ARCHITECTURAL CONCRETE NORMS: CAUSES AND PROCESSES AFFECTING PERFORMANCE, CONSTRUCTION, AND APPEARANCE

by

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by Clarence Blewett
This thesis is dedicated to Judi,
for helping me bring it into being.
Concrete as a visual material has been used only for foundations and retaining walls until recent success by many designers has presented it as a major architectural building material. Unfortunately due to its limited use in the past, there is a lack of comprehensive information on architectural concrete available to architects, students and young designers.

This manual provides a basic outline of information relative to concrete performance, construction, and appearance with the intention of making the reader aware of the critical causes and processes affecting their results.

The performance of concrete is related to its inherent material properties, its use in precast and cast-in-place construction, and its expression as a natural building material. Material qualities include such subjects as durability, insulation characteristics (sound, thermal, and fire), and concrete movement.

Construction norms include commonly used materials and methods of forming concrete as well as criteria for mixing, batching, placing, curing, and finishing. Structural considerations include such subjects as cast-in-place wall construction variations, construction joints and reinforcing details. Typical floor systems in both precast and cast-in-place concrete are presented as a guide to aid designers in electing appropriate choices.

Concrete appearance in terms of surface characteristics include factors relating to color and texture uniformity, lighting variations and surface defects. The appearance of a concrete building is affected by joint locations, rustications, surface finishes and atmospheric weathering. Each element is discussed in detail.
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I am grateful to Eduardo Catalano, Professor of Architecture, Massachusetts Institute of Technology, for providing me with technical information, guidance and many helpful suggestions. I would also like to thank the following for assisting with this study:

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INTRODUCTION
INTRODUCTION

Much has been published on the subject of concrete and especially on concrete technology. Cement and concrete association libraries are abound with vast stories of theoretical knowledge on every technical aspect from aggregate selection to curing compounds. While this information is available to all concerned, it is primarily produced by and directed toward the engineering-oriented. One also finds that it is relatively segregated with each publication addressing one closely defined aspect of production. Closer investigation reveals that the material available deals primarily with the structural application of concrete. This is due in part to the fact that prior to the middle of this century, concrete was used mainly for that purpose and saw little use as a visual material; however, with successful achievements by several architects, concrete was well on its way to becoming a major building material in the United States.

In the past ten years many architects have been cautious in accepting concrete primarily due to a lack of basic knowledge of the medium. Though it is a free-forming, plastic material, architectural concrete requires the design discipline to be as demanding as that for other building materials, (i.e. brick, stone, etc.) and it must be understood that this discipline be particular to concrete and that it derive from both the constituent material properties and the methods of handling and assembly on the site. Good designs can easily be damaged by a lack of preconstruction planning resulting in a building with surface variations, discoloration, or poor weathering characteristics. Concrete can be very unforgiving if handled improperly. The solution to a design must be conceived with the design, or inevitable problems are certain to occur. This does not imply that distinct design be compromised in lieu of a continuity of approach, only that the designer be cognitive of the discipline for the material.

Concrete as a visual material is one of the most logical approaches to building; in that, it satisfies both needs of structure and enclosure, but one should be aware that with concrete
the difference between success and failure depends on understanding not only its possibilities, but its limitations. Subtle adjustments in mix design, distribution timing, and conditions of formwork are crucial to the final results.

Through this manual an attempt will be made to develop a comprehensive format of those norms of architectural reinforced concrete construction that will assist an architect in making preliminary decisions. Each section will be supplemented by as many graphics as possible to further its understanding and will also include a reference list for additional research. A representative list of material suppliers has been included for obtaining more specific information, but in no way should be interpreted as complete or as being recommended.

Following the "Definition of Architectural Concrete" as it applies to this manual, the first section examines both methods of concrete construction: cast-in-place and precast, and outlines important criteria for the selection of each.

The organization of the remaining sections of the manual investigates design criteria, formwork fabrication, structural considerations, materials and mixes, handling and placing, curing, and finishing techniques. The sections on formwork fabrication investigates materials and methods used in forming both precast and cast-in-place concrete; however, most of the information is aimed at cast-in-place construction. This is due to two reasons: First, comprehensive information on this subject is unavailable, and second, precast forming and erection techniques are well presented in a manual entitled, "Architectural Precast Concrete." Architects should review this publication by the Prestressed Concrete Institute, as it contains very thorough and descriptive coverage of precast construction.

In conclusion, certain methods and materials of construction have been omitted because they are generally considered architecturally unacceptable. Concrete sculpture, also, will not be included.
DEFINITION

ARCHITECTURAL CONCRETE

The term "architectural concrete" as referred to in this manual will apply to reinforced concrete used for visual purposes. It shall cover all those applications in the normal context of building where concrete can be exposed as a finished surface--both precast and cast-in-place. At this time, there should be a clear distinction made between architectural concrete and structural concrete, although each performs a structural support function.

Raw structural concrete is that material which is used purely for its structural merits and is not exposed as an architectural feature. It is typically found in footings, foundations, and sub-basements.

On the other hand, architectural concrete--whether precast or cast-in-place, is the same basic ingredient given special consideration in all aspects of production so that the finished product can be expressed architecturally. An analogy to the relationships of structural concrete and architectural concrete can be found in the comparison of rough carpentry and millwork. Special details and specifications will be needed to produce quality results beyond those of structural concrete.

Specifications for architectural concrete and structural concrete should have separate sections within the concrete division to assure proper recognition of important details. The specification should also indicate that the architectural concrete section relates to matters of achieving architectural expression while the structural section governs those matters relating to structural integrity. It is also well advised by architects and engineers alike that an experienced concrete technologist who is aware of the conditions necessary to produce the intended results be retained for all architectural concrete work.
2

PERFORMANCE
FACTORS AFFECTING THE PERFORMANCE OF CONCRETE

The decision to use architectural concrete for a project will be influenced by its performance, constructibility and appearance. The performance of concrete results from its inherent nature and the practices involved in its construction. The following outline represents several subjects included in this manual for evaluation of performance.

ARCHITECTURAL EXPRESSION
Material Character
Building Character

CONCERNS FOR CAST-IN-PLACE CONSTRUCTION
Availability of Concrete
Forming System
Placing & Finishing

CONCERNS FOR PRECAST CONSTRUCTION
Availability of Concrete
Delivery Factors
Placing Factors

PROJECT CONSTRUCTION RATE
Factors Affecting Construction Rate
Factors Influenced by the Construction Rate
Influence of Concrete

FIRE RESISTANCE
Concrete Endurance and Heat Transmission
Heat Transmission

DURABILITY—WEATHER & ABRASION RESISTANCE
Water Tightness
Freeze-Thaw Resistance

THERMAL INSULATION
Inertial Effects
Weather Protection
Conductivity Factors

SOUND INSULATION
Impact Transmission
Absorbed and Airborne Sound Transmission

CONCRETE MOVEMENT
Deflections
Thermal Movement
Shrinkage-Cracking

SECURITY FACTORS RELATED TO CONCRETE MASS
Penetration
Radioactive Particle Barrier
Structural Rigidity

ENERGY CONSUMPTION OF BUILDING MATERIALS
Concrete Production
ARCHITECTURAL EXPRESSION

MATERIAL CHARACTER
Criteria for evaluation of surface aesthetics should include the following elements and the conditions that affect them.

- Cement & Sand Matrix
- Exposed Aggregate
- Additives – Colorants
- Form Sealants
- Form Release Agents

TEXTURE
- Inherent – Aggregates
  - Cement Binder
- Imposed – Formwork
  - Architectural Treatments

SURFACE FIGURE
- Color Blend
- Texture Range
- Shrinkage Cracks
- Surface Irregularities
- Variable Porosity
- Lighting Variations

WEATHERING PATINA
- Age – State of Maturity
- Environmental Reactions
- Dirt Collection
- Formwork

BUILDING CHARACTER
Precast or cast-in-place buildings have an inherent vocabulary common only to concrete.

PERMANENCE
- Durable, Stable

BOLDNESS
- Richness in Spirit

MATERIAL HONESTY
- Structure and Enclosure
  - United

SCULPTURAL FLUIDITY
- Patterning Flexibility
- Varying Limits of Scale
CONCERNS FOR CAST-IN-PLACE CONSTRUCTION

AVAILABILITY OF CONCRETE

Preconstruction investigation should evaluate what services are available, the quality of these services, and their reliability.

Materials:
- Variety of available cements, aggregates, admixtures
- Adequate storage facilities if stockpiling is necessary

Batching & Mixing:
- Ready-mixed facilities
- Facilities for on-site work

Quality Control:
- Accurately proportioned mixes
- Flexibility to respond to varying conditions

Supply:
- Delivery capabilities—
  - Time & distance of delivery
  - Daily supply rate
  - Truck capacity

FORMING SYSTEM

The forming system should be familiar to the local work force as well as providing strength and surface for the intended finish.

Form Materials & Accessories:
- Available in sufficient quantities and sizes to complete the project

Fabrication:
- Competence of tradesmen on-site or in-shop
- Speed and quality of fabrication

Quality:
- Proper association of materials, sealants, release agents, joinery, gaskets, modularity

Erection:
- Ease of assembly, proper alignment, tight joints
- Ganged forming for faster erection

Stripping:
- Ease of disassembly & movement, material quality, number of reuses

Shoring:
- Alignment, adjustment & adequate support
- Reshoring after movement of modular formwork
- Cantilevers, high walls, long spans

PLACING & FINISHING

Placing and finishing of concrete will require adequate work space for both men and equipment.

Distribution:
- Space for equipment: trucks, cranes, pumps
- Space for workman: platforms, scaffolds

Containment:
- Sufficient form strength, proper spacing of reinforcement, space for piping, proper strength & adjustment

Consolidation:
- Proper vibration, adequate work force & equipment, suggested rate & volume of pour

Finishing:
- Adequate work force, proper equipment, size of work area, correct time of application

Curing:
- Time required, curing agents, coverings, methods of heating
CONCERNS FOR PRECAST CONSTRUCTION

AVAILABILITY OF CONCRETE
Precast plants should be investigated to determine the quality of work produced with various materials, formwork, and finishing techniques.

Materials: Variety of available cements, aggregates, admixtures Adequate storage facilities if stockpiling is necessary

Batching & Mixing: Plant Facilities Facilities for on-site batching & mixing

Quality Control: Accurately proportioned mixes, close tolerance of castings

Formwork: Availability of desired materials & accessories, quality fabrication, reuse characteristics, modification characteristics, strength & rigidity

Reinforcing: Methods available—conventional, prestress, poststress

Casting: In-plant, on-site, consolidation techniques, methods of finishing, use of proper tools, vibrators

Curing: To assure color & strength uniformity, prevent warpage

DELIVERY FACTORS
Plant Production: Set-up time—Contract to production of first piece Daily output—Cu. yds., or No. pieces per day

Transportation: Methods—trucks, railroad Available capacities, shipping costs

Local Transportation: Limitations and restrictions Heights, widths, lengths, tonnage, turning radii

Storage: On-site, at plant, covered to avoid staining Properly positioned to avoid damage

PLACING FACTORS
Equipment: Cranes, availability, capacity No. required, height, reach, tonnage

Site Conditions: Storage, crane movement, delivery truck movement, soil conditions, adjacent buildings

Erection Sequence: Avoid repetition of equipment Assure stability of completed work

Connections: Welded or bolted, speed of erection
**SHIPPING RATES AND LIMITATIONS**

**SHIPPING RATES FOR PRECAST CONCRETE PRODUCTS**

<table>
<thead>
<tr>
<th>Distance (Miles)</th>
<th>Load A (Legal)</th>
<th>Load B</th>
<th>Load C</th>
<th>Load D</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-20</td>
<td>$12.50/ton/mile</td>
<td>$3.00</td>
<td>$3.50</td>
<td>$4.50</td>
</tr>
<tr>
<td>20-100</td>
<td>$7.50/ton/mile</td>
<td>$2.00</td>
<td>$3.25</td>
<td>$3.50</td>
</tr>
<tr>
<td>&gt;100</td>
<td>$5.50/ton/mile</td>
<td></td>
<td>$2.75</td>
<td>$3.50</td>
</tr>
</tbody>
</table>

**LEGAL TRANSPORTATION LIMITS (MASSACHUSETTS 1977)**

- Tonnage Limit: 36.5 Tons
- Height: 13'-6" to 20'-6"
- Width: 8'-6" to 10'-0"
- Length: 42'-0" to 80'-0"

**ADDITIONAL COSTS PER MILE/TON FOR LOADS B.C. & D (PERMITS REQUIRED)**

- **Load B**
  - Height: 8'-6" to 8'-9"
  - Width: 8' to 10'
  - Length: 42' to 60'
- **Load C**
  - Height: 8'-9" to 12'-0"
  - Width: 10' to 12'
  - Length: 60' to 80'
- **Load D**
  - Height: More than 12'
  - Width: More than 12'
  - Length: More than 80'

**EXAMPLE**

- **Load:** 8'x8'x65'
- **Weight:** 30 Tons
- **Distance:** 45 Miles
- **Special Permit Required:** Load C
- **Total Shipping Cost:** $225

**LIMITATIONS & RESTRICTIONS**

Transportation of objects greater in proportion than the legal limits allowed will require a permit and are subject to restrictions imposed by the governing state. Authorities should be contacted in the event of doubt.

Loads exceeding the following measurements will require notification of and approval by state authorities. Moving loads of this size is difficult.

- **Height:** 13'-6" to 20'-6" (Police escort required)
- **Length:** 120' (Pavement analysis required)
- **Width:** 14'-0" (Permits are not issued for loads reducible in nature)

**Reference:**

"OVERWEIGHT-OVERDIMENSIONAL PERMIT POLICY."
Standard Operating Procedure, Publication No. MWD-75-06-1-00, Department of Public Works, Commonwealth of Massachusetts.
PROJECT CONSTRUCTION RATE

FACTORS AFFECTING CONSTRUCTION RATE

Trade Unions: No. of unions participating, quality of work performed, unity between unions, contract expiration dates

Project Organization: Adequate work force, efficient logistics of men & materials, proper supervision, inspection & control

Project Planning: Complete plans & specifications, coordination of architect, engineer & contractor

Scheduling of Work: Integration of trades to maximize efficiency, sequential organization of the building to avoid repetition of trades & equipment

Special Equipment (Crans, etc.): Amount required

Availability of Materials: Time of use

FACTORS INFLUENCED BY THE CONSTRUCTION RATE

Investment: Interest accumulation

Completion Date: Project becomes self-supporting

General Construction Requirements:

Material Costs: Price increases

Labor Costs: Renewed contracts

Performance Bond Cost:

INFLUENCE OF CONCRETE

The major advantages of concrete construction are that materials, equipment, and tradesmen are usually available in the general locality of the project. Material delivery delays are rarely a problem and special equipment is seldom needed. Local contractors are usually reliable for most architectural concrete work in the United States; however, local resources should be carefully examined to determine the capabilities for either pre-cast or cast-in-place construction. Cast-in-place concrete construction usually involves a larger integration of trades at one time than most other building types. Typically the sequence of construction involves forming, placing of reinforcing, place of sub-systems, casting of concrete, curing, and stripping of formwork. Several different trades are involved in each phase of this
process. With this large number of operations affecting each stage, building progress seems slow in relation to a steel building where the structure is rapidly erected. The results however, are realized in the extent of work completed on each stage. As the building progresses upward, each floor system and primary enclosure system is completed sequentially. In many cases, after the forms are removed, the resulting surfaces are considered finished and do not require further work. Since the building may be enclosed after each floor is cast, finishing trades may have access sooner. A second advantage is that the degree of completion is directly related to costly repetition of men and equipment.

Precast concrete construction requires a minimum of on-site labor and erection may be accomplished in any weather. Prefabrication of components and fast erection time result in earlier access by finishing trades as well as shorter overall construction time. As with cast-in-place, precast construction also is capable of being integrated with building sub-systems. Due to this integration, trade overlaps can be reduced.
FIRE RESISTANCE

Concrete is a material with excellent resistance to fire damage in comparison to most building materials. The following characteristics indicate the advantage of concrete in providing protection against disaster.

