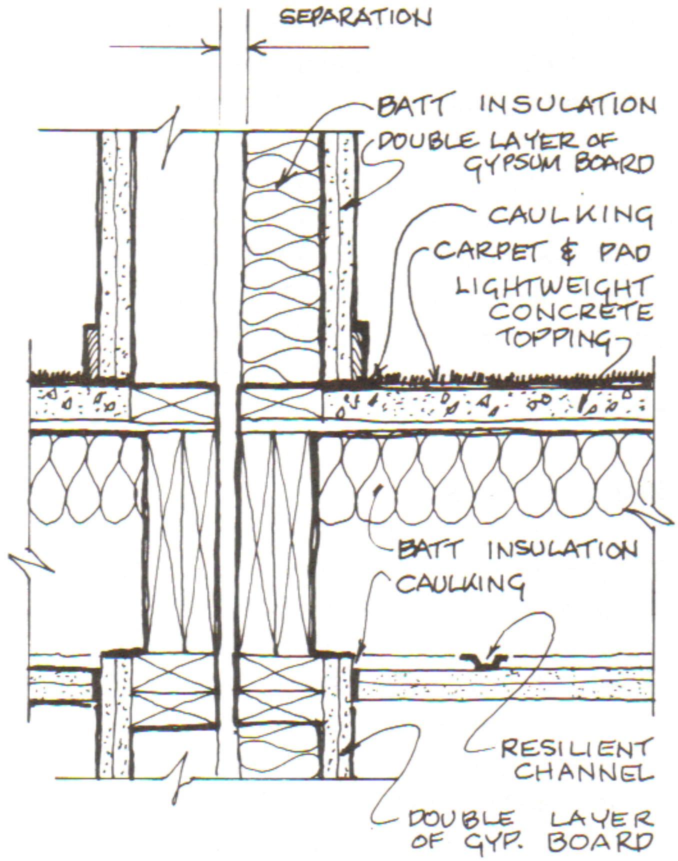
The level of outside noise which a *receiver* can tolerate may be expressed as the Preferred Noise Criteria (PNC), for which applicable standards are published. Building construction must reduce noise generated by outside sources to a tolerable level. There are two basic ratings of assemblies of materials: STC and IIC. Sound Transmission Class (STC) is the method of rating the acoustic efficiency of various wall and floor systems in isolating airborne sound transmission. The higher the STC rating, the more efficient the construction. STC ratings are not appropriate in considering the effect of impact noises on floor assemblies caused by foot traffic or machinery. For that purpose, Impact Isolation Class (IIC), also referred to as Impact Noise Rating, is used. This is a simple numerical rating developed by the Federal Housing Administration to estimate the impact sound isolation performance of floor/ceiling systems.

In selecting assemblies and developing details, an architect must be familiar with the following principles of acoustical design: lightweight, porous materials are effective for sound *absorption*, while heavy, impervious materials are effective for sound *isolation*; they cannot be used interchangeably. Penetrations at walls, floors, and ceilings must be minimized, and openings, including those at the tops and bottoms of partitions, should be airtight. Impact noises, such as those cause by foot traffic on floors, can be minimized by the use of resilient flooring. Finally, sound waves are transmitted over long distances through structural frames. Discontinuities at junctions of walls, partitions, floors, and ceilings, therefore, are valuable sound control devices.

Sound absorption within spaces must also be considered. The Noise Reduction Coefficient (NRC) is a rating which compares absorptive capabilities of acoustical materials. Echo and reverberation control is critical in the design of spaces. For a given use, there is an optimum balance of absorption and reflection achieved largely through the selection of appropriate materials. Porous, fibrous finish materials are more effective in absorbing sound than hard, reflective surfaces. Carpets are used to reduce impact noise from foot traffic and also absorb airborne sounds. Sound absorbing materials may be applied to walls, although less effectively than when applied to ceilings. Acoustical tile is an effective absorptive material for use at ceilings. Light fixtures and air diffusers, which reflect sound, must also be considered in the design of ceilings.

Sound Absorption Coefficients of Materials @ 500 Hertz

Acoustical plaster (average)	*0.50*
Brick, exposed and unpainted	*0.03*
Carpet, heavy, on solid surface	*0.14*
Concrete block, unpainted	*0.31*
painted	*0.06*
Concrete, unpainted	*0.02*
Wood floor	*0.10*
Glass, ordinary window	*0.10*
Gypsum board, 1/2" on 2x4s @ 16" oc	*0.05*
Plaster on lath	*0.06*



DISCONTINUITIES IN SOUND PATHS

In summary, consider:

1. Sound source, path, and receiver.

2. Sound Transmission Class (STC) and Impact Isolation Class (IIC) ratings of walls and floor assemblies that equal or exceed required Noise Reduction (NR) criteria.

3. Sealing joints, openings, and other penetrations in walls and ceilings/floors between spaces.

4. Sound absorption within spaces.

Durability and Maintenance

Building materials should be both durable and easily maintained. The appropriate level of durability or required maintenance may vary, depending on the building's occupancy (use), its required life span or that of its component parts, its available level of required maintenance, accessibility, and other factors. Trade-offs between initial and long-term costs may have to be made. For example, it may be more economical to replace a system or component every ten years than to purchase and install one that will last for twenty years. This type of analysis is referred to as *life cycle costing*.

Safety

Fire Protection

The purpose of licensing architects is to assure that architects are competent to protect the public's health, safety, and welfare. An architect must be able to design buildings that are structurally safe and meet the requirements for fire and life safety. The safety requirements specified in building and fire protection codes are minimum standards only, and do not necessarily provide the best solution in every case.

Architects should understand some basic concepts of fire protection in building codes:

1. A fire in one building should not damage another building.

2. A building's construction should be able to withstand the effects of fire for a specified period of time.

3. The more hazardous the use, the more protection the building's construction must provide.

4. As the size of a building or the number of its occupants increases, the fire protection, fire separation, and required means of egress also increase.

5. Occupants should be provided with a direct and safe means of escape from a building in the event of fire.

Building codes regulate how these basic concepts are applied to building design. There are three model building codes used in the United States: the BOCA code, used primarily in the east; the SBCCI (Southern) code, used primarily in the south; and the Uniform Building Code (UBC), used primarily in the west. A model code must be adopted by a state or local jurisdiction in order to be enforced. Some jurisdictions amend the model codes and several write their own.

An outline of the basic steps in determining code compliance for a building design follows:

1. **Construction documents:** Determine compliance with the requirements for construction documents.

2. **Use group:** Determine the appropriate use group classification of the building.

3. **Height and area:** Determine the type of construction required based on the building use group and the height and area limitations.

4. **Type of construction:** Determine compliance with the required type of construction of the building by the building materials used and the fire resistance rating of the building elements.

5. **Siting:** Determine the location of the building

on the site, including separation distances from lot lines and other buildings. Determine exterior wall and wall opening requirements based on proximity to lot lines and adjacent buildings.

6. **Fire performance:** Determine compliance with detailed requirements for fire resistance and fire protection systems.

7. **Interior environment and design:** Determine compliance with special use and occupancy requirements, *means of egress* requirements, accessibility requirements, and interior environment requirements.

8. **Exterior envelope:** Determine compliance with exterior envelope requirements, as well as energy conservation.

9. **Structural performance:** Determine compliance with structural requirements and building material requirements.

10. **Building service system:** Determine compliance with various building service system requirements.

Once the use, massing, and location on the site of a building have been determined, the architect can consider options for the type of construction. For example, an office building could be constructed of a type of construction which uses a combination of unprotected noncombustible and combustible construction. The same building could also be constructed of a more restrictive type of construction, using only protected noncombustible materials. Note that *protected* means having fire-resistive protection, such as sprayed fireproofing or concrete around structural steel construction, while *combustible* refers to a material which can ignite and burn, such as wood. Conversely, for a similar building, but which houses a more restrictive use, such as a hospital, a more restrictive construction type would be required. In general, the higher the construction type, the more costly the building. The basic allowable areas, heights, and number of stories can be increased by providing other features to increase the building's fire resistance, such as an automatic fire sprinkler system, setbacks from adjacent buildings and streets, and fire separation assemblies within the building.

Once the use group, allowable area, height, number of stories, and type of construction have been determined, the next major safety consideration is egress. The building code includes the requirements for calculating the number of occupants, the number of exits for each room, floor, and building, and the arrangement and width of each component of the *means of egress* (aisle, door, corridor, stair). Dimensional requirements for stair treads and risers, guardrails and handrails, and vertical clearances are also found in the code.

Additionally, specific drawings should be checked as follows:

1. **Site Plan**
   a. Is there proper access to streets?
   b. Are building separations adequate? All objects, such as other structures, which might expose a building to fire must be located and separation distances correlated with fire resistance ratings of exterior walls. Walls with windows and other unprotected openings may require additional treatment.