- Does not produce smoke or noxious gas—safety for occupants
- Noncombustible—zero flame spread—will not contribute to or extend fire
- Total fire loss unlikely—greater security
- Fire ratings available—no additional structural protection required
- Excellent insurance classification—lower insurance costs

Most fire ratings in concrete are given in reference to beams and slabs that make-up floor systems. In such cases properties of the materials used in the construction govern their behavior during a fire. In reinforced and prestressed concrete, steel resists tensile stresses and concrete resists compressive stresses; therefore, the behavior of beams and slabs during a fire depend upon the tensile strength of the steel and the compressive strength of the concrete. Most ordinary reinforcing steels retain about one-half of their room temperature tensile strength at about $1500^\circ$ F; however, for prestressing steel, the corresponding temperature is about $800^\circ$ F.

The strength of concrete at elevated temperatures depends somewhat on the type of aggregate used. Most Portland cement concretes retain much of their room temperature compressive strength up to about $800^\circ$ F. Those made with lightweight aggregates have far greater endurance. The fire resistance of concrete floors is directly related to the thickness of the slab and the moisture content of the concrete. Tests have found that concrete specimens with a

REFERENCE:
moisture content at equilibrium with the air have greater fire endurance than artificially dried specimens; although, those with excessive moisture content have a tendency to spall.

**CONCRETE ENDURANCE**

![Graph showing fire endurance of concrete slabs with different thicknesses and aggregate types.](image)

The structural behavior of concrete beams, floors, and roofs during fire exposure is mainly dependent upon the method of support. If beams or slabs are simply supported, the most important factors are the load intensity, the thickness of cover, the type of concrete, and the type of reinforcement. Concrete beams and slabs are not simply supported in most cases, rather they are supported in such a manner that longitudinal expansion and rotation at the supports are restrained. In such cases, a redistribution of stresses occurs which greatly enhances fire endurance. Transmission of heat through concrete is principally affected by the type of aggregate, the thickness of concrete, and the moisture condition of the concrete.

**HEAT TRANSMISSION FACTORS FOR CONCRETE SLABS**

![Diagram illustrating the effects of load intensity, reinforcement location, and thickness of cover on heat transmission.](image)

**REFERENCE:**

GUSTAFERRO, ARMAND H. "FIRE RESISTANCE OF ARCHITECTURAL PRECAST CONCRETE." JOURNAL OF THE Prestress Concrete Institute, SEPTEMBER-OCTOBER 1974.
DURABILITY-WEATHER & ABRASION RESISTANCE

Concrete is one of the most widely used construction materials and consideration of its extensive uses in present day construction is revealing testimony to this fact. Concrete as a building material is in its infancy with potentials yet untapped; however, the greatest disadvantage of concrete is that its quality is highly dependent on field conditions. The quality is controlled by many factors ranging from weather conditions, to inexperienced supervision, to general lack of understanding concerning its behavior. The life of concrete is directly related to these factors and its durability is measured in terms of its resistance to weather and resistance to mechanical action. Weathering includes the action of freezing and thawing and the differential length changes due to temperature variations and alternate wetting and drying. Mechanical action includes those conditions relating to cyclic loading and abrasion.

Freezing and thawing of concrete will exert internal forces whenever the concrete contains moisture. Concrete kept continually wet on all surfaces will usually be damaged or destroyed when subjected to freezing temperatures. On the other hand, concrete structures having at least one surface exposed to the air continually will show various behavior from total failure, usually localized, to complete immunity to freezing effects. Research has demonstrated that resistance to freezing and thawing is related to both the cement paste and the aggregates. Cement paste typically contains air-filled spaces which accommodate volume increase (9%) by water when it freezes. Upon freezing the cement particles and the aggregate both evaporate absorbed, unfrozen water into these cavities. Essentially, the evaporable water that remains is not freezeable while the water held in the cavity is freezeable. If the cavities or air bubbles are close enough together the osmotic pressure developed by freezing will not be destructive. Therefore, the criteria for durable concrete is to utilize materials that have a low absorbency, entrain air uniformly into the mix, and keep the concrete as dry as possible. Aggregates should be sound and the
Cement paste should be watertight. Watertight mixes result from a low water-cement ratio and proper curing methods.

Air entrainment also improves watertightness by increasing density through improved workability and reduced segregation and bleeding. Because the total water requirement of air entrained concrete is less, the paste will have a lower water-cement ratio. It follows then, that higher strength concrete has greater durability; however, tests have proven that this might not always be true. Compressive strength is not as successful an indicator of concrete performance as durability in aggressive environments. Durability, on the other hand, is difficult to measure immediately like compressive strength, and is considered to be more closely related to curing conditions and inclusion of additives. Concrete that has been subjected to freezing temperatures will deteriorate faster than concrete properly cured, although the compressive strength may be similar.

The effects of cyclic loading are directly related to concrete strength, dryness, and its air content. The higher the strength and lower the moisture content the greater the number of cycles needed to produce failure. With concrete that has been subjected to freezing temperatures, the number of cycles to failure will be less, although two samples subjected to similar conditions of freezing, the one with the higher air content will display greater durability.

Resistance to abrasion or wear, as in the application of floors, pavements and water conductors, is dependent on the quality of strength and durability combined (i.e. good quality materials, entrained air and low water-cement ratio). Resistance to abrasion is also increased by uniform practices in finishing the concrete, adequate cover over the reinforcing steel and rigorous specifications relating to hot and cold weather concreting; however, in many instances concrete subjected to extreme exposure will deteriorate.
It is therefore advised that surface treatments be utilized if such conditions are eminent. Surface scaling due to freezing and thawing in the presence of water can be greatly reduced by integral coatings with epoxy paints. Concrete surfaces subjected to heavy traffic abrasion may be hardened by the addition of mineral or metallic aggregates to the mix.

In general, concrete mixes that are properly designed for architectural situations will exhibit the following:

- **Low Absorbency**
  Unaffected by cleaning or unwanted water entry

- **Frost Resistance**
  Durability under freeze-thaw cycles

- **Corrosion Resistance**
  Painting or protective coating should not be required

- **Impermeable Surface**
  Preventing entry of vermin or insects

**DURABILITY FACTORS**

![Graphs showing leakage, durability, and compressive strength](image)

**REFERENCE:**

"DESIGN AND CONTROL OF CONCRETE MIXTURES." PORTLAND CEMENT ASSOCIATION, PUBLICATION NO. EBOO1.11T, 1968, PP. 7-11.

THERMAL INSULATION-INERTIAL EFFECTS

Due to the density of concrete, its dynamic response to energy transfer is slowed in relation to lighter weight materials of the same U-values. Depending on the mass in use, the temperature variations within a building can be significantly reduced. This results in lower peak loads with mechanical heating and cooling systems being sized accordingly.

RESULTS OF LOWER PEAK LOADS AND LEVELING OUT OF HEAT FLOW

Lower annual energy consumption
Small mechanical equipment requirements
More efficient design of equipment—smaller response range
Reduction of peak demand on energy producing industries

RESPONSE EFFECTS

CONCRETE WALL

METAL WALL

INSULATED

HEAT LOSS COMPARISONS FOR WALLS

HEAT GAIN COMPARISONS FOR ROOFS

REFERENCE:
THERMAL INSULATION-WEATHER PROTECTION

EXTERIOR WALL DESIGN

Concrete, a material with relatively high thermal conductivity, will usually require some form of insulation when used in exterior walls in cold climates, especially where the enclosed spaces are continually inhabited. When concrete walls are exposed on only one side (exterior) insulating can be easily handled; however, for walls that are exposed on both sides insulating can be difficult and expensive. In cases such as large assembly rooms that receive occasional use, walls exposed on both sides are best left uninsulated as it may be more economical to rely on an effective heating system. Lightweight concrete and thicker walls can improve insulation value.

METHODS OF INSULATING CONCRETE WALLS

PRECAST OR C-I-P CONSTRUCTION

CONCRETE
WATERPROOF MEMBRANE
INSULATION
WALL PANEL
SINGLE WALL SYSTEM
EXPOSED CONCRETE - 1 SIDE

C-I-P CONSTRUCTION ONLY

CONCRETE
INSULATION
DOUBLE WALL SYSTEM
EXPOSED CONCRETE - 2 SIDES
EXPENSIVE TO FORM AND CAST CONCRETE TWICE

PRECAST OR C-I-P CONSTRUCTION

CONCRETE (CAST HORIZONTALLY)
INSULATION
C-I-P
INSULATION TIED TO REINFORCING CONCRETE CAST ON BOTH SIDES AT SAME TIME
SANDWICH SYSTEM
EXPOSED CONCRETE - 2 SIDES
SECURING INSULATION FOR C-I-P CONSTRUCTION IS DIFFICULT

EFFECTS OF CONDENSATION

CONDENSATION OCCURS WHEN HUMIDITY REACHES SATURATION

COLD AIR FILM
COOLED CONCRETE
WARM AIR FILM
DROPLETS FORM DUE TO LOW ABSORPTION OF CONCRETE
UNINSULATED CONCRETE WALL

VAPOR BARRIER
SUFFICIENT INSULATION
ADEQUATE VENTILATION
POROUS MATERIAL SURFACE
TREATMENTS

MATERIAL SATURATION POINTS

WATER ABSORBED AS A % OF WT.

NORMAL WEIGHT CONCRETE 5
BRICK 20
CELLULAR CONCRETE 35

IN INDUSTRIAL APPLICATIONS WITHOUT INSULATION, DESIGN CONSIDERATIONS SHOULD BE MADE FOR COLLECTION AND CHANNELING OF RESULTING WATER.

COLD BRIDGES MUST BE AVOIDED AS A 15% INTERCONNECTION CAN REDUCE INSULATION EFFECTIVENESS BY 50%.

REFERENCE:
HEINLE, ERWIN AND MAX BACHER. "BUILDING IN VISUAL CONCRETE." TECHNICAL PRESS, LONDON, 1971.
THERMAL INSULATION—CONDUCTIVITY FACTORS

CONDUCTIVITIES FOR NORMAL WEIGHT CONCRETE

STANDARD UNIT OF AREA 1 SQ. FT.

STANDARD TEMPERATURE DIFFERENTIAL 1°F

R = 0.075

THERMAL TRANSMISSION U = \frac{1}{R} = 13.3

R = 0.075 \times 6 = 0.45

U = \frac{1}{R} = 2.22

R-VALUES FOR SOLID CONCRETE*

<table>
<thead>
<tr>
<th>CONCRETE TYPE</th>
<th>UNIT WEIGHT (LBS. PER C.F.)</th>
<th>PER INCH</th>
<th>THICKNESS OF CONCRETE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td>2</td>
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<tr>
<td>INSULATING LIGHTWEIGHT</td>
<td></td>
<td>20</td>
<td>1.43</td>
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<td></td>
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<td>30**</td>
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<td></td>
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<td>150</td>
<td>.065</td>
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</table>

* VALUES DO NOT INCLUDE EFFECTS OF SURFACE RESISTANCE

** ROOF FILL, ROOF SLABS, AND WALL SLABS

*** AVERAGE WEIGHT FOR Sanded LIGHTWEIGHT STRUCTURAL CONCRETE

DEFINITION - ACI 318-71 LIMITS STRUCTURAL LIGHTWEIGHT TO 115 PCF

**** USUAL WEIGHT FOR NORMAL-WEIGHT CONCRETE

REFERENCE:
"THE CONCRETE APPROACH TO ENERGY CONSERVATION."
PORTLAND CEMENT ASSOCIATION, 1974, 49 PP.
### THERMAL INSULATION - WALL DESIGNS

#### STRUCTURAL WALLS

<table>
<thead>
<tr>
<th>Description</th>
<th>Normal Weight</th>
<th>Lightweight</th>
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<tbody>
<tr>
<td>Thickness</td>
<td>NW</td>
<td>LW</td>
</tr>
<tr>
<td>11 7/8&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11 3/4&quot;</td>
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<tr>
<td>12 3/8&quot;</td>
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#### Thermophysical Values

| Surface Film (Outside) | .17 | .17 | .17 | .17 |
| Concrete 10"           | .75 | 1.09 | .75 | 1.39 |
| Insulation 1"           | 4.00 | 3/4" | 3.00 | 2 1/4" | 9.00 | 2" | 6.00 |
| Plasterboard 1/2"      | .45 | .45 | .45 | .45 |
| Surface Film (Inside)  | .68 | .68 | .68 | .68 |
| Total, R               | 6.05 | 5.19 | 11.05 | 11.19 |
| U-Factor, 1/R          | 0.17 | 0.16 | 0.09 | 0.09 |

#### PRECAST PANELS

<table>
<thead>
<tr>
<th>Description</th>
<th>NW</th>
<th>LW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness</td>
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<td>8 1/2&quot;</td>
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<td>Surface Film (Outside)</td>
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<td>.17</td>
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<tr>
<td>Concrete 5 1/2&quot;</td>
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<td>1&quot;</td>
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<tr>
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<tr>
<td>Plasterboard 1/2&quot;</td>
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<td>.45</td>
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<tr>
<td>Surface Film (Inside)</td>
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<td>.68</td>
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<td>Total, R</td>
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<tr>
<td>U-Factor, 1/R</td>
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#### SANDWICH PANELS

<table>
<thead>
<tr>
<th>Description</th>
<th>NW</th>
<th>LW</th>
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</thead>
<tbody>
<tr>
<td>Thickness</td>
<td>2 1/2&quot;</td>
<td>2 1/2&quot;</td>
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<tr>
<td>Surface Film (Outside)</td>
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<td>.17</td>
</tr>
<tr>
<td>Concrete 2&quot;</td>
<td>.16</td>
<td>3&quot;</td>
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<tr>
<td>Insulation 2 1/2&quot;</td>
<td>10.00</td>
<td>1 1/4&quot;</td>
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<tr>
<td>Concrete 3&quot;</td>
<td>.15</td>
<td>3&quot;</td>
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<tr>
<td>Surface Film (Inside)</td>
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<td>.68</td>
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<tr>
<td>Total, R</td>
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<td>9.99</td>
</tr>
<tr>
<td>U-Factor, 1/R</td>
<td>0.09</td>
<td>0.10</td>
</tr>
</tbody>
</table>

**REFERENCE:**

THERMAL INSULATION - ROOF DESIGNS

FLAT PLATE, FLAT SLAB, BEAM & SLAB

SURFACE FILM (OUTSIDE) | .17
ROOFING | .33
INSULATION BOARD | 1" 4.00
INSULATING CONCRETE TOPPING | 4 1/2" 4.80
NORMAL WEIGHT CONCRETE | 5" .38
SURFACE FILM (INSIDE) | .61

TOTAL, R | 9.98
U-FACTOR, I/R | 0.10

JOIST SYSTEMS

SURFACE FILM (OUTSIDE) | .17
ROOFING | .33
INSULATION BOARD | 3/4" 3.00
3" 3.00
5" .38
ACOUSTICAL TILE | 1.89

TOTAL, R | 9.38
U-FACTOR, I/R | 0.11

DOUBLE TEES, SINGLE TEES, CHANNELS

SURFACE FILM (OUTSIDE) | .17
ROOFING | .33
INSULATION BOARD | 2" 6.00
NORMAL WEIGHT CONCRETE | 3" .23
ACOUSTICAL TILE | 1.89
SURFACE FILM | .61
TOTAL, R | 11.23
U-FACTOR, I/R | 0.09

CORED SLABS

SURFACE FILM (OUTSIDE) | .17
ROOFING | .33
INSULATION BOARD | 1 3/4" 7.00
AVERAGE CORED SLAB 8" | 3.00
ACOUSTICAL TILE | --
SURFACE FILM | .61
TOTAL, R | 11.11
U-FACTOR, I/R | 0.09