2. **Plans and Sections**
   a. Verify that ceiling heights are permissible. Check heights of habitable spaces below grade.
   b. Verify that the height of the building, in feet or number of stories above grade, is within allowable limits.
   c. Verify that the floor area of each floor is within permissible limits. Area limitations may be increased under certain conditions.
   d. Verify fire resistance of all building components.

3. **Plans, Sections, and Elevations**
   Verify that openings are protected where they are exposed to property lines, adjacent buildings, interior courts, or other openings in the same wall, above and below.

4. **Plans and Sections**
   a. Confirm the number of occupants anticipated to occupy each floor of a building. This number may be based on an actual count, such as the number of seats in an auditorium, or on an assumed number of occupants per unit of floor area.
   b. Verify the correct number, width, and arrangement of exits.
   c. Verify that distances to exits are within allowable limits.
   d. Verify that required exit door hardware is specified.
   e. Confirm the adequacy of aisles, corridors, and horizontal exits.
   f. Check that all stairways are properly located and enclosed, and that they provide a legal means of egress.

5. **Plans**
   a. Verify that different occupancy types are separated by properly rated fire walls, etc.
   b. Verify that elevator, escalator, and vertical shaft enclosures are properly fire rated.

6. **Specifications**
   Determine that finishes and trim meet requirements for proper classifications. Installation methods must meet code requirements for control of smoke emission and limitations on smoke toxicity.

7. **Miscellaneous**
   Verify that roof coverings have required ratings.

Life Safety

The primary objective of building codes is the protection of life, health, and property. Codes published by the National Fire Protection Association (NFPA) are designed to protect human life. The NFPA code that most directly affects the architectural design of buildings is NFPA 101, the Life Safety Code, which is also a model code. It may be adopted and enforced by state or local officials. In many cases, the egress portions of building codes are based on NFPA 101.

NFPA's Life Safety Code Handbook, the companion to NFPA 101, cites the Code's goals, which form a good checklist in preparing or reviewing a set of construction documents:

1. To provide for adequate exits without dependence on any one safeguard.

2. To ensure that construction is sufficient to provide structural integrity during a fire while occupants are exiting.

3. To provide exits that have been designed to the size, shape, and nature of the occupancy.

4. To ensure that the exits are clear, unobstructed, and unlocked.

5. To ensure that the exits and routes of escape are clearly marked so that there is no confusion in reaching an exit.

6. To provide adequate lighting.

7. To ensure early warning of fire.

8. To provide for backup or redundant exit arrangements.

9. To ensure the suitable enclosure of vertical openings.

10. To make allowances for those design criteria that go beyond code provisions and are tailored to the normal use and needs of the occupancy in question.

Barrier-free Provisions

For the past twenty years or so, federal and state regulations concerning accessibility to buildings by persons with disabilities have been developed. These regulations are typically based on the American National Standards Institute (ANSI) Standard 117.1. Once adopted, these regulations are enforced like any other code requirement; that is, plans must be reviewed by a code official before a building permit is issued, and the work must be inspected before a certificate of occupancy is issued.

In 1990, the Americans With Disabilities Act (ADA) was enacted. In contrast to building codes, the ADA is civil rights legislation. A person denied equal access to a building may sue the owner of the building if the owner does not make the building accessible. Code officials do not enforce the ADA. However, architects are exposed to professional liability if they ignore the accessibility guidelines included in the ADA. State and local code officials, as well as the model code organizations, are currently studying the feasibility of modifying their codes to conform to the ADA.

Design criteria for persons with disabilities usually include requirements for:

1. Walks, ramps, stairs, and circulation routes.

2. Parking space size, number, and location.

3. Site furniture.

4. Tactile, visual, and audible warning signals.

5. Overhanging and projecting objects.

6. Entries, doorways, and hardware.

7. Elevators.

8. Floor surfaces.

9. Water closets, drinking fountains, toilet stalls, urinals, lavatories and mirrors, dispensers, and receptacles.

10. Electrical systems, outlets, switches, and telephones.

Architects must determine which of the various codes and standards apply to a particular project. As with other aspects of architectural practice, written records in this regard should be kept and copies distributed to the various interested parties.