REFERENCE:
"THE CONCRETE APPROACH TO ENERGY CONSERVATION."
PORTLAND CEMENT ASSOCIATION, PUBLICATION NO. SP014.01B, 1974.
SOUND INSULATION

SOUND TRANSMISSION RATINGS

<table>
<thead>
<tr>
<th>NORMAL WEIGHT CONCRETE WALLS</th>
<th>STC</th>
</tr>
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<tbody>
<tr>
<td>48</td>
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<td>56</td>
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<td>59</td>
<td>62</td>
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</table>

SOUND TRANSMISSION CLASS

NOISE REDUCTION THROUGH WALLS (db)

<table>
<thead>
<tr>
<th>WEIGHT (PSF)</th>
<th>STC</th>
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</thead>
<tbody>
<tr>
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<td>40</td>
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<tr>
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<tr>
<td>80</td>
<td>46</td>
</tr>
<tr>
<td>100</td>
<td>49</td>
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</tbody>
</table>

IMPACT TRANSMISSION

INR (-17)

| 1,100 CPS | 1,100 CPS |

ACOUSTIC RATING IMPROVEMENTS (db) FOR VARIOUS CONCRETE FLOORS

<table>
<thead>
<tr>
<th>TREATMENT</th>
<th>STC</th>
<th>INR</th>
</tr>
</thead>
<tbody>
<tr>
<td>CARPET &amp; PAD</td>
<td>0</td>
<td>48</td>
</tr>
<tr>
<td>ACOUSTIC CEILING</td>
<td>10</td>
<td>77</td>
</tr>
<tr>
<td>CARPET, ACOUSTIC CEILING</td>
<td>5</td>
<td>58</td>
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<tr>
<td>VINYL TILE</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>PLASTER CEILING</td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td>T &amp; G WOOD PARQUET</td>
<td>0</td>
<td>25</td>
</tr>
<tr>
<td>FINRED CORKTILE</td>
<td>0</td>
<td>21</td>
</tr>
<tr>
<td>2&quot; CONCRETE TOPPING</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

WALL TREATMENTS FOR IMPROVEMENT

60 db (AVERAGE OFFICE)

REFLECTED 59.9 db

TRANSMitted 19 db (WHISPER)

STC 41 db

50 db

TRANSMitted 3 db (BARELY AUDIBLE)

STC 57 db

4% ABSORBED

STC 57 db

ACOUSTICAL RECOMMENDATIONS

ISOLATE MECHANICAL EQUIPMENT & SOUND BARRIERS

GASKET FLOOR & WALL OPENINGS

SEALER

ABSORBER

RESILIENT FLOOR COVERING

CONTINUOUS FLOATED SLAB ON RESILIENT MATERIAL

RESILIENT HUNG CEILING

FLEXIBLE CONNECTIONS FOR PIPES, DUCTS, CONDUITS

NOISE ISOLATION STRUCTURE BORNE TRANSMISSION

REFERENCE:

CALLENDER, JOHN H. "TIME SAVER STANDARDS FOR ARCHITECTURAL DESIGN DATA." MC GRAW-HILL BOOK CO., INC., 1974.

RANDALL, FRANK A. "ACOUSTICS OF CONCRETE IN BUILDINGS." PORTLAND CEMENT ASSOCIATION, PUBLICATION NO. TA037.018, 1974.
MOVEMENT, SECURITY FACTORS, ENERGY CONSUMPTION

CONCRETE MOVEMENT
DEFLECTIONS
IMMEDIATE DEFLECTION LIMIT \( \frac{L}{360} \)

IMMEDIATE LONGTIME (CREEP)

THERMAL MOVEMENT
COEFFICIENT OF THERMAL EXPANSION
\( 5.5 \times 10^{-6} \) IN./IN./\(^\circ\)F

\( \Delta T = 60^\circ \)F

EXAMPLE
\( \Delta L = 5.5 \times 10^{-6} \times 60^\circ \)F \times 50\' \times 12" \)
\( \Delta L = 0.2" \)

SHRINKAGE-CRACKING

CAST VOLUME

CURED VOLUME

SHRINKAGE 0.0002 TO 0.0007 IN./IN.

SHRINKAGE RESTRAINED BY STEEL

FACTORS AFFECTING CREEP
TIME MAGNITUDE OF LOAD EXPOSURE QUALITY OF CONCRETE

SECURITY FACTORS RELATED TO CONCRETE MASS

PENETRATION
REDUCES THEFT AND VANDALISM

PENETRATION ONLY BY USE OF HEAVY TOOLS

12" CONCRETE = 1" LEAD

12\(^\circ\)F RADIATION SHIELDING

WIND RESISTANCE THROUGH CONCRETE WEIGHT AND RIGIDITY

ENERGY CONSUMPTION OF BUILDING MATERIALS

AVERAGE ENERGY CONSUMPTION IN A CONCRETE BUILDING

ENERGY CONSUMPTION PER RUNNING METER OF SIMPLY SUPPORTED BEAM LIVELoad = 2 TONS PER METER

REFERENCE:
BEIJE, OSCAR. "ENERGY CONSUMPTION RELATED TO CONCRETE STRUCTURES." JOURNAL OF THE AMERICAN CONCRETE INSTITUTE, NOVEMBER 1975.

CONCRETE SURFACE EVALUATION

When evaluating architectural concrete surfaces, one should always bear in mind the designer's intentions as well as the state of the art at the time of construction. Concrete work that is properly planned and executed with skill should reflect this. Defective work should not be passed off as being inherent to the material. While some architects prefer the rough board form character of concrete, others strive for a much more refined appearance. What may be objectionable to some is sought after by others; however, almost all will agree upon the criteria that acceptable surfaces should be uniform in color and texture with a minimum of defects. The conditions under which this criteria is established is quite subjective although the following parameters should be taken into consideration.

CONDITIONS INFLUENCING THE VISUAL APPEARANCE OF CONCRETE

<table>
<thead>
<tr>
<th>OPTIMUM</th>
<th>PROBABLE CONDITIONS AFFECTING OPTIMUM</th>
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</thead>
<tbody>
<tr>
<td>Uniform Lighting</td>
<td>Shadows, cloud cover, time of day</td>
</tr>
<tr>
<td>Surface Dryness</td>
<td>Water stains, rain saturated</td>
</tr>
<tr>
<td>Scheduled Form Removal</td>
<td>Surface cast in large sections</td>
</tr>
<tr>
<td></td>
<td>Forming left for shoring</td>
</tr>
<tr>
<td></td>
<td>Form removal delayed for other reasons (climatic, labor, etc.)</td>
</tr>
<tr>
<td>Concrete Dryness (Maturity)</td>
<td>Surface cast in sections at different times</td>
</tr>
<tr>
<td></td>
<td>Varied form removal rates</td>
</tr>
<tr>
<td></td>
<td>Type of form material used</td>
</tr>
<tr>
<td></td>
<td>Thickness of concrete</td>
</tr>
<tr>
<td></td>
<td>Shaded areas affecting drying rate</td>
</tr>
</tbody>
</table>
CONCRETE SURFACE CHARACTERISTICS

Visual evaluation of a concrete surface must take into consideration several aspects for the determination of quality which is primarily a matter of architectural expression rather than structural integrity or weathering durability. The intended purpose is to provide guidance and understanding of processes in achieving uniformity of finish. This may not be the ultimate goal of the designer; however, one should be aware that uniform practices leading to quality surfaces are directly related to the integrity of the material itself. Unevenness of color and texture, if desired, should not be the result of faulty craftsmanship and improper specifications, but as part of an intention that affects the design and construction process.

The following four elements should be viewed under the optimum conditions previously described.

Uniformity of Color
Uniformity of Texture
Lighting Variations
Surface Defects

UNIFORMITY OF COLOR

Uniformity of color is related to the distance from which one observes the surface. This distance is relative and relates to many conditions and should be left to the discretion of the architect; however, it should be taken into consideration that concrete is a blend of several materials, produced and cast under conditions that range from tightly-controlled to impossible-to-control. Secondly, it must be understood that concrete, although thought of structurally as a homogeneous mass, is very much a collection of materials held together by a binder. Unlike steel, there is not a total chemical blending of the raw materials. Upon close inspection under varying conditions, one can easily differentiate the individual constituents. Properly cast concrete will have a very rich sand-cement surface.
varying in thickness and shielding the coarse aggregate behind. The coarse aggregate, unless exposed, will not influence the surface color except in cases of aggregate transparency, where low sand content permits the coarse aggregate to cast a shadow. Where the concrete surface is removed, the exposed aggregate becomes the primary color constituent. In summary, color results from the cement and sand in untreated concrete and from primarily the coarse aggregate in treated concrete. In untreated concrete the color may range from an eggshell white to a very dark, greenish black. The density of the cement particles is directly related to color intensity. Areas having a lower water content will have a greater density and will be darker in color. Variations in water content may be the result of several causes such as form absorption, form leaks, and inadequate mixing. Producing color uniformity in untreated concrete is as difficult as in the production of any smooth surface consisting of a blending of materials. All the conditions affecting production must be uniform, not only the mixing or blending, but the casting, forming and curing. A comprehensive list of these many aspects follows and outlines the paramount task involved in attaining a degree of color consistency. Therefore, with untreated concrete it is important to recognize what has influenced the color and to determine what shall be considered acceptable.

Color uniformity of exposed aggregate-treated concrete depends on the degree of exposure and the method of exposing. The greater exposure of the coarse aggregate will cause the cement-sand matrix to become less apparent. In cases where a smooth surface is to receive an abrasive blasting, the uniformity of the surface color is improved by slightly exposing the smallest of the coarse aggregates. A portion of the rich sand-cement layer is partially removed with surface color becoming a blend of all the constituents. Where the coarse aggregate color is desired, the conditions for production vary from untreated concrete. Depending on the degree of exposure, the distribution of aggregate within the mix becomes a major concern while other influences such as the nature of the form surface takes a lesser role.
## FACTORS AFFECTING COLOR

### CONCRETE MIX

**Materials:**
- Cement type (mill brand), variations in batch fineness
- Aggregate variations--quarry to quarry, within same quarry, porosity, moisture content
- Admixtures
- Water purity
- Inclusion of deleterious materials

**Mix:**
- Water-cement ratio
- Grading--fines to coarse
- Workability
- Temperature
- Batch to batch consistency

### FORMWORK

**Materials:**
- Rigidity, absorbancy, condition--new, aged, dirt stains, reaction with concrete, if any

**Surface Preparation:**
- Sealers, release agents, retarders, type, purity, viscosity
- Application--uniformity, method, quantity
- Reaction with--concrete, form, each other
- Resistance to--ultraviolet, heat, evaporation
- Period of effectiveness

**Form Tightness:**
- Grout leakage, entrance of air

**Reinforcement:**
- Corrosion protection prior to pour, adequate cover, coatings, oils

### DISTRIBUTION

**Variations in:**
- Mixing time, placing time

**Equipment:**
- Type, contamination of, variation in use

**Segregation During Handling:**
- Additional water, coffee, coke, etc.

**Contamination by Workers:**
- Additional water, coffee, coke, etc.
FINISHING - WEATHERING

Surface Treatment: Uniformity of application, method of application, intensity of application

Blemish Repair: Time of application, method of application, uniformity of application

Weathering: Streaking—dirt, rain, rust stains, efflorescence
Sensible color selection to coexist with the degree of atmospheric pollution that it will experience

PLACEMENT

Segregation: Method of pouring, improper vibration

Vibration: Internal, External, Revibration
Equipment size, frequency (VPS)
Application—method, time of application, effective area, form rigidity

Rate of Pour: Depth, width, location of reinforcement

Temperature: Formwork, air and mix

CURING

Methods: Curing in forms, Moist curing, Liquid membrane
Rate of drying, uniformity of drying, temperature
Exposure—wind, sun, etc.
Purity of curing agent
Application of curing agent—uniformity, method, quantity
Surface contact with cover, soiled covers

Stripping of Formwork: Time of removal
UNIFORMITY OF TEXTURE

Uniformity of texture may be thought of as a reciprocal of color uniformity. When a surface is flat and smooth, the color is a very important element in evaluating its quality. On the other hand, when a surface is highly textured, its color uniformity becomes less important. Concrete may be cast against several types of form surfaces that will not impart a texture. Among these are elastomeric, plastic, wood, and steel. Extreme care must be given to each aspect of construction to assure quality results. In many cases large smooth surfaces are lightly blasted to obtain color uniformity as mentioned in the previous section.

Textured concrete may be produced by either treating flat surfaces or by using profiled form surfaces which in turn can be treated. Textures may range from lightly-figured surfaces to deep striations. Profiled as-cast surfaces are the result of an impression made by either the actual formwork or a form lining.

Formwork is typically constructed of wood, steel, or reinforced plastics. Form linings are commonly attached to plywood or steel formwork and usually consists of rubber or neoprene mats, plastic sheets or boarding. Selecting a material for the purpose of creating a texture will depend on the nature of the texture and the number of reuses intended. Certain foamed plastic linings are satisfactory for only one use, while some profiled steel forms may be used in excess of 200 times. Initial form cost as well as the number of reuses it will have must be carefully examined. An outline of the factors affecting texture follows.

Smooth and profiled as-cast surfaces can be treated to expose the aggregate. Treatment may result in removing either the cement-sand matrix between the coarse aggregates or a portion of the entire surface. Removal of the sand-cement matrix can be accomplished by using a surface retarder and brushing the surface with water shortly after casting. Abrasive blasting and acid etching are also used to
remove the matrix. Complete surface removal will require fracturing the surface with a variety of available hammers or grinding with abrasives.

In view of the techniques available, uniformity will depend on the depth and method of creating the texture as well as whether additional treatment will be applied, and if so, what method. Caution must be observed in the treatment of concrete surface. Certain methods may conceal deficiencies while others accentuate them; i.e., aggregate blasting may accentuate cracks.

FACTORS AFFECTING TEXTURE

DIRECTLY PROFILED

MIX
Proper grading of mix
Sufficient Workability

Material
Absorbency
Rigidity

Surface Preparation
Release agent--
Application quantity
Reaction with form
Period of effectiveness
Retarders

TREATED AFTER CASTING

Proper grading of mix
Workability
Batch consistency

Material Rigidity

FORMWORK

Contamination
Vibration--
Equipment size, Frequency,
Application, Effective area,
Form Rigidity
Segregation

FINISHING

Uniformity of application
Method of application
Intensity of application
The textures available for a concrete surface are in one sense limitless. Surface textures may range from a polished eggshell hardness, to a porous wood-grained figure, to a deeply patterned mosaic of exposed aggregate. Concrete has unlimited formability in that it can take almost any form; however, caution is advised in the creation of shapes that do not represent the inherent nature of concrete. Concrete is a composite of heavy materials, cast into a homogeneous mass that is strong in compressive strength and impervious to the elements of nature. It is the designer's responsibility to present this material in a way that honestly represents these qualities and displays a sensitivity to its method of construction.

LIGHTING VARIATIONS

Being a material light in color and varying in texture, concrete usually has varying surface intensities. These light variations will depend on the nature of the planned texture and the resulting surface irregularities. Smooth vertical surfaces are especially prone to defects known as surface voids—commonly called bugholes. Bugholes are the result of trapped air that leaves hemispherical cavities usually no larger than one-half inch in diameter. Depending on the absorbency of the formwork and the degree of consolidation achieved, bugholes may be a very prominent surface feature. It is therefore necessary to be aware of their probable existence in any work planned. Many architects find them inherently pleasing, while others do as much as possible to eliminate them. If they are sought as part of its surface texture, care should be taken to achieve a degree of uniformity. Bugholes will be seen as dark spots and may significantly contribute to the shadings of the surface. Planning and evaluation should take into consideration the effect these light variations will have on the overall character of the surface.
SURFACE DEFECTS IN EXPOSED CONCRETE

The appearance of architectural concrete is quite often damaged by the occurrence of surface defects. These irregularities are commonly visible after removing the formwork and usually result in poor forming and consolidation techniques. Some defects occur after time and are more severe in nature. It is therefore important to be aware of the conditions that cause them, as they may have effects other than visual. A list of common defects and their causes are listed below.