In summary, consider:

1. Codes are intended to provide minimum standards of building design for the protection of persons and property.

2. The greater the risk, the greater the level of protection required.

3. In order for codes to be enforced, they must be adopted by an enforcing agency of the federal, state, or local government.

4. The Americans With Disabilities Act (ADA) is federal civil rights legislation, not a building code.

Dimensional and Finish Tolerances

Architectural details must be able to accommodate construction tolerances and imprecision of workmanship. Consequently, details must allow for some dimensional adjustments, such as slotted holes at connections, shim spaces, and trim applied over imperfect joints. The problem is to determine how much dimensional tolerance is necessary.

Dimensional tolerance depends on both the quality of materials used and the stage in the construction process. Less expensive or bulky materials have poorer dimensional quality and stability. For example, concealed concrete and rough carpentry work do not require the same level of precision as tile work or cabinetry.

In some cases, a very high level of precision may be required. For example, walls at property or setback lines must be located very accurately. Spaces or recesses to receive prefabricated or manufactured equipment of a specific size must be precisely constructed. Precision may be so critical that the contractor may have to make measurements of the completed construction before ordering required equipment. High levels of precision and low tolerances, however, usually result in higher costs and increased construction time.

Trade associations, such as the American Institute of Steel Construction (AISC) and the American Concrete Institute (ACI), publish construction standards applicable to their materials. An example is the table on page 1-23. These standards provide useful rules of thumb. However, if an architect refers to these standards in specifications, the necessary relevant tolerances must also appear in the detail drawings. Otherwise, conflicts may result. For example, steel construction that is meant to be at the same elevation as adjacent concrete construction may not align exactly, even if both materials are within the requirements of their individual tolerances.

In summary, consider:

1. There are dimensional variances within materials.

2. The accuracy and precision of building

TYPICAL DIMENSIONAL TOLERANCES IN CONCRETE CONSTRUCTION

Formwork Tolerances for standard reinforced concrete buildings up to approximately 100 feet tall.

Variation from plumb

1. *In the lines and surfaces of columns, piers, and walls:*
   1/4" per 10', but not more than 1".
2. *Exposed corner columns, control joint grooves, and other conspicuous lines:*
   In any bay, or 20' max .... 1/4".
   In 40' or more .... 1/2".

Variation from level

1. *In slab soffits, ceilings, and beam soffits:*
   In 10' .... 1/4".
   In any bay, or 20' max .... 3/8".
   In 40' or more .... 3/4".
2. *For exposed lintels, sills, parapets, horizontal grooves, and other conspicuous lines:*
   In any bay, or 20' max .... 1/4".
   In 40' or more .... 1/2".

Variation of linear building lines *(from established position in plan and related position of columns, walls, and partitions):*

In any bay, or 20' max .... 1/4".
In 40' or more .... 1/2".

Variation of sizes and locations

Sleeves, floor openings, and wall openings .... 1/4".

Variation in

Cross-sectional dimensions of columns and beams; thickness of slabs and walls:
Minus .... 1/4".
Plus .... 1/2".

Footings

1. *Variation in dimensions in plan:*
   Minus .... 1/2".
   Plus .... 2".*
2. *Misplacement or eccentricity:*
   2% of the footing width in the direction of misplacement but not more than 2".*
3. *Reduction in thickness:*
   Minus .... 5%.

**Concrete only, not reinforcing bars or dowels.*

Variation in steps

1. *In a flight of stairs:*
   Rise .... 1/8".
   Tread .... 1/4".
2. *In consecutive steps:*
   Rise .... 1/16".
   Tread .... 1/8".

construction is limited by the ability of materials and workers to perform within their inherent limitations.

3. High levels of precision may be costly and unnecessary.

4. Where great precision with minimum tolerances is mandatory, it should be specified.

Aesthetics

Specifications may require a contractor to submit shop drawings, product data, or samples. An architect can control aesthetics, in part, by reviewing these submittals. Shop drawings show precisely how a contractor intends to install a specific item of equipment or material. Product data are standard information sheets that define and describe the physical and operational characteristics of items of equipment. Samples may show the proposed color, texture, or finish of materials. Samples approved by an architect become the standard against which actual installations are compared.