COLOR VARIATIONS

<table>
<thead>
<tr>
<th>DEFECT</th>
<th>DESCRIPTION</th>
<th>MOST PROBABLE CAUSES</th>
</tr>
</thead>
<tbody>
<tr>
<td>INHERENT COLOR VARIATION</td>
<td>VARIATION IN COLOUR OF THE SURFACE</td>
<td>MATERIALS INCONSISTENT GRADING OR COLOUR</td>
</tr>
<tr>
<td>AGGREGATE TRANSPARENCY</td>
<td>DARK AREAS OF SIZE AND SHAPE SIMILAR TO THE COARSE AGGREGATE, MOTTLED APPEARANCE</td>
<td>CONCRETE MIX INCOMPLETE MIXING, SEGREGATION OR VARIATION IN PROPORTIONS</td>
</tr>
<tr>
<td>NEGATIVE AGGREGATE TRANSPARENCY</td>
<td>LIGHT AREAS OF SIZE AND SHAPE SIMILAR TO THE COARSE AGGREGATE, MOTTLED APPEARANCE</td>
<td>FORMWORK TOO FLEXIBLE</td>
</tr>
<tr>
<td>HYDRATION DISCOLORATION</td>
<td>VARIATION IN SHADE OF THE SURFACE</td>
<td>CEMENT LOW SAND CONTENT, GAP-GRATED</td>
</tr>
<tr>
<td>SEGREGATION DISCOLORATION</td>
<td>VARIATION IN COLOUR OR SHADE, GIVE A FLECKED APPEARANCE</td>
<td>MIXING METHODS EXCESSIVE VIBRATION, EXTERNAL VIBRATION</td>
</tr>
<tr>
<td>DYE DISCOLORATION</td>
<td>DISCOLORATION FOREIGN TO THE CONSTITUENTS OF THE MIX</td>
<td>FORMWORK VARIABLE ABSORBENCY; LEAKAGE</td>
</tr>
<tr>
<td>OIL DISCOLORATION</td>
<td>CREAM OR BROWN DISCOLORATION, SOMETIMES SHOWING SAND OR AGGREGATE</td>
<td>RELEASE AGENT THROUGH JOINTS</td>
</tr>
<tr>
<td>DUSTING</td>
<td>LIGHT-COLOURED DUSTY SURFACE WHICH MAY WEATHER TO EXPOSE AGGREGATE</td>
<td>UN Even OR INADEQUATE APPLICATION CURING</td>
</tr>
<tr>
<td>RETARDATION</td>
<td>MATRIX NEAR THE COLOUR OF SAND AND LACKING IN DURABILITY</td>
<td>FORMWORK STAINS, DYES OR DIRT ON THE FORM FACE</td>
</tr>
<tr>
<td>DRYING DISCOLORATION</td>
<td>VARIATION IN SHADE OF THE SURFACE, FROM LIGHT TO DARK</td>
<td>RELEASE AGENT IMPURE MATERIALS DIRTY</td>
</tr>
<tr>
<td>EFFLORESCENCE</td>
<td>WHITE POWDER OR BLOOM ON THE SURFACE</td>
<td>RELEASE AGENT EXCESSIVE, LOW VISCOSITY, IMPURE, APPLIED TOO LATE</td>
</tr>
<tr>
<td>CONTAMINATION</td>
<td>DISCOLORATION FOREIGN TO THE COLOUR OF CONSTITUENT MATERIALS</td>
<td>CEMENT INADEQUATE (VERY RAPID DRYING) AIR-SET</td>
</tr>
</tbody>
</table>

REFERENCE:
BLAKE, L.S. "RECOMMENDATIONS FOR THE PRODUCTION OF HIGH QUALITY CONCRETE SURFACES." CEMENT AND CONCRETE ASSOCIATION, MARCH 1967, 38 PP.
GAGE, MICHAEL. "GUIDE TO EXPOSED CONCRETE FINISHES." CEMENT AND CONCRETE ASSOCIATION, 1979, 158 PP.
SURFACE DEFECTS

PHYSICAL IRREGULARITIES

DEFECT

DESCRIPTION

MOST PROBABLE CAUSES

HONEYCOMBING

COARSE STONY SURFACE WITH AIR VOIDS AND LACKING IN FINES

CONCRETE MIX

INSUFFICIENT FINES, TOO LOW WORKABILITY

FORMWORK

JOINTS LEAKING

PLACING METHODS

CAUSING SEGREGATION:

DESIGN

INCOMPATIBLE MIXTURES

FORMWORK

PLACING METHODS

DESIGN

INSUFFICIENT FINES, TOO LOW WORKABILITY

BLOWHOLES

INDIVIDUAL CAVITIES USUALLY LESS THAN 1/2" DIAMETER, SMALL CAVITIES APPROXIMATELY SEMISPERICAL; LARGER CAVITIES OFTEN BOUNDED BY STONE PARTICLES

FORMWORK

FORM FACE IMPERMEABLE, WITH POOR WETTING CHARACTERISTICS;

RELEASE AGENT

INCLINED; TOO FLEXIBLE

CONCRETE MIX

NEAT OIL WITHOUT SURFACTANT

PLACING METHODS

TOO LEAN, TOO COARSE A SAND, TOO LOW A WORKABILITY

INSUFFICIENT COMPACTED MATERIALS:

EXTERNAL VIBRATION

FORMWORK

PLACING METHODS

GROUT LOSS

SAND TEXTURED AREAS, DEVOID OF CEMENT, USUALLY ASSOCIATED WITH DARK COLOUR ON ADJOINING SURFACE

FORMWORK

LEAKING AT JOINTS, TIE HOLES, ETC.

SCOURING

IRREGULAR ERODED AREAS AND CHANNELS HAVING EXPOSED STONE OR SAND PARTICLES

CONCRETE MIX

EXCESSIVELY WET; INSUFFICIENT FINE PARTICLES; TOO LEAN

PLACING METHODS

WATER IN FORMWORK; EXCESSIVE VIBRATION ON WET MIX; LOW TEMPERATURE WHEN PLACING

PROFILE VARIATION

STEP, WAVE OR OTHER DEVIATION FROM THE INTENDED SHAPE

FORMWORK

DAMAGED; DEFORMED UNDER LOAD:

PLACING METHODS

JOINTS NOT TIGHTLY BUTTED

TOO RAPID OR CARELESS
<table>
<thead>
<tr>
<th>DEFECT</th>
<th>DESCRIPTION</th>
<th>MOST PROBABLE CAUSES</th>
</tr>
</thead>
<tbody>
<tr>
<td>PLASTIC CRACKING</td>
<td>SHORT CRACKS OFTEN VARYING IN WIDTH ALONG THEIR LENGTH, WITH VERTICAL CASTING, CRACKS MORE OFTEN HORIZONTAL THAN VERTICAL.</td>
<td>CONCRETE MIX: HIGH WATER/CEMENT RATIO; LOW SAND CONTENT, FORMWORK, POOR THERMAL INSULATION; IRREGULAR SHAPE (RESTRAINING SETTLEMENT)</td>
</tr>
<tr>
<td>SCALING</td>
<td>THIN LAYER OF HARDENED MORTAR REMOVED FROM THE CONCRETE SURFACE, EXPOSING MORTAR OR STONE.</td>
<td>FORMWORK: RELAXING AFTER COMPACTION; FORM FACE EXCESSIVELY ROUGH, INADEQUATE APPLICATION OR REMOVED DURING SUBSEQUENT OPERATIONS; INEFFECTIVE LOW STRENGTH, TOO EARLY</td>
</tr>
<tr>
<td>FORM SCABBING</td>
<td>PARTS OF THE FORM FACE, INCLUDING BARRIER PAINT, ADHERING TO THE CONCRETE.</td>
<td>FORMWORK: FORM FACE EXCESSIVELY ROUGH, WEAK OR DAMAGED, INADEQUATE APPLICATION OR REMOVED DURING SUBSEQUENT OPERATIONS; INEFFECTIVE TOO LATE</td>
</tr>
<tr>
<td>SPALLING OR CHIPPING</td>
<td>PIECES OF CONCRETE REMOVED FROM THE HARDENED SURFACE, DEEPER AND USUALLY MORE SEVERE THAN SCALING.</td>
<td>FORMWORK: DIFFICULT TO STRIKE, INADEQUATE APPLICATION OR REMOVED DURING SUBSEQUENT OPERATIONS; INEFFECTIVE LOW STRENGTH, AGGREGATES SUSCEPTIBLE TO DAMAGE BY FROST OR WATER, TOO EARLY, MECHANICAL DAMAGE AFTER STRIKING, WEATHERING; FROST ACTION: CORROSION OF REINFORCEMENT</td>
</tr>
<tr>
<td>CRAZING</td>
<td>A NETWORK OF FINE CRACKS IN RANDOM DIRECTIONS, BREAKING THE SURFACE INTO AREAS FROM ABOUT 1/4&quot; TO 3&quot; ACROSS.</td>
<td>FORMWORK: FORM FACE OF LOW ABSORBENCY, SMOOTH OR POLISHED, CONCRETE MIX: TOO RICH IN CEMENT, TOO HIGH WATER/CEMENT RATIO; CURING INADEQUATE, STRIKING TIME: TOO EARLY, ESPECIALLY IN COLD WEATHER</td>
</tr>
</tbody>
</table>
WEATHERING CONSIDERATIONS

DESIGN SUGGESTIONS
Building materials must fall within a sensible range of colors and textures to coexist with a degree of atmospheric pollution that they will experience. At the same time, considerations for good weathering must be concerned with the design and massing and general configurations of the building, its elements, and its details to promote both acceptable dirtying from the atmosphere and acceptable natural rain cleaning of some or all of this dirt.

Depending on individual design attitudes, there are many strategies that can be employed and these would include the following:
(a) The use of intense modeling to overwhelm the effects of weathering disfigurement
(b) The use of modeling to channel rainwater into preferred courses or lines or water shed
(c) The acceptance in the design of accumulated dirt in shadowed areas.

WEATHERING OF WINDOWS
WITHOUT SILLS & WITH SHALLOW REVEALS

WATER FLOW OVER VERTICAL SURFACES

WATER NEVER FLOWS EVENLY OFF A WALL TOP WITHOUT AN OVERHANG
USE A COPING OR ARTICULATE WALL FACE—SEE PARAPET DETAIL
PLAIN WALL SURFACES WILL TEND TO BE CLEANER AT THE TOP DUE TO DIRT FALLOUT AS RAINWATER PROGRESSES DOWNWARD. TEXTURES HELP MASK STAINS
BUILDING CORNERS ARE CLEANER THAN INTERMEDIATE WALL SECTIONS DUE TO A LARGER CONCENTRATION OF WATER AND HIGHER WIND SPEEDS.
SEPARATION OF LARGE SURFACES INTO DIVISIONS HELPS REDUCE THE OVERALL STAINING EFFECT. RUSTICATION JOINTS BREAK UP WATER FLOW CAUSING MORE UNIFORM WEATHERING.
AVOID PROJECTIONS AT THE BOTTOM OF WALLS AS THEY COLLECT DIRT.

WEATHERING OF WINDOWS
WITHOUT SILLS & WITH SHALLOW REVEALS

WEATHERING OF COLUMN AND BEAM CONNECTIONS

COLUMN IN FRONT OF BEAM

COLUMN STOPPED AT EDGE BEAM

COLUMN FLUSH WITH BEAM

BEAM WATER DRIPS CLEAR OF COLUMN

LARGE BEAM LEDGES ENCOURAGE DIRT COLLECTION

BEAM LEDGES CONTRIBUTE TO STAINING
INCLINED SURFACES
SMOOTH TROWEL INCLINED SURFACES

INCLINED SURFACES ARE RECOMMENDED TO ENCOURAGE RUNOFF

HORIZONTAL SOFFIT AND TREATMENTS
WATER MOVEMENT DOWN VERTICAL SURFACE
DRIP MOLDS ENCOURAGE WATER TO DRIP FREE

WATER CLINGS TO HORIZONTAL SURFACES
RUNOFF STAINS VERTICAL SURFACES
STOP DRIP MOLD BEFORE COLUMN TO PREVENT RUNOFF STAINS

SLOPED SOFFIT TREATMENTS
UPWARD SLOPES ENCOURAGE WATER TO DRIP FREE AT FRONT EDGE
SLIGHT DOWNWARD SLOPES MAY BE SUBJECT TO STAINING
STEEP DOWNWARD SLOPES ARE SUBJECT TO RUNOFF STAINING

KEEP SLOPE ANGLE SMALL WITH TEXTURED SOFFITS

REFERENCE:
MARSH, PAUL "CONCRETE AS A VISUAL MATERIAL." CEMENT AND CONCRETE ASSOCIATION, 1974.
ARCHITECTURAL SURFACES - JOINT LOCATIONS

Large architectural concrete surfaces should reflect the nature of their construction and the limitations of their strength. The best results are achieved when surfaces are divided into practical sizes that respond to construction practices including limitations for placement, consolidation, form size (when ganged), and rejection of unsatisfactory work. Construction joints should be planned integral with separations in structural elements (i.e. beams, columns, walls, slabs), wall openings and practical segments of concrete placement. Depending on the quality of fabrication, location of form joints may also be incorporated into the surface. Concrete is continually subject to cracking as a result of thermal stresses and unequal settlement. This cracking must be controlled so as not to impair the integrity of the structure or disrupt its appearance. Control joints therefore should be incorporated into long exterior walls within the range of 15-60 feet, depending on conditions of mass and temperature variations. Through systematic planning these joints may be integrated with one another, and expressed as rustication strips. The use of rustication strips are recommended although they are not mandatory in obtaining acceptable results.

**FORM PANEL JOINTS**

- COMMON FORM PANEL POSITIONING
  - TWO OF SEVERAL POSSIBILITIES

**CONSTRUCTION JOINTS**

- WITHIN PRACTICABLE LIMITS-USUALLY 30'-90' RANGE

**CONTROL JOINTS**

- CONTROL JOINTS AND CONSTRUCTION JOINTS SHOULD BE INCORPORATED WITH PANEL JOINTS
  - 15'-60' RANGE DEPENDING UPON CONDITIONS

**ELEVATION POSSIBILITIES**

- TWO OF SEVERAL SOLUTIONS
  - JOINTS ACCENTUATED
  - JOINTS MINIMIZED
JOINT DETAILS

VERTICAL AND HORIZONTAL RUSTICATIONS FOR CONSTRUCTION AND CONTROL JOINTS

BATTEN REMAINS AFTER EACH CASTING

STAGGER NAIL PLACEMENT

BATTEN SECTION SHOULD BE UNIFORM

USE CASING NAILS TO ALLOW EASY RELEASE FROM FORM

KERF LARGER BATTENS TO AID IN REMOVAL FROM CONCRETE

BATTEN SHOULD BE LEFT TO DRY OUT & SHRINK BEFORE REMOVAL

SPACE MAY BE NEEDED FOR SEALANTS

PROVIDE DRAFT ON ALL BATTENS

DESIGN JOINTS TO MASK FORM MISALIGNMENT

BATTENS SHOULD BE SEALED WITH RELEASE AGENT TO FACILITATE REMOVAL

EXTREME CARE & SUPERVISION MUST BE EXERCISED WITH SMALL SECTIONS

MATERIAL SHOULD BE OF SUFFICIENT STRENGTH TO MAINTAIN ALIGNMENT

EXPANSION JOINTS

FEATURE STRIPS

COMPRESSIBLE FILLER BETWEEN POURS

USED TO BREAK-UP LARGE SURFACES

WIDTH AND DEPTH OF RUSTICATION STRIPS WILL VARY ACCORDING TO AESTHETICS, SEALANT REQUIREMENTS AND CONSTRUCTIBILITY. THE EXAMPLES SHOWN ARE COMMONLY USED, BUT SHOULD NOT BE INTERPRETED AS THE ONLY POSSIBILITIES.

ALL JOINTS MUST BE WATER-TIGHT. SPLINES SHOULD BE NEATLY FIT. INTERSECTIONS SHOULD BE MITRED OR COPED AND TIGHTLY FIT.

RUSTICATIONS ARE USUALLY CUT FROM WOOD, HOWEVER, LIMITED VARIETIES ARE AVAILABLE IN METAL AND PLASTIC.

RUSTICATION REDUCES THE EFFECTIVE SIZE OF MEMBER AND THE COVER OF REINFORCING.

SEE PAGE 93 FOR GASKETING DETAILS.
OUTSIDE CORNERS

1. Corners must be protected before, during and after construction.

2. Wood, metal, plastic and neoprene chamfer strips are available.*

3. Gasket joints to prevent leakage.

INSIDE CORNERS

4. Detail to facilitate removal without damage to concrete.

5. Avoid exposed end grain due to different absorption.

ACUTE ANGLE CORNERS

6. Edge thickness must be sufficient to prevent spalling.

*REFERENCE:

ELLIS CONSTRUCTION SPECIALTIES, LTD., OKLAHOMA CITY, OKLAHOMA.
SYMONS CORPORATION, DES PLAINES, ILLINOIS.
COATINGS AND SEALANTS

SURFACE COATINGS
Coatings may be applied to architectural concrete surfaces for the purpose of either waterproofing or changing the natural color. Water repellents are usually clear liquids which reduce surface moisture absorption and consequent staining. Before application, test samples should demonstrate that the water repellents will not stain or change the color of the exposed concrete. Pigmented coatings and stains may be applied to surfaces when it is desired to alter the color, but retain the texture. In some cases these coatings may also serve as water repellents. Cautious selection of these materials is advised as certain types have a tendency to fade, change color, or wash out after a period of time.

JOINT SEALANTS
Various building joints require the application of sealants and caulks to prevent the passage of moisture. In most instances, these joints are a visual part of the exposed surface. Attention therefore should be given to the color of the joint material and the shape of the joint. The sealant color should be harmonious with the adjacent surfaces. The material should not discolor with age or attract atmospheric dirt. The shape of the joint may be flat, concave, or convex and flush or recessed with the building surface. This decision is up to the architect; however, uniformity of application should be required.

The sealants must be applied before the building is waterproofed to assure proper bonding. Sealants must also be compatible with these coatings.
<table>
<thead>
<tr>
<th>SPECIFICATION TYPES</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PERFORMANCE</td>
<td>The quality of the end product is specified. Recommended methods may be specified. Complete responsibility is placed on the contractor.</td>
</tr>
<tr>
<td>PROPRIETY</td>
<td>Specific materials, methods and processes are specified.</td>
</tr>
</tbody>
</table>

Specifying architectural concrete can be a very demanding task if acceptable results are to be achieved. Initially a distinction should be made between architectural concrete and structural concrete with separate sections resulting for each. It is important that the contractor know that architectural concrete be an exposed finished surface and that its construction be treated with special care and attention. Extreme care should be exercised in the development of the contract documents. Both drawings and specifications should reflect a clear understanding of the process of concrete construction. Each phase of production must be viewed in terms of what the expected results will be, how they will be accomplished, and with what methods and equipment. Specifications therefore must relate to the particular project and not be a fabrication of older, unrelated specifications. Equipment and operations are constantly changing, and it is the architect's responsibility to be aware of how his project can best be executed. Specifications are most effective when they are equal in performance and propriety. The performance specification allows the contractor freedom in selecting the methods of construction, while the propriety specification relieves him of making critical choices of material, mix proportions, etc. Specifying only performance criteria places a tremendous burden and responsibility on the contractor and may not attain the desired quality. On the other hand, propriety specifications require more detailing on the part of the architect and may cost more. The best results are usually achieved when the document results from continuous coordination between the architect, engineer, inspector, and contractor. Concrete, unlike many other building materials results from a complex on-site process. Even with the best documents and intentions, this process must be carefully controlled to produce satisfactory results. It is highly recommended that all architectural
concrete construction be constantly supervised by experienced personnel who can discipline the process.

Actual specifications of the desired finish are best left to reference samples of work produced by the contractor. Methods of construction should be the choice of the contractor, but demonstrated for approval in a sample preconstruction mock-up.

REFERENCE SAMPLES

Surface criteria for architectural concrete finishes must be first set down by the architect. Then, it is the architect’s responsibility to select the desired finish (from samples) which may come from experimentation by testing laboratories or from requirements to match an existing building. After a finish is selected, it is submitted for bidding to the perspective contractors. After selection of a contractor, a reference sample may be required from the contractor for acceptance after which it is referenced as the accepted standard. At this point it attains legal status with the contract documents and must be available for inspection. In some cases, existing adjacent structures are referenced for desired quality and appearance. Experience has indicated that it is best to allow the contractor to produce the acceptable standard.

A pre-bid sample should exhibit all the desired surface characteristics and should be prepared using materials and methods intended for the actual project. The size of the sample is left to the discretion of the architect. Although 18” x 18” has become somewhat of a standard, it should be large enough to adequately demonstrate the nature of the surface and small enough to be transported. The sample may also be divisioned for treatments or applied coatings so as to make comparisons within the same surface.

PRECONSTRUCTION CONFERENCE

A preconstruction conference should be held between the architect, structural engineer, architectural concrete consultant, contractor, concrete subcontractor, reinforcing steel fabricator, form supplier, concrete supplier, and testing laboratory. At this time, the special requirements and specifications should be
thoroughly explained and clarified. The architect and contractor should become equally aware of the objectives and needs of each other in order to achieve the desired results. Questions concerning working space, engineering requirements, and general constructibility should be clarified. Following the preconstruction conference the contractor should proceed with the construction of the mock-up.

**PRECONSTRUCTION MOCK-UP**

Preconstruction mock-ups are full scale samples of actual work performed by the selected contractor. Construction is on-site with proposed materials, equipment, and procedures. During this construction, supervisors, foremen, inspectors and tradesmen that will be working on the actual building are required to be present. The primary purpose of a mock-up is for the contractor to demonstrate his ability to meet the standards and workmanship as specified and detailed. In some cases, an approved mock-up must be completed before the signing of the contract. If personnel are changed during construction, the architect may require that they demonstrate their abilities by performing work in non-critical areas of the project. The size, location, and required details to be constructed are specified in the contract document. For the sake of surface evaluation, mock-ups should be oriented to accept the best possible viewing light. Mock-ups typically call for the demonstration of complex floor, column, and wall construction—all of which are to be completely visible. Mock-ups may also incorporate joints, glazing, special reinforcing, and any situation critical to the success of the projects. The architect may also require the use of several different methods and materials so as to select the ones best for the actual building. All architectural concrete mock-ups should include a repaired area so that acceptable materials and techniques can be developed for remedial work. It is important that repairs be aged—usually one month before determination of acceptability is made. Time and money spent perfecting a repair procedure can be very beneficial to the final outcome of the project. Where situations permit, experimentation with architectural concrete can take place on actual portions of the structure that will eventually be hidden from view.
FORMWORK
FORM MATERIAL SELECTION

Formwork is a term generally used to describe a system used in containing and shaping plastic concrete. Containing the concrete is the responsibility of the contractor who selects a system that can efficiently produce the desired results. This system must be designed, constructed, and maintained in strict accordance with engineering standards. Materials should be selected that will assure the integrity, uniformity, and character of the finished product within acceptable limits. The form must be designed as a stable envelope to contain the plastic mix with the back-up members providing alignment and controlling deflection. Shaping the concrete involves determination of the physical size and selection of the appropriate form face to impart a texture. This is the responsibility of the architect and is accomplished by means of drawings, specifications, samples, and mock-ups. Specification of the actual form face material is commonly done to assure that the desired texture and color will result. Selection of a form material to produce a desired texture may require several decisions. The initial cost and number of reuses of form materials must be thoroughly investigated. At all times the quality and uniformity of the finished product must be kept in mind when addressing budgetary solutions. When a form can be reused many times, the type of forming material may have little affect on the budget provided the material is suitable for the finish. It is also important that the architect be aware that shapes requiring elaborate formwork or designs requiring sophisticated form surfaces may be detrimental to project economically, if their costs are not considered initially. The following major factors should be considered when a choice of forming surfaces exists.
<table>
<thead>
<tr>
<th><strong>Finish Objective</strong></th>
<th>As-cast surface—Smooth, Textured, Profiled</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Treated surface—Type of treatment</td>
</tr>
<tr>
<td><strong>Repetition</strong></td>
<td>Number of reuses of panel</td>
</tr>
<tr>
<td></td>
<td>Surface uniformity of reuse—quality</td>
</tr>
<tr>
<td><strong>Labor</strong></td>
<td>Available carpenters</td>
</tr>
<tr>
<td></td>
<td>Quality of workmanship</td>
</tr>
<tr>
<td><strong>Fabrication</strong></td>
<td>On-site—when labor is available</td>
</tr>
<tr>
<td></td>
<td>Shop-built—more costly, better quality</td>
</tr>
<tr>
<td></td>
<td>Accelerates construction</td>
</tr>
<tr>
<td><strong>Modularity</strong></td>
<td>Available sizes</td>
</tr>
<tr>
<td><strong>Absorbency</strong></td>
<td>Absorbent, nonabsorbent</td>
</tr>
</tbody>
</table>

Final selection of a form material should center on the fundamental effect it will have on the concrete and on the ultimate finish. Forming materials are usually modular and may provide some structural purpose for containment or may be liners attached to a structural back-up. Available options for form surfaces include several different grades of plywood, variations and species of board forms, hardboard, fiberglass reinforced plastic, foamed and expanded plastics, steel, and elastomerics; rigid and flexible. Back-up materials for form liners can be plywood, boards, steel, or fiberglass reinforced plastic.
Selection of an absorptive versus a nonabsorptive form is critical to the outcome of the final surface color and texture. Knowledge of the chemistry of concrete can be beneficial in understanding this concern. When Portland cement and water react, the byproduct calcium hydroxide occurs. The calcium hydroxide is water soluble and moves throughout the wet mix until it is deposited as a result of the water being evaporated or used in a chemical reaction. As a clear crystal, calcium hydroxide is unstable and capable of reacting with carbon dioxide present in the atmosphere to form calcium carbonate. Calcium carbonate is a white powder commonly known as efflorescence.

Depending on the absorption of the form material the ultimate color of the concrete surface can be predicted. With absorptive forms, the calcium hydroxide along with excess water is absorbed by the form material. Consequently, the concrete surface will appear darker for two reasons. First, the calcium hydroxide in the surface region has been absorbed and will not contribute to lightening the surface when it converts to calcium carbonate. Secondly, the absorption of the surface water reduces the water-cement ratio which in turn produces a more dense, darker-colored concrete. Also due to this absorption, particles of the concrete surface become embedded in the form surface. When the form is stripped these particles are sheared from the main body of the concrete leaving a porous surface somewhat like sandstone.

It is important to point out that certain types of form surfaces, such as wood, vary in absorbency due to their natural density variation. Sealers should be applied to absorbent form surfaces to control color variation and to extend the form life. Release agents usually do not prevent absorption. It is also advised to wet form surfaces with water prior to the casting of the concrete. Form surfaces with a moisture content at saturation will not absorb water from the plastic concrete.
LUMBER FORMWORK

A wide variety of board-marked patterns and profiles may be cast into concrete depending upon the type and quality of lumber used. Lumber form materials may be left rough, resawn, planed smooth, abrasive blasted, or soaked in water to further accentuate the difference in surface figure. Light abrasive blasting removes the softer springwood growth. Soaking lumber in water or a weak (1 - 3%) ammonia solution raises the grain. Softwood species of common grade boards and flooring (kiln-dried) are commonly used and readily available. These woods typically have a marked contrast between the spring growth and the summer growth. This contrast is readily imparted to concrete as a result of varying absorbency. Hardwood is often used for rustication and feature strips, and may be used as a form surface, but local availability and cost should be thoroughly investigated. When selecting board forms, it is important that the local supplier have a sufficient quantity available to complete the project. If color uniformity is desired, the lumber should come from one source. The quality of lumber may vary within the same source, but generally should be sound, straight, and free of major defects.

One should be aware of conditions that may exist when lumber is exposed to varying weather conditions. Lumber that is exposed to sunlight may exhibit a greater porosity than that which is concealed. The reason for this is the ultraviolet rays breakdown of hemicelluloses at the surface which are hydrolized into sugar leaving a porous cell wall. The sugar is capable of breaking down certain types of wood sealers. Excessive sugar content in raw lumber can also retard the set of the concrete surface which may lead to dusting. Dusting is a condition whereby the surface texture can be removed by hand rubbing. Variations in color can therefore result if boards of different ages are used or if one part of a form panel is exposed to more sunlight than another when stored. Depending on storage conditions wood may also vary in moisture content. Lumber should not be too dry, otherwise it will tend to swell with any absorbed moisture and make removal of the formwork difficult.
'Green' lumber will dry out during hot weather causing excessive warpage which will make alignment difficult and surfaces uneven. It is highly recommended that wood form materials be properly stored off the ground in a protective environment. This applies to both loose boards and fabricated forms.

Concrete surfaces cast against lumber forms will vary in intensity of lighting due to the natural variation in absorbency across and between the boards with each use. Lumber forms produce concrete of a lighter color as a result of the pores becoming filled with release agent and cement particles. As mentioned earlier, the moisture content of lumber affects its absorbency and the consequent color of the concrete. When color uniformity is desired, it is important to take certain precautions. New boards should be thoroughly treated with permeating sealer that will not stain the concrete (Cuprinol). This also prevents warpage. Board forms not treated with proper sealants before their first use may deteriorate after less than five uses. After sealing, it is advisable to 'age' the boards by applying a slurry coat of rich Portland cement. A coating of at least 1/2" thickness helps facilitate removal. This treatment will be a cost factor, but should be weighed against the desired degree of surface uniformity. After removal of the slurry coating, the forms should be well oiled with a uniform coat of release agent. New lumber should receive several coats of release agent if use of a sealer is not planned. The release agent should be allowed adequate time to permeate the wood. Insufficient release agents on raw wood can lead to form scabbing whereby the wood fibers adhere to the concrete.
LUMBER USED FOR FORMS

LUMBER TYPES & GRADES

types of softwoods used for forming
- douglas fir
- western larch
- ponderosa pine
- idaho white pine
- western red cedar

lumber classification

<table>
<thead>
<tr>
<th>common grades</th>
<th>form quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1 select</td>
<td>excellent</td>
</tr>
<tr>
<td>#2 construction</td>
<td>good, knots vary</td>
</tr>
<tr>
<td>#3 standard</td>
<td>good, larger knots</td>
</tr>
<tr>
<td>#4 utility</td>
<td>rough use only</td>
</tr>
<tr>
<td>#5 economy</td>
<td>unsuitable</td>
</tr>
</tbody>
</table>

lumber used for forms

lumber types & grades

- douglas fir
- western hemlock
- western larch
- ponderosa pine
- idaho white pine
- western red cedar

lumber classification

common grades

- #1 select: excellent
- #2 construction: good, knots vary
- #3 standard: good, larger knots
- #4 utility: rough use only
- #5 economy: unsuitable

grain type

- hef-fir
- sugar pine
- lodgepole pine
- incense cedar
- engelmann spruce

southern yellow pine

- available sizes (in.)
  - thicknesses: 5/16, 7/32, 9/32
  - nominal size: 1 x 4, 1 x 6, 1 x 8, 1 x 10, 1 x 12

surface texture

- rough sawn
- resawn - bandsaw
- smooth planed
- raised grain

common grade boards

s4s

- nominal size: 1 x 4, 1 x 6, 1 x 8, 1 x 10, 1 x 12
- width: dress, face
- area factors: 1.14, 1.09, 1.10

shiplap

- nominal size: 1 x 4, 1 x 6, 1 x 8, 1 x 10, 1 x 12
- width: dress, face
- area factors: 1.17, 1.16, 1.13

tongue and groove (t&g)

- nominal size: 1 x 4, 1 x 6, 1 x 8, 1 x 10, 1 x 12
- width: dress, face
- area factors: 1.28, 1.17, 1.16

area factors are given for determining the amount of material needed for the five basic types of wood paneling. multiply square footage to be covered by factor (length x width x factor).

common wood flooring

wood types

- douglas fir
- western hemlock
- southern yellow pine

available sizes (in.)