Where an installation is the first use of an untested material or system, or where many repetitive elements occur, a mock-up of that element may be required. Full scale mock-ups are generally not within the architect's or owner's budget during the preconstruction phases. On occasion, a material supplier or fabricator may be willing to produce such a mock-up. However, more commonly, the specifications may require the successful bidder to construct a full scale mock-up at the job site or at the factory. Visual mock-ups, such as brick panels, may be used to select brick shades and mortar colors, and to demonstrate the contractor's ability to construct the brickwork as detailed and specified. Performance mock-ups, such as aluminum and glass curtain walls, may be tested to verify that the assembly can withstand specified wind loads, seismic loads, and rain and wind infiltration criteria. The results of these mock-ups may lead to refinements in the detailing and methods and sequence of construction. However, during the construction phase, major design changes are not feasible without the owner's agreement to issue a change order, if requested by the contractor.

A mock-up may cost ten times as much as the same amount of work on the job. Since contractors include such expenses in the contract sum, architects must be selective, requiring mock-ups only when necessary.

The AIA General Conditions (Document A201) gives the architect the right to reject construction work that does not comply with the intent expressed in the construction documents. Usually such rejection must be based on objective standards, such as field tests. For decisions concerning aesthetics, however, the architect is the final authority.

COST MANAGEMENT

For a detailed description of the architect's role in managing cost, and for the various types of cost estimates, see Lesson Four.

Initial Cost of Materials and Equipment

In order to control construction costs, the architect considers initial cost, installation cost, and long-term cost in specifying products and materials. Poorly defined requirements will result in the selection of inadequate materials and products or those containing unnecessary features. Consequently, the architect must specify products or materials with the necessary properties to achieve the required performance. Building codes establish minimum requirements for certain products and materials; however, their main purpose is to promote safe construction rather than performance.

Most products, materials, and equipment are available with various qualities and features. It is important, for example, to select the proper grade of wood that will provide the necessary strength and desired appearance, the appropriate type of concrete, the desired quality of hardware, the necessary flexibility in an HVAC system, the proper amount and source of light, and the proper type of wall covering, all in accordance with the specific requirements of the particular applications. Another important consideration is that individual products or components may be combined into assemblies and systems. One must consider that the installed cost of an assembly or system may be greater than the sum of the installed costs of the individual elements.

Cost may vary with time and locality. For example, steel may be the most economical structural material in Pittsburgh, but not in Miami. Similarly, plywood or gypsum board shortages may result in price fluctuations from one area to another. It is a mistake to assume that cost information from one project in one location will necessarily apply to a similar project in a different location. Material and labor costs must be projected on the basis of up-to-date information.

Labor Costs

Labor is a significant part, often more than 50 percent, of the total construction cost. Consequently, architects strive to design buildings and prepare drawings and specifications to minimize the amount of on-site labor.

While labor costs have increased, productivity has decreased. Union rules contain numerous requirements that tend to perpetuate traditional and, consequently, more expensive installation methods. Building codes may also restrict or prohibit the implementation of new, labor-saving techniques.

Merit shops, or *open shops*, which are non-union employers, attempt to address the issue of increased labor costs. Some have successfully lowered labor costs while increasing productivity. Most projects are built with either all union labor or no union labor in order to avoid labor problems which may result when non-union construction workers are involved in unionized projects. Some states require that contractors pay a *prevailing wage* to all workers in a trade for public work as a way to equalize union and non-union pay scales. An architect cannot, however, determine whether a project will be constructed by a contractor employing union or non-union labor.

Regardless of the labor situation, drawings and specifications that reduce the amount of on-site labor and encourage the use of factory or shop labor will generally provide a less expensive project. Factory workers work under more controlled and efficient conditions than those for on-site construction workers. All elements fabricated off-site must, of course, be installed on the job. Consequently, on-site labor is always required. Qualified workers must make the installations and connections, which require adequate maneuvering space for workers and equipment.

Construction costs can be reduced through the use of repetitive materials and/or construction details, which enable workers to be more efficient. Construction details that allow work to be performed inside building enclosures will improve construction quality and, at the same time, efficiency. Thus, although labor costs will always be a major factor in the overall cost of construction, they can be controlled.

Long-Term Costs

Operational Costs

Generally, long-term costs are inversely proportional to initial costs; that is, the more money spent initially, the less spent over the long term. For example, high quality mechanical equipment usually operates more efficiently and economically than less expensive equipment. Similarly, the use of solar energy systems may increase initial costs, but result in lower operational costs. It is important to balance initial cost against long-term value.