- thicknesses: 5/16, 7/32, 9/32
- nominal size: 1 x 4, 1 x 6, 1 x 8, 1 x 10, 1 x 12

specification

mention of the following factors should be indicated for accurate specification of materials

example

- product classification: boards
- species: douglas fir
- grade: #2 common
- nominal size: 1 x 6
- grain type: edge grain
- seasoning: seasoned, unseasoned

caution!

southern yellow pine should be avoided because the sap, which is not removed by curing, is acid in nature and at unpredictable times can rise to break through the scaler and release agent to place the alkaline concrete in an acid environment when setting should be taking place. the result is a lack of reaction of the concrete and the surface is "killed" resulting in a blotchy, dusty appearance. also, this type of form lumber is subject to considerable dimensional variation with moisture changes.


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LUMBER FORM DETAILS

SMOOTH LUMBER FORM SURFACES
HIGH QUALITY SMOOTH FACE

- SMOOTH FACE
- FLUSH, TIGHT JOINTS
- HIGH QUALITY BOARDS OR FLOORING
- NARROW BOARDS TO MINIMIZE WARPAGE
- UNIFORM WIDTHS

SURFACE MAY LACK BOARD FORM CHARACTER AND CLOSELY RESEMBLE PLYWOOD

BOARD FORM QUALITY FACE

- PROFILED FACE
- SLIGHT OFFSET TIGHT JOINTS
- GOOD QUALITY FORM LUMBER (FLAT GRAIN)
- END JOINTS PERMITTED
- RANDOM OR UNIFORM WIDTHS

JOINTS—BOARD EDGES AND SURFACE FIGURE TRANSFER TO CONCRETE

RECESSED JOINTS

- PLYWOOD BACK-UP
- GASKET JOINT
- BEVEL RECTANGULAR FILLETS TO FACILITATE REMOVAL FROM CONCRETE

OVERLAPPING JOINTS

UNIFORM

RAISED JOINTS

- RAISED & RECESSED JOINTS
- RAISED JOINTS
- PROJECTION MAY BE TREATED AFTER CASTING, I.E. BROKEN OFF
- SCULPTURAL EFFECTS DEEPLY PROFILED PATTERNS LETTERING
- DRAFT IS REQUIRED ON ALL SECTIONS
  - 9" MIN. HARDWOODS
  - 14" MIN. SOFTWOODS

JOINT TYPES

- BUTT
- SHIPLAP
- T & G
- SPLINE

JOINTS MUST BE TIGHT TO AVOID A LOSS OF FINES

STEPS JOINTS

LUMBER IS NOT THICKENED, STRONG BOARD MARKED PATTERN IN LOW RELIEF

VARIATIONS

RADIAL PATTERN OF RAISED JOINTS

JOINT OPEN

SPLINE JOINT

JOINT CLOSED
PLYWOOD FORMWORK

Plywood is manufactured in more than 40 different surface textures ranging from glass-smooth surfaces to textured panels. Plywood is most commonly used to form smooth as-cast surfaces. Textured surfaces may also be obtained by abrasive blasting smooth panels prior to use. Textured panels have a tendency to adhere to concrete, making stripping difficult and consequently limiting their number of reuses. Most softwood types of exterior grade plywood fabricated with waterproof glue can be used for concrete formwork. Plywood veneers are usually cut circumferentially from a log, and no distinction is made between heartwood and sapwood for the surface veneer. In addition, this surface may be composed of mixed strips of veneer. Consequently, the variations in absorbency existing across the sheet and from sheet to sheet will be reflected by variations in the surface character of the concrete.

Several manufacturers now produce special grades of high-performance plywood specifically intended for forming. These products are made of select quality veneers for additional strength and stiffness. Variations in surface absorbency are still unpredictable from sheet to sheet unless coated with a sealer. Certain types of these products are available either mill-oiled with form release agents or resin impregnated.

Resin impregnated plywood is treated with thermosetting phenolic or melamine resins to produce a hard, smooth, nonabsorbent surface of exceptional durability. With special care, resin impregnated plywood can be used 200 or more times. Forming plywood usually have similar face surfaces on both sides and can be reused interchangeably.

In summary, plywood may be treated with release agents, sealers, or plastic resins. Selection will depend on the character of the surface desired and the size of the project. Form cost must be carefully weighed against the number of reuses attainable; however, it is important to mention that a distinction should be made in untreated plywood between sapwood and heartwood if color uniformity
is critical. More detailed information on sealers and release agents can be found in consecutive pages.

Additional plywood grades designed for concrete forming include special overlay panels and proprietary panels. These panels are generally designed to produce a smooth uniform concrete surface and may be mill-oiled with a release agent. Specific manufacturers should be contacted for details and available types. Selection of special materials should be made with caution as they may be in limited supply and will cost more than standard materials.

Plywoods are manufactured in a wide variety of thicknesses and panel sizes; however, caution must be observed when specifying plywood. Although suppliers list all the manufactured choices, obtaining them readily may be difficult. Thicknesses of 5/8" and 3/4" with a panel size of 4' x 8' are most commonly used and are readily available.

It is also important to note the grain direction of the panel. Plywood has a strong and a weak use direction. The use providing the greatest strength in plywood is where the grain direction is perpendicular to the initial support. The weak use would be where the grain direction is parallel to the initial supports. Plywood can be usually ordered with the grain direction in either the long dimension or the short dimension. If plywood is used in the weak way (grain direction parallel to the initial support), the form should be redesigned to compensate for the reduced structural capability of the plywood.

Plywood panels are typically manufactured with very exacting tolerances. In extreme cases panels within manufacturing tolerances should be able to limit variations to 1/32" from panel to panel. Realignment or shimming usually solves any variation problem.

Standard panels are manufactured with edges cut exactly square and upon special order, tongue and groove-edged panels may be
obtained. Most contractors obtain square-edged panels and fabricate their own joining means. Tongue and groove-edged panels have a main advantage in construction of large, prefabricated forms where the joints hold the panels flush and minimize panel face variations caused by nailing.

Nails used with plywood should be small and as few as practicable to hold the sheet within specified tolerances. It is also recommended that common rather than box nails be used since they will hold into the backup material more effectively. Improved methods of attachment such as screw nails, recessed screws, header teks, and split rivets may be used to further extend the reuse potential of the panel. Blind fastening devices are also available for use where a fair faced surface is required.

Irrespective of the type of joint or attachment used, it is important that all edges be well sealed before fabrication. Recut edges, penetrations of the form face by fastening devices, and any damages should be properly sealed or resealed where moisture absorption is likely to enter. Absorbed water and moisture can cause the panels to swell unevenly (thicken) creating indentations in the concrete.

Plywood forms should be stripped as soon as practicable to prevent excessive moisture absorption through joints and openings. Wood wedges should be employed in form removal to prevent damage. After stripping forms, all plywood panels should be cleaned and inspected for damage. Damaged areas should be allowed to dry out before application of a sealer. After cleaning and resealing all panels should be recoated with release agents and properly stored. Storage requirements are the same as those for lumber forms.
WOODEN FORM COATINGS AND SEALERS

Wooden form materials such as lumber and plywood are usually coated with sealers during their manufacture or on the project site to serve one or more of the following purposes:

To primarily protect and prolong the useful life of the portion of a lumber or plywood form that will be in contact with the concrete.

To prevent color variations and dusting of the concrete surface.

To alter the texture of the contact surfaces (e.g., prevent transfer of grain patterns that may not be desired).

To facilitate release from concrete during stripping (despite careful application of release agent, some of it may be removed accidentally before or during concreting).

To aid in obtaining a uniform depth of surface retardation when desired.

Factory-applied surface coatings usually have uniform characteristics that can be relied on. Surface coatings applied in the field are subject to varying conditions which directly effect their quality and reliability.

Selection of a form coating will depend on the following:

Desired surface characteristics
Cost—mill-sealed vs. site-sealed
Form material
Number of form reuses
Environment of use

Available Types

Epoxy resin treated plywood
Glass Fiber reinforced plastic bonded to plywood
Resin impregnated plywood

REFERENCE:
The manufacturer should be contacted concerning the availability and use of the first two mentioned panel types.

Resin impregnated plywood is also known as high density overlaid plywood or filmed faced. The resins may be either melamine or phenolic, which is most commonly used. The resin is impregnated into the face of high density plywood under high temperature and pressure. The resin coating (usually 45% by weight) may be varied in thickness on mill request to effect its reuse value. The finished surfaces are nonabsorbent and are completely free of any grain pattern. The durability is exceptionally good and with proper care some contractors have reported up to 400 reuses. Because the surfaces are moisture resistant, hard, and smooth, labor costs are reduced due to less repair, less cleaning, and less use of release agents. Repair to damaged areas can usually be accomplished with one of the following waterproofing sealers:

- Urethane sealers
- Chlorinated rubber base paints
- Water based vinyl paints
- Modified spar varnish

In all cases the manufacturers' recommendations should be followed regarding use of release agents and sealers for repair. During the first few uses of resin impregnated plywood, its natural surface color may be transferred to the concrete. This is commonly called 'pinking' and is a reddish or pinkish discoloration most noticeable on lighter colored concrete. The stain, a fugitive dye, is temporary and usually disappears with exposure to sunlight and air. Where sunlight cannot reach the stain, natural bleaching takes longer. Household bleaching agents such as Clorox or Purex (5% solutions of sodium hypochlorite), followed by clear-water flushing, have been found effective in hastening stain removal.

Treatments that will form an alkali-resistant film between the concrete and the overlaid surface may significantly reduce 'pinking.' Form release agents may also contribute to this resistance.
The major advantage of using coatings on untreated plywood is to increase the resistance of the form face to abrasion and impact and so to extend its life to between 10-15 uses. Uniform applications of surface coatings are critical to creating non-absorbent surfaces. Improper application may result in absorption of bleed water by the form face and consequent color variations. Selection of an appropriate coating will depend upon the manufacturers' recommendations for application, results of trials, past experience, and cost.

Available Types

Chlorinated rubber paint applied in several coats has good resistance to abrasion and alkalis. Because it is a thermoplastic material, it softens at elevated temperatures and is therefore not suitable for steam curing.

Polyurethane paints are thermosetting and dry to a hard, durable surface with good resistance to acids, alkalis, and abrasives. Site application is critical, moisture cannot be tolerated.

Catalyzed resins of the thermosetting type cure to a hard surface yet remain flexible. They typically have good resistance to alkalis and acids.

Solvent release agents and lacquers are not recommended because they degrade in the presence of alkaline bleed water and ultraviolet light. They also tend to chip and peel.
PLYWOOD USED FOR FORMS

SMOOTH EXTERIOR PLYWOOD

PLYWOOD USED FOR CONCRETE FORMING SHOULD BE OF THE EXTERIOR TYPE FABRICATED WITH EXTERIOR GLUE. PANELS ARE AVAILABLE UNTREATED, MILL-OILED OR RESIN IMPREGNATED. IMPREGNATED PANELS DO NOT TRANSFER WOOD GRAIN.

FACE VENEER GRADES

A. SMOOTH PAINT GRADE SURFACE PERMITTING A NUMBER OF NEATLY MADE REPAIRS, PLUG OR PATCHES WITH CERTAIN RESTRICTIONS.

B. SOLID SURFACE VENEER, EXCEPT FOR SPECIFIED MINOR CHARACTERISTICS, MAY HAVE A CONSIDERABLE NUMBER OF NEATLY MADE REPAIRS AND IS SUITABLE FOR FORMWORK.

C. LOWEST QUALITY OF VENEER USED IN EXTERIOR PLYWOOD DEFECTS INCLUDE TIGHT KNOTS UP TO 1/2", KNOT HOLES UP TO 1 1/2" AND SPLIT UP TO 1/2" TAPERING TO A POINT. USUALLY UNACCEPTABLE FOR CONCRETE FORMWORK.

JOINT DETAILS

WHEN MODULAR FORMING MATERIALS SUCH AS PLYWOOD ARE USED AND THE SURFACE CAST IS LARGER THAN THE MODULE, CONSIDERATION MUST BE GIVEN TO TREATING THE JOINTS. IF THE SURFACE IS TO BE TREATED AFTER CASTING, BUTT JOINTS COVERED WITH JOINT TAPE ARE USUALLY SATISFACTORY. IN CASES WHERE A LIGHT ABRASIVE BLASTING IS THE ONLY TREATMENT, JOINT TAPE SHOULD BE AVOIDED IN LIEU OF A BETTER QUALITY JOINT. SMOOTH SURFACES WILL REQUIRE VERY TIGHT JOINTS WITHOUT OFFSETS. USE OF SPLINE JOINTS WITH COMPRESSIBLE FILLERS ARE RECOMMENDED. JOINTS MAY ALSO BE ARTICULATED BY THE SAME MEANS AS THOSE EMPLOYED IN LUMBER JOINTS.

TREATED SURFACES

1. BUTT JOINT

2. W/TAPE

3. W/COMPRESSIBLE FILLER

USE COMPRESSIBLE FILLERS WHEN ABRASIVE BLASTING (LIGHT)

4. SPLINE JOINT

5. MITERED JOINT

6. MILLED T&G JOINT

APPLICATION OF PLYWOOD IN FORMS

FACE GRAIN DIRECTION SHOULD ALWAYS BE PERPENDICULAR TO INITIAL SUPPORTS FOR GREATEST STRENGTH

GRAIN IN SHORT DIMENSION

GRAIN IN LONG DIMENSION

WEAKEST USE

INEFFICIENT USE OF MATERIAL

REQUIRES INCREASED NUMBER OF SUPPORTS OR USE OF THICKER PLYWOOD

TEXTURED PLYWOOD

PANELS HAVE A TENDENCY TO DELAMINATE AFTER FEW USES. SEAL SURFACES TO PREVENT SCABBING AND EXTEND LIFE.

SEVERAL TYPES OF TEXTURED PLYWOOD ARE AVAILABLE

GROOVED

KERFED

ROUGH SAWN

M D

77LT

MD

1 Milled T&G Joint

2 W/TAPE

3 W/COMPRESSIBLE FILLER

4 Spline Joint

5 Mitered Joint

6 Milled T&G Joint
<table>
<thead>
<tr>
<th>GRADES</th>
<th>AMERICAN PLYWOOD ASSOCIATION</th>
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<tbody>
<tr>
<td>MANUFACTURER:</td>
<td>&quot;STRUCTURAL I PLYFORM&quot; PLYWOOD</td>
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<tr>
<td>PRODUCT NAME &amp;</td>
<td>&quot;PLYFORM CLASS I&quot; PLYWOOD</td>
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<tr>
<td>DESCRIPTION:</td>
<td>&quot;PLYFORM CLASS II&quot; PLYWOOD</td>
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<td></td>
<td>&quot;HIGH DENSITY OVERLAID - HDO&quot;</td>
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PLYFORM IS AN EXTERIOR, SMOOTH SANDED PLYWOOD MILL-OILED FOR CONCRETE FORMING. ALL THREE GRADES MAY BE OBTAINED.

(HDO) PHENOLIC RESIN IMPPREGNATED FOR A HIGH DENSITY SMOOTH SURFACE. ALL "PLYFORM" PLYWOOD IS FACED WITH B-B GRADE VENEERS. EDGES ARE MILL-SEALED.

AVAILABLE SIZES
GRAIN IN LONG DIMENSION
MOST COMMONLY AVAILABLE IN 5/8" & 3/4" PANEL THICKNESSES (4'x8' SIZE)

REFERENCE:
"PLYWOOD FOR CONCRETE FORMING." AMERICAN PLYWOOD ASSOCIATION, 1971, 31 PP.
"FINNFORM" PLYWOOD

GRADE

MANUFACTURER: PLYWOOD AND DOOR MANUFACTURERS CORPORATION
PRODUCT NAME & DESCRIPTION: EXTERIOR FINLAND BIRCH "FINNFORM" PLYWOOD

"FINNFORM" IS PHENOLIC RESIN IMPREGNATED FOR A HIGH QUALITY SMOOTH SURFACE. EDGES ARE FACTORY SEALED. SURFACE FIGURE (GRAIN DIRECTION) IS INDICATED FOR STRUCTURAL USE ONLY - IT DOES NOT TRANSFER TO CONCRETE.

AVAILABLE SIZES

GRAIN IN SHORT DIMENSION
COMMONLY STOCKED

GRAIN IN LONG DIMENSION
MUST BE MILL ORDERED

LARGER PANELS AND SPECIAL SIZES ARE AVAILABLE ON MILL REQUEST

STRONGEST USE

MINIMUM BENDING RADII

BENDING ACROSS THE GRAIN

RADIUS (FT.)

AVAILABLE THICKNESSES

NUMBER OF PLYS

REFERENCE:
"RED FINNFORM PLYWOOD" PLYWOOD & DOOR MANUFACTURERS CORPORATION, 1977, 4 PP.
FINNISH PLYWOOD

GRADES

MANUFACTURER:
FINNISH PLYWOOD DEVELOPMENT ASSOCIATION

PRODUCT NAME:
BIRCH FACED "COMBI" PLYWOOD

PRODUCT DESCRIPTION:
"COMBI" - BIRCH FACES, INNER PLIES OF BIRCH & SOFTWOOD
"FINPLY" - ALL BIRCH, ADDITIONAL STRENGTH

BOTH PRODUCTS ARE PHENOLIC IMPREGNATED FOR A HIGH DENSITY SMOOTH SURFACE. EDGES ARE FACTORY SEALED. SURFACE FIGURE (GRAIN DIRECTION) IS INDICATED FOR STRUCTURAL USE ONLY—IT DOES NOT TRANSFER TO CONCRETE. PRECUT "FLOOR TO CEILING" PANELS CAN BE MANUFACTURED AND SHIPPED TO SPECIFIED DIMENSIONS. WHEN REQUIRED LONG GRAIN PANELS CAN BE PROVIDED WITH THE GRAIN RUNNING PARALLEL TO THE LONG PANEL DIMENSION.

AVAILABLE SIZES

<table>
<thead>
<tr>
<th>GRAIN IN SHORT DIMENSION</th>
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COMMONLY STOCKED

STANDARD MILL SIZES

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<tr>
<th>RADIUS (FT.)</th>
<th>NUMBER OF PLIES</th>
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<tr>
<td>14</td>
<td>5</td>
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<td>12</td>
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<td>17</td>
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MINIMUM BENDING RADII

BENDING ACROSS THE GRAIN

RADIUS (FT.)

14 12 10 8 6 4 2

AVAILABLE THICKNESSES

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<tr>
<th>NUMBER OF PLIES</th>
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<td>5</td>
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AVAILABILITY

THICKNESSES

REFERENCE:
STEEL FORMWORK

Steel forms may be of two general types, modular component systems and specially designed fabrications for single purpose use. Modular forms are of the proprietary type and are typically used in cast-in-place construction in forming walls, columns, and floors. Each system consists of a varying range of components with appropriate hardware for their assemblage. They are usually light in weight, manageable, and have a high reuse potential, rising from 100 uses with smooth formwork to over 200 uses with profiled steel. In most cases wall and column forms are total systems providing both form face and complete structural support. Modular forms are capable of adapting to most conditions although they cannot be considered completely flexible as with plywood. Tie holes are usually in predetermined locations and alterations involve considerable expense. Some manufacturers will fabricate special forms to satisfy conditions that their system cannot adapt to. If the use of steel is planned, it is essential to consult manufacturers on the onset, so that the design can evolve within the limitations of the proprietary system chosen.

Specially designed steel forms are commonly used in precast construction for special structural shapes and architectural wall panels. Fabrication of steel forms is initially very costly and reuse is an important factor in recovering this cost.

Steel forms are impervious and if properly protected from rusting, will produce concrete of good color uniformity. Caution should be observed, however, in that steel plate is manufactured by different rolling processes. Steel produced by each process will effect the appearance of concrete in different ways. When casting with white or light-colored cement, it is also important that the steel skin be pickled to remove mill scale and to prevent staining. The skin of steel forms should be thick enough to limit deflection between structural members; however, individual form panels are almost always reflected in the surface due to various problems associated with panel joints. Misalignment of panels due to damage or distortion is common, as is grout loss through improperly
matched joints. Joints should be gasketed or taped where possible or featured when the design or form system will allow such. Leakage will cause hydration discoloration and possible honeycombing. Welds should be carefully ground to match the adjacent surface and blued to prevent staining.

Nonabsorbent forms have a tendency to produce blemishes on smooth surfaces. Concrete cast against a vertical steel form will have more bugholes than if it were cast against an absorbent form. Proper use of release agents and adequate vibration will lessen their occurrence. Another blemish associated with smooth steel form faces is crazing, which is a network of fine surface cracks. Crazing is a result of the surface drying faster than the internal mass of concrete. Due to steel's poor insulating characteristics, it is advised that forms be protected when temperatures are critical.

Steel forms should be stripped as soon as practicable to prevent rusting and consequent staining. After stripping, all forms should be cleaned, oiled, and properly stored. Form oils should contain a rust inhibitor that is nonstaining.
STEEL FORMS

WALL FORMS

SMOOTH STEEL FACE FORM PANELS MAY BE USED HORIZONTALLY OR VERTICALLY. JOINTS ARE BUTTED AND SECURED WITH BOLTS. THIS SYSTEM DOES NOT REQUIRE WALERS EXCEPT WHERE VERY LARGE SECTIONS ARE BUILT-UP. TIE HOLES ARE IN PREDETERMINED LOCATIONS ON THE PERIMETER OF EACH PANEL. JOINTS SHOULD BE GASKETED FOR ARCHITECTURAL CONCRETE WORK.

COLUMN FORMS

STANDARD FORM

STANDARD COLUMN FORMS ARE AVAILABLE AS SECTIONALIZED COMPONENTS THAT ARE FABRICATED TO FORM COLUMNS OF VARYING DIAMETERS AND LENGTHS. COMBINATIONS OF FIVE STANDARD SECTION COMPONENTS ARE USED TO FORM EACH COLUMN DIAMETER. THE NUMBER OF SEAMS IN EACH SECTION VARIES ACCORDING TO THE DIAMETER OF THE COLUMN. FABRICATION MAY BE IN-SHOP OR ON-SITE. SECTIONS ARE BUTT JOINED AND CONNECTED BY JOINT STRIPS, SECURED BY METAL WEDGES. THIS SYSTEM INVOLVES A LARGE NUMBER OF PARTS TO FABRICATE A FORM WHICH RESULTS IN MANY SEAMS.

HEAVY DUTY FORM

HEAVY DUTY COLUMN FORMS ARE DESIGNED FOR USE IN FORMING LARGE COLUMNS WITH A MINIMUM NUMBER OF SEAMS. HALF-ROUND SECTIONS ARE BUTT JOINED AND ARE SECURED BY BOLTS.

REFERENCE:
"SONOCO PRODUCTS FOR CONCRETE CONSTRUCTION." SONOCO PRODUCTS COMPANY, 1974.
ONE-WAY RIBBED SLABS
REFLECTED CEILING PLANS

STRAIGHT
TAPERED

SECTIONAL FORMS
INTERMEDIATE FORMS
END CAP
TAPERED END CAP

DEPTH (IN.)

20
16
12
8
4

20'
30'

JOINT DETAILS
RAISED JOINT
RECESSED JOINT

RECEDED PLAN
ONE-HALF SECTION

STRAIGHT
TAPERED

ONE-PIECE FORMS

TYPICAL LENGTH 12'
SPLICED OR CUT TO SUIT SPAN LENGTH

DEPTH (IN.)

20
16
12
8
4

20'
30'

JOINT DETAILS
FLUSH JOINT
INTERMEDIATE SUPPORT
RECESSED JOINTS
CONTINUOUS SUPPORT

INTERMEDIATE
BEAM

DOME FORMS

MODULE

DEPTH (IN.)

14
12
10
8
6
4

10'
12'
24'

JOINT DETAILS
RECESSED JOINTS
FILLERS

W/BEAM
BEAMLESS

FILLERS
AVAILABLE IN ALL DEPTHS
OVERALL PLAN SIZE

20 x 20
20 x 26
20 x 30
26 x 36

REFERENCE:
"CECO CONCRETE FORMING SERVICES," THE CECO
CORPORATION, BULLETIN #4001-CC, 1976,
10 PP.
PLASTIC FORM MATERIALS

Plastic forming materials can be divided into three general categories: reinforced, unreinforced, and foamed and expanded. These materials are assuming a greater role in forming architectural concrete due to their almost unlimited formability and non-absorbent character. Plastics have also proved to be less expensive in many applications than other materials with similar surface characteristics. Plastic forms have good resistance to abrasion, require little cleaning, and are not subject to corrosion.

REINFORCED PLASTICS

Glass fiber reinforced plastics can be easily formed into intricate shapes capable of producing high quality surface finishes. They are widely used in shapes for forming columns, beams, and floor systems. Several standard proprietary shapes are available and some manufacturers will make up designs to order. Large, flat sections are used as liners for wall forms and the joints can be so designed that several sections can be sealed together on-site, with application of resin and glass fiber mat to produce seamless, smooth surfaces. Complex, low relief forms can be easily fabricated in plastic with accurate reproduction in the concrete.

Glass fiber forms may be compared to steel forms, in that they have a high initial cost which can only be recovered by many reuses. Due to their durability, most plastics can provide almost unlimited reuse depending on how they are handled. Again, as with steel forms, plastics can be site repaired at minimal cost.

The range of surface textures and patterns attainable in plastic are only limited by the material itself. Concrete finishes range from coarse textures to eggshell smoothness. As with other non-absorbent forms, concrete cast against plastic is subject to surface defects. Bugholes and crazing may occur unless proper care is exercised during placing and in curing. Smooth, highly-polished forming materials also have a tendency to produce aggregate transparency in

REFERENCE:
"FIBERGLASS REINFORCED PLASTIC FORMS."
PORTLAND CEMENT ASSOCIATION,
PUBLICATION NO. 15050.01A, 1965.
glazed concrete surfaces. Aggregate transparency is a mottled appearance with dark areas similar in shape to the coarse aggregate. This concrete which is very dense will effloresce slowly and eventually lighten in time.

Glass reinforced plastic is a combination of resin formulations reinforced with glass fibers. Basically the method of production involves impregnating the glass fibers with resin to which a catalyst and accelerator have been added for curing. Several resins are available, although polyester and epoxied resins have been found more suitable for concrete forms. The glass fiber material may be chopped fibers, strand mat, woven cloth, surface mat, or glass roving. Selected fillers may be added for coloring and abrasion resistance. The life of the form largely depends on the exterior resin coating remaining intact with the fibers beneath. The thickness of fiberglass forms generally varies from 3/16 to 5/8 in. depending on structural requirements and the amount of strength and stiffness provided by other reinforcing materials incorporated in the form. The normal thickness for wall forms is 3/8 in. while column forms usually are 1/2 in. thick. The structural requirements of a form and the number of intended reuses generally dictate its thickness. Due to the alkalinity of fresh Portland cement, it is advisable to use a release agent to prevent reaction (saponification) with polyester resins.

Repair of glass reinforced moulds involves sanding the damaged area and reapplying a fresh resin coating; however, in most instances forms cannot be readily repaired at the project site.

UNREINFORCED PLASTICS

Unreinforced plastics are available for use as form liners in thin sheets and films. They are relatively inexpensive and capable of accurately reproducing textured or profiled finishes. Flat surface liners are generally unreliable due to wrinkling and premature lifting. Selection of a glass reinforced plastic would be the better choice for this type of surface. The degree of pattern flexibility with plastics is somewhat limitless, and selection of
an appropriate material will depend on the pattern complexity and the number of intended reuses.

Depending on the material used, thickness of plastic liners may vary. Thin film can accurately reproduce fine textures and be easily stripped from the concrete, but because their strength is limited, they are easily damaged during placement and may distort when stripped. Difficulty has occurred in securing thin materials to form backings and in preventing leakage.

Thicker, more rigid plastics have proved more suitable for architectural concrete forming. They are sized in lightweight, manageable sheets that can be joined effectively and may be easily replaced in the event of damage without disrupting the entire form.

Several plastics of this type are now available as proprietary items in the form of liners and dome pans for slab construction. Their formability has certain limitations over films due to their thickness, but they have proved reliable for a great variety of textured and profiled surfaces with high reuse characteristics.

Unreinforced plastics used as form liners produce concrete with similar surface defects as reinforced plastics. Form faces with a mat finish can be used to reduce crazing and discoloration when a smooth finish is required. Excessive bugholes occurring in concrete with intricate shapes may severely damage their visual appearance. When selecting heavily-profiled liners, it is important that the concrete mix be designed so that it can be easily compacted in the form. Profiles should be sufficiently drafted to allow stripping without damage. Plastic liners are not subject to shrinkage and moisture movement, and can be butted together or heat welded and taped on the back. Attachment to the form backing is usually accomplished by pins, screws, and adhesives. Manufacturers' recommendations should be strictly adhered to regarding liner attachment.

Most plastic materials are thermoplastic and are molded by a vacuum forming process to produce liners that are smooth and uniform in color. The plastic thickness and the nature of the vacuum forming
process control the depth of profiles and the accuracy of imparted textures. Very fine textures may be lost in the production of moulds made with thicker sheets of plastic.

Unreinforced plastics that may be vacuum formed for use as concrete form liners include the following:

<table>
<thead>
<tr>
<th>TYPE</th>
<th>FORM IN WHICH SUPPLIED</th>
<th>PERFORMANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rigid PVC</td>
<td>Calendered sheet</td>
<td>Weathers better than polystyrene; low abrasion resistance; medium cost; more flexible than polystyrene</td>
</tr>
<tr>
<td>Polystyrene</td>
<td>Extruded sheet</td>
<td>Poor weathering; wears better than PVC; cheaper than rigid PVC or ABS</td>
</tr>
<tr>
<td>ABS</td>
<td>Extruded sheet</td>
<td>Best impact strength; most expensive</td>
</tr>
<tr>
<td>Polyethylene</td>
<td>Extruded film and sheet</td>
<td>Poor wear; tends to wrinkle; low cost; easily stripped</td>
</tr>
<tr>
<td>Polypropylene</td>
<td>Extruded film and sheet</td>
<td>Stiffer than polyethylene; less likely to wrinkle</td>
</tr>
</tbody>
</table>

Various vinyl resins are available for use as form liners and are fabricated by a liquid process. Molten resins are poured over mould forms consisting of the desired shape to be imparted. Vinyl resins are usually pliable enough to permit undercuts and returns to be cast in one piece.

Plastic form liners should be stripped as soon as the concrete has gained sufficient strength to prevent possible bonding. Most plastic liners are easily cleaned and have excellent reuse characteristics. Damaged panels are usually replaced, vinyl liners can be remelted and recast.
FOAMED AND EXPANDED PLASTICS

Foamed and expanded plastics fall into a category of plastics that are commonly thought of in terms of their sculptural moldability and insulating characteristics. The foam plastics are porous and result from the controlled foaming action of two different constituents. Expanded plastics are by contrast very dense and are produced by containing polymers induced into rapid expansion. The density of both materials can easily be controlled. Both of these materials are readily available in plank form for use in forming high relief sculptural shapes. They are relatively inexpensive and can be used only one time. They are commonly employed in forming deep or re-entrant recesses where removal is accomplished by destructive means of heat, chemical, or mechanical processes. Blockouts in beams and walls are typical applications. Foamed and expanded plastics are also used as back support for vacuum-formed plastic liners to prevent deformation.