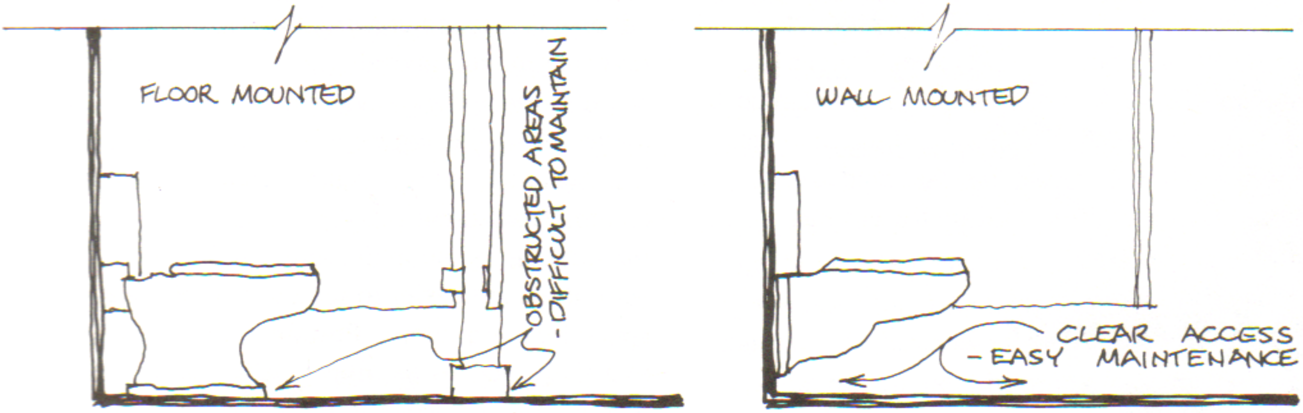
Some owners may be unwilling to invest in materials and equipment with high initial costs to realize long-term value. A speculative apartment developer, for example, may build a project for quick profit rather than long-term operation. Consequently, he or she may be more interested in the initial construction costs than the long-term operating costs. On the other hand, a government agency investing in a facility projected to last at least 50 years may be more concerned about annual and long-term operating and maintenance costs than initial costs.

The cost of energy required to operate a building is significant. Furthermore, energy sources are not uniformly available. Prices in some industries are regulated by government. Consequently, an architect must select and specify equipment that is efficient, and utilize energy sources projected to have the most stable prices.

Site planning and building design which take advantage of local climatic conditions and incorporate passive solar design and the use of daylighting may also contribute to reducing operational costs. Since long-term costs are significantly greater than initial costs, they deserve an architect's full attention.

Maintenance Costs

Maintenance costs are approximately equal to the sum of all other costs of operating a project. The specification of appropriate materials can affect maintenance costs. Schools, transit facilities, and other buildings that serve large numbers of people must be able to withstand the effects of heavy usage. For example, floor coverings in lobbies of public buildings must be selected for durability, soil and stain resistance, and ease of maintenance. Furnishings and wall coverings must have similar qualities. The selection of an appropriate material for a particular use will result in reduced maintenance costs. Materials used in residential facilities are normally not required to withstand the same wear and tear as those used in commercial



PROVISIONS FOR ACCESS & WORK SPACE

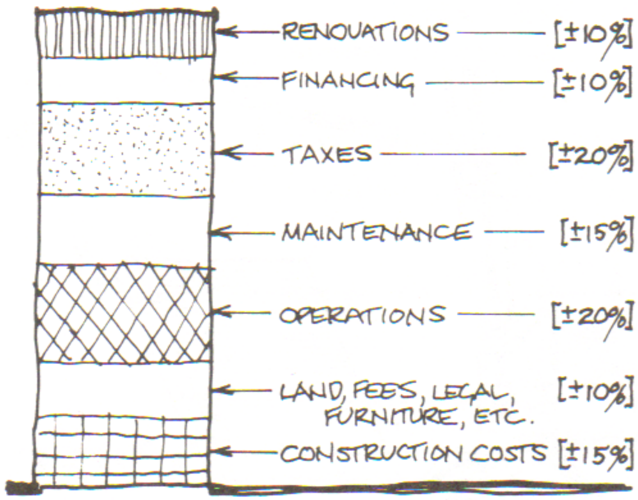
facilities, nor are they subjected to commercial cleaning agents.

Labor is also a significant contributor to the total cost of maintenance. Architects' designs can make required maintenance more or less difficult to perform. For example, wall or ceiling mounted toilet partitions provide fewer obstacles to workers cleaning restroom floors than floor mounted partitions. Although they may cost more than floor mounted units, they result in lower maintenance costs during the life of a building.

Provisions for easy access to equipment, and with adequate surrounding work space, will also result in lower maintenance costs. Modular or component systems may minimize replacement or service costs because only faulty units or elements require attention or replacement. In these circumstances, it may be more cost effective to replace a product or system than to repair it.

Life Cycle Costs

Life cycle costs include operational and maintenance costs, taxes, financing, replacement, and renovation. Although financing costs are not within an architect's control, they may be decreased if an architect's services provide for the acceleration of both the design and construction processes. This is the basis for *fast-track* and other delivery approaches that are appropriate when interest rates and financing costs increase.



ELEMENTS OF LONG-TERM COST

Replacement costs can also be predicted and controlled. Generally, high quality products require less maintenance and have a longer life span than lower quality products. They also cost more to purchase. Initial costs and maintenance and replacement costs can be projected and compared over a period of time for various available products.

TIME MANAGEMENT

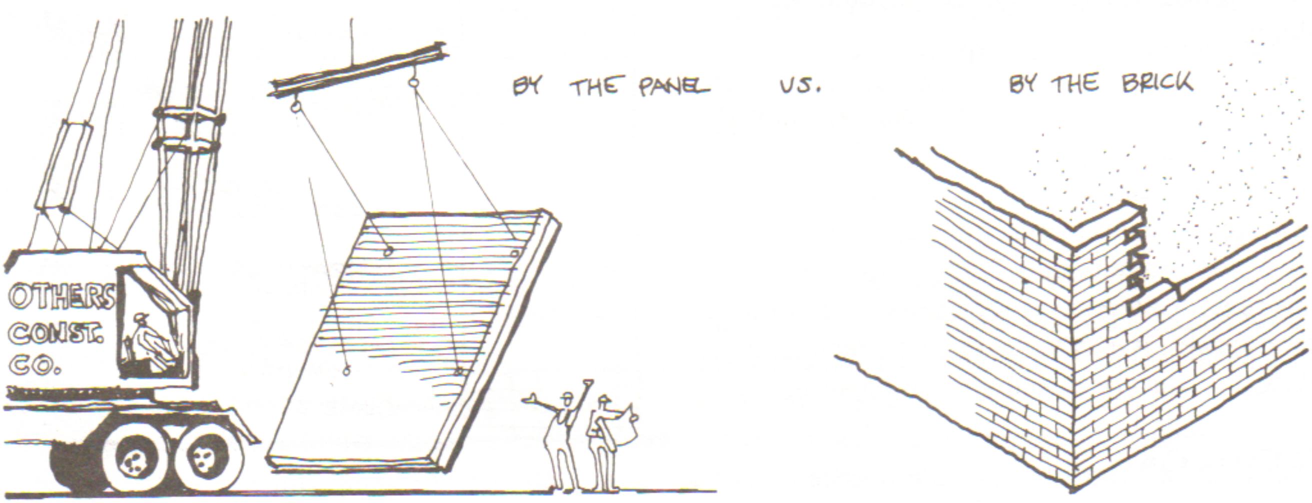
Fabrication Time

Most products and components of assemblies or systems are specially fabricated for individual construction projects. Whether an item is prefabricated off-site or fabricated or constructed on-site may have an effect on a project's timely completion.

Architects may decide whether to select off-the-shelf, ready-made components, or to design and specify components fabricated in a shop for subsequent installation on-site. Custom designed and fabricated elements may have adverse effects on construction time, thereby favoring manufactured items. Manufactured or prefabricated elements provide many advantages. Design time is shortened, because it is faster to select standard products from a catalog than to custom design new ones. And manufacturers' shop drawings and other submittals are easier to review than those of specialty contractors. Prefabricating elements in a shop reduces the impact of inclement weather on construction time. Work can be performed during winter, rainy days, and even nights if necessary. All of these factors save time.

Other aspects of construction may be shifted from field to shop, as well. For example, metal-framed panels with brick facing may be mass-produced in a shop and erected on-site, instead of laboriously constructing brick by brick on-site.

Trade union jurisdictions and work rules may



PREFABRICATED ELEMENTS VS. FIELD LABOR

also affect construction time. Building construction trade unions may have a vested interest in specific methods and construction processes. Where shop labor is not subject to trade union jurisdiction, it may be possible to bypass certain union rules to shorten construction durations by using prefabricated products and systems.

Erection Time

A project's construction time is affected by, among other things, the extent of prefabrication of its component parts. Erection time may be shortened if a project is composed of mostly discrete building components that have been prefabricated off-site. The various components can be brought on-site, placed, and connected to other elements.

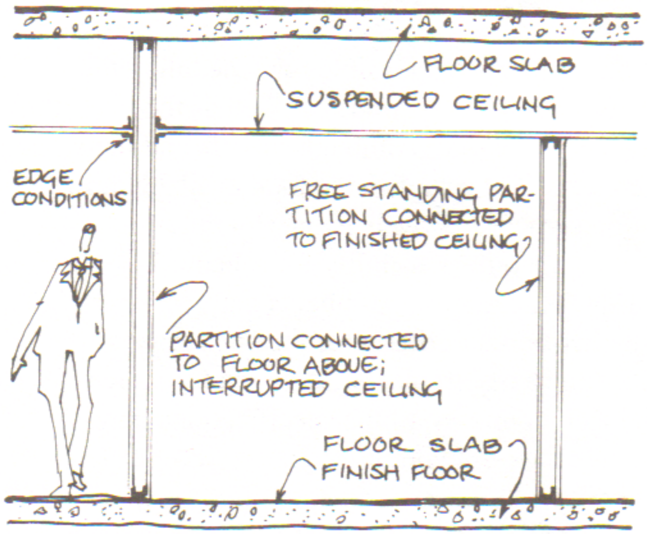
Certain aspects of prefabricated items must be considered, however. Prefabricated elements must, for example, be strong enough to resist lifting and handling. Attachments to other components must be simple, ideally requiring only one construction trade. Adequate clear space must be provided to maneuver prefabricated elements into place. Within these constraints, one may effectively use prefabricated elements to reduce erection time.

The timing of on-site operations must be considered. For example, inclement weather affects the construction time, and may even affect the design process. Winter weather may require that drawings be completed ahead of schedule to allow construction to begin before the onset of cold weather. All of these factors affect the time necessary to erect a building.

Sequencing of Construction Trades

Construction sequence is the order in which the various building trades perform their work, and is within a contractor's control. For example, foundation drains must be placed prior to backfilling. However, the design of a project may contribute to improved sequencing by minimizing the need for "on and off" construction. For example, if a large electrical conduit is placed in the same trench, but above a foundation drain, the construction sequence would be to place the drain, backfill the trench, place the conduit, and complete the backfilling of the trench. Locating the conduit elsewhere allows the contractor to place the drain and conduit independently and do all the backfilling simultaneously, thus eliminating one operation.

The design of a project may limit the ability of various building trades to perform work in a particular sequence. For example, if office



PARTITION/CEILING RELATIONSHIP

partitions are designed to extend to the underside of the floor above, the ceiling installation cannot take place until all partitions are in place. Furthermore, scaffolding required for the ceiling installation must be disassembled and moved from space to space. If the program requirements can be met without the use of full height partitions, or with partitions that extend to the underside of the finished ceiling only, the ceiling contractor can complete larger areas and encounter fewer edge conditions where walls meet ceilings. Furthermore, scaffolds can be moved more efficiently.

Although construction sequencing is the contractor's responsibility, an architect's design can contribute to construction efficiencies by minimizing the need for on-again, off-again labor. Additionally, this will reduce cleanup time, provide for more efficient use of equipment, and avoid potential problems.

Scheduling of Construction Trades

Contractors are responsible for scheduling the various construction trades as well as the sequence of work. Although owners and their architects may establish the total available time for construction as well as interim milestones, they have no responsibility for scheduling construction trades. Architects may, however, establish certain criteria for the contractor's scheduling requirements. Division One, General Requirements, of the specifications may include the following:

1. That all dates be established for ordering and delivery of materials, for submittals (including time for review, revision, and resubmittal, if necessary), and for testing.

2. That scheduling be done according to the Critical Path Method (CPM). CPM schedules are superior to bar chart schedules because they show interrelationships among activities.

3. That the schedule show the time allotted for each activity, as well as the cost, crew size, and equipment requirements for each activity.

4. That subcontractors provide input related to their scope of work.

5. That the schedule be updated monthly by the contractor to reflect the actual progress and current status. If a project is behind schedule, the contractor may be required to propose a plan for regaining lost time.

Comprehensive scheduling requirements which are fairly administered and enforced will ultimately contribute to a project's timely completion.