Special concerns in the use of foamed and expanded plastic must be given to their molding and handling. Shapes are specially designed for each use and in most cases molded by hand. They are, however, easily sculpted or profiled with simple cutting tools or softened with heat. Various patterns are usually attached to back-up forms with special adhesives. Joints between panels are easily sealed with plaster of paris or similar proprietary compounds. Care must be exercised in placing and vibrating of the concrete to prevent damage to the moulds. Adequate consolidation and compaction of the concrete is essential especially in deep relief patterns.

Foamed and expanded plastic linings are practically impermeable and produce concrete of uniform color; however, bugholes are a common occurrence due to their rough surface texture. A final appearance of the concrete will be governed by the quality of mould and the character of the sculptural effect. As with other sculptural surfaces formed by various means, weathering should be a consideration that is incorporated into the design.
The following foamed and expanded plastics have proved useful in concrete forming:

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expanded polystyrene</td>
<td>White rigid material formed by fusion of expanded beads of polystyrene. Also obtainable in precompressed form which is more flexible and resilient, and in granular form as unfused expanded beads.</td>
</tr>
<tr>
<td>Extruded expanded polystyrene</td>
<td>White or light-colored material formed by a simultaneous extrusion and foaming process</td>
</tr>
<tr>
<td>Expanded polyvinyl chloride (PVC)</td>
<td>Yellow to deep brown rigid material, formed by foaming pvc when in a plastic state, and cooling to solidify</td>
</tr>
<tr>
<td>Foamed urea-formaldehyde (UF) resins</td>
<td>White friable material, usually formed by foaming an aqueous dispersion of resin and curing it in this condition</td>
</tr>
<tr>
<td>Foamed phenol-formaldehyde (PF) resin (phenolic foam)</td>
<td>Pink or deep red rigid material, somewhat friable, made by foaming and subsequently curing phenolic resin</td>
</tr>
<tr>
<td>Foamed polyurethane (urethane foam)</td>
<td>Colorless to deep brown material, sometimes artificially colored. Prepared from two liquid components which are sometimes pre-expanded before complete chemical interaction and curing occurs</td>
</tr>
<tr>
<td>Expanded ebonite</td>
<td>Deep brown or black rigid materials, which usually have a surface rigid skin</td>
</tr>
</tbody>
</table>

These plastics are usually left in position after casting of concrete. This is done to aid in the curing and to provide protection for the surface during subsequent stages of work. Expanded plastics are usually removed by abrasive blasting while foamed plastics can be easily removed by wire brushing.
PLASTIC FORM LINERS
SELECTED STANDARD SAMPLES

TRAPEZOIDAL RIB

STRIATED

GROOVED & RANDOM BOARD

BOARD FORM

ROUGH SAWN

RAISED GRAIN

These liners are usually available in either unreinforced or reinforced plastics. Reinforced liners are commonly known as either fiberglass reinforced plastic or GRP. Reinforced plastic liners are either rigid or flexible thermoplastics. Rigid plastics are usually available in strong durable sheets. Flexible plastics, also known as elastomers, are available in varying thicknesses depending on their profile. Rigid plastics are usually lighter in weight than flexible plastics. Individual manufacturers should be consulted for further information on the plastic materials used in their liners and on other available liner faces.

REFERENCE:
"A FLEX-LINER CONCRETE SURFACE," STYRO MATERIALS CO., DENVER, COLORADO.
FORM LINER DETAILS

MATERIALS
LINER SIZES:
VARYING ACCORDING TO SURFACE
PANELS USUALLY 4' x 10'
STRIPS 12" WIDE, B'W" LONG,
SPECIAL TO 24'
SHEETS - SMOOTH GRP TO 8' x 40'
LINER BACKUPS:
PLYWOOD, BOARDING, STEEL
LINERS PROVIDE NO STRUCTURAL SUPPORT
METHOD OF ATTACHMENT: STAPLES, NAILS
ADHESIVES, SHEET METAL SCREWS
JOINT SEALANTS: THIN VINYL TAPE,
PLASTIC FOAM TAPE, ELASTIC CAULKING
FORM LINERS MUST BE SEALED AT ALL
ENDS, EDGES, JOINTS, CORNERS AND TIE
HOLES TO PREVENT SAND STREAKING,
DISCOLORATION AND FINS ON THE CON-
CRETE SURFACE. IT IS ADVISED TO IN-
STALL PLASTIC FORM LINERS UNDER WARM
CONDITIONS TO AVOID BUCKLING CAUSED
BY THE HIGH RATE OF THERMAL EXPAN-
SION. A 10' LONG PLASTIC LINER WILL
EXPAND APPROXIMATELY .006" PER °F
TEMPERATURE INCREASE.

SHALLOW PROFILE JOINTS
END CONDITION
RUSTICATION
CAULK OR TAPE JOINT
USE WHEN LINES
CANNOT BE JOINED
ATTACHED WITH
FOAM TAPE
SEAL WITH
CONTACT CEMENT
OCCURS AT
cus IN CONSTRUCTION JOINTS
SECOND LIFT
GASKET JOINT
TAPE OR TAPE JOINT
TAPE OR CAULK JOINT
DO NOT ATTACH LINER TO WOOD CORNER BLOCK

OUTSIDE CORNER DETAILS
LOW PROFILE LINERS
LINER WELL COMPRESSED BY RUSTICATION
LINER MAY BUNCH OR RIPPLE
TAPE JOINT BETWEEN BLOCK AND LINER
USE FOAM TAPE AT JOINT CORNER

REFERENCE:
"A PLASTIC FORM LINER CONCRETE SURFACE."
SYMONS CORPORATION, PUBLICATION NO.
COLUMN FORMS
4-PC. RECTILINEAR
STANDARD CONFIGURATIONS

ROUND CAPITAL FORM

COLUMN CAPITALS ARE USED WHERE VERY LARGE FLOOR LOADS MUST BE TRANSFERRED TO COLUMNS. CAPITAL FORMS ARE COMMONLY AVAILABLE IN BOTH PLASTIC AND STEEL. CAPITALS OF SIMILAR SIZES MENTIONED ARE ALSO AVAILABLE FOR SQUARE COLUMNS (ROUND CAPITAL TO SQUARE COLUMN). SOME MANUFACTURERS WILL FABRICATE CAPITALS TO ADAPT TO SPECIAL PROJECT REQUIREMENTS.

ROUND SPRINGFORM

FORM REMOVAL

FORM IS SPRUNG OPEN AND REMOVED FROM AROUND CAST COLUMN

CARE MUST BE TAKEN DURING REMOVAL TO PREVENT DAMAGE TO 'GREEN CONCRETE'

VERTICAL JOINTS

LOCATION OF RUSTICATIONS OR KEYWAYS MUST BE AT OR OPPOSITE THE SPRINGFORM JOINT

REFERENCE:
"CECO CONCRETE FORMING SERVICES," THE CECO CORPORATION, BULLETIN 4001-CC.
"SONOCO PRODUCTS FOR CONCRETE CONSTRUCTION," SONOCO PRODUCTS COMPANY, 1974.

FLOOR FORMING SYSTEMS

DOME FORMS

CONSTRUCTION DETAILS

END CONDITION

TYPICAL CONSTRUCTION JOINT

CONSTRUCTION JOINT VICE JOIST

JOINT DETAILS

FLUSH JOINT

RECESSED JOINT

RAISED JOINT

PAN FORMS

ALL THE VARIOUS PAN LENGTHS ARE AVAILABLE IN WIDTHS AND DEPTHS MENTIONED AT THE LEFT. THE 3" END FLANGE IS CONSTANT AND MAY BE TRIMMED TO VARY SPAN LENGTH. LENGTH GREATER THAN 15' IS AVAILABLE ON SPECIAL ORDER; HOWEVER, IT IS RECOMMENDED THAT STANDARD SIZES BE UTILIZED WITH CROSS JOISTS. PAN FORMS ARE AVAILABLE WITH ONE END TAPERED UP TO 4'6".

BEAM FORMS

STRAIGHT

BEAM SYSTEMS ARE AVAILABLE WITH BEAM TO COLUMN CONNECTORS FOR CONTINUOUS COLUMN TO COLUMN FORMING. BEAM FORMS ARE ONE PIECE, NON-TAPERED, STRAIGHT SIDED, SECTIONS. BEAM FORMS ARE ALSO AVAILABLE (CUSTOM-BUILT) HAUCHED, CURVED AND CAMBERED. CONSULT INDIVIDUAL MANUFACTURERS FOR SPECIFICATIONS ON AVAILABLE SYSTEMS.

STAGING

REFERENCE


"SONOCO PRODUCTS FOR CONCRETE CONSTRUCTION." SONOCO PRODUCTS COMPANY, 1974.
RUBBER AND NEOPRENE FORM MATERIALS

Rubber and neoprene are well-known materials used in forming keyways, waterstops, and roughened surfaces. Non-architectural surfaces are often roughened to improve bonding between concrete and applied surfaces.

For architectural applications rubber and neoprene are molded into sheets and solid extrusions for lining forms; however, they have seen little use as a result of the limitations imposed on the designer by having to select from the manufacturers' stock items. If the demand for a new pattern is large enough some manufacturers will fabricate a master mould for production. Unfortunately, this becomes a major expense for the manufacturer and as a result, it is seldom done. These linings by comparison to other form liners are relatively expensive. When only small amounts of sheeting are needed it is sometimes economical to use less durable latex rubber linings.

Liners used for vertical surfaces are glued or mechanically fastened to the form backing depending on their weight and size. The method of attachment may imprint the concrete depending on the liner texture used. Use of rustication strips at joints is advisable as preventing leakage through butt joints can be difficult. Rubber and neoprene linings should be handled carefully and protected from damage during use and storage. Certain types of rubbers are subject to deterioration by ultraviolet rays and should be stored out of direct sunlight.

Sheet linings may be used for textured and low profiled surfaces of low relief. They are usually very thin, but their thickness is dependent upon the depth of the surface figure and the overall size of the sheet. Care should be exercised with thin sections as they may wrinkle during placement and tear when stripped. Rigid, thicker liners have proved more reliable. Some manufacturers will laminate
their linings to plywood for this reason. Close or intricate patterns should be avoided as they have a greater tendency to form bugholes. The size of form liners vary with each manufacturer and with each surface texture, but the average range is between 10 and 40 square feet of area. There are exceptions; however, as some liners as large as 12 x 40 feet are available on special order. With proper care most linings will last through 30 or more uses.

The application of release agents to rubber and neoprene linings is recommended; however, excessive application may result in staining of the concrete. Manufacturers' recommendations should be followed as the use of certain release agents may damage some linings. Mineral oil must not be used on rubber linings for this reason.

The use of rubber in neoprene linings is advantageous from the standpoint of concrete placement in that they are less subject to damage by vibrators and placing equipment. Linings should be stripped as soon as practicable to prevent them from losing their resiliency and making removal difficult. Forms should be removed with care to prevent tearing of the lining and spalling of the concrete.
FIBROUS FORM MATERIALS

Fibrous materials used in forming architectural concrete generally include various pressed and tempered hardboard and laminated fiber materials. These materials are absorbative and used to obtain smooth surfaces free from bugholes. Their use is characteristically limited to one application, although some types may provide more. Fibrous materials tend to swell and become soft after a few uses and exposure to weathering. As with all absorbative form materials, color uniformity is difficult to control. This results from variation in surface absorbency and variations in concrete pressure on the form face, depending on the distance from the top of the lift. The best results are achieved when fibrous surfaces are coated with sealers such as wax. If well coated, these materials may be used to produce smooth surfaces, textures, or light profiles such as fluting without color irregularities.

Standard and oil-tempered hardboard is used primarily in wall forms and in precast forming. Standard hardboards are the most absorbent and variations will appear within sheet surfaces as well as from sheet to sheet. Oil-tempered hardboards are more dense, less absorbent, and may be expected to last through two or more uses.

Hardboards should be well coated with sealers as they have a tendency to discolor concrete. Hardboards have proved very useful in precast plants that use surface retarders for exposed aggregate finishes. Absorbent materials give a more uniform spread to the retarder and are also easier to clean. Precasters have also reported use of hardboards as cutouts for low relief patterns.

Where hardboard panels are going to be joined for only one use, joint treatment is not critical as long as the panels are properly aligned and carefully butted. If several uses are planned, the joints should be sealed; however, in all cases to avoid variations especially in color, it is advised that joints be kept to a minimum or featured.
Laminated fiber materials are available for the use of forming round columns and voids in floor systems. Column forms are spirally constructed of laminated plies of fiber. These materials are very absorbent and must be protected from weathering prior to use. Fiber column forms are used to produce uniform surfaces without joint lines. Two types of fiber forms are commonly used: one that imparts the effect of being spirally constructed, and one that produces a smooth, uniform surface. The standard form is coated with polyethylene plastic and mechanically perforated to insure uniform absorption. The smooth form has several inner laminant layers specially constructed to minimize the spiral effect and allow uniform absorption. Both of these forms are wax sealed on the outside to prevent weathering and penetration of moisture.

Care should be exercised in placing these forms over reinforcing steel so as not to mar their inner surface. Use of manufacturer recommended release agents is advised to facilitate form removal. Fibrous forms should be stripped as soon as the concrete has set to prevent discoloration. Column forms cannot be removed without damage and as a result are used only once. Some of the advantages of fibrous form materials are: they can be readily cut to adapt to other forming systems, they are relatively inexpensive, and they minimize stripping and clean-up time.

Various fibrous materials are available in different shapes for forming voids and floor slabs. These materials are cast-in-place and cannot be removed. In many cases they are specially treated to serve a secondary purpose in the concrete such as heat ducts (with foil linings).
FIBROUS FORMS

HARDBOARD PANELS

Hardboard is a panel manufactured primarily from inter-felted ligno-cellulosic fibers which are consolidated under heat and pressure in a hot press to a density of 31 lbs./cu. ft. or greater. Tempered panels are impregnated with oils (tung, linseed, soybean) and then heated to 3000 F in a kiln to complete a polymerization process. Tempered panels have increased strength and reduced moisture absorption characteristics. Tempered and standard panels are available surfaced both sides or only one side. Panels surfaced on both sides have a greater moisture absorbency. Smooth surfaces are free from visible variations in the surface plane. Moisture absorbency is relatively uniform over the panel surface.

COLUMN FORMS

STANDARD LENGTH

6" TO 48" DIAMETERS

2" INTERVALS

6" TO 48" DIAMETERS

4" X 8" PANEL IS MOST READILY AVAILABLE

SEAMLESS

STANDARD WALL FORM

SPIRAL GAPS OR SEAMS ARE MINIMIZED

OUTLINE OF SPIRAIIY CONSTRUCTED

LAMINATIONS WILL TRANSFER TO

CONCRETE SURFACE

LIGHT WALL FORM

FOR CONSTRUCTION OF COLUMNS NOT

EXCEEDING 10' IN HEIGHT

FORM STRIPPING

RELIABLE RELEASE AGENTS WILL ASSURE

EASY REMOVAL. FORMS SHOULD BE

STRIPPED AFTER THE CONCRETE HAS SET.

TO STRIP, SET A POWER SAW BLADE TO

JUST LESS THAN THE THICKNESS OF FORM

AND MAKE A VERTICAL CUT. ANY SHARP

BLADE WILL THEN CUT INNERMOST LINING.

COMPLETE REMOVAL OF FORM WITH

ANY BROAD-BLADED TOOL. FORMS MAY ALSO

BE STRIPPED BY UNWINDING. RECOMMENDED STRIPPING TIME FOR EASIER

REMOVAL IS 48 TO 72 HOURS AFTER

POURING. TO PROTECT COLUMNS DURING

CONSTRUCTION, STRIP FORMS, THEN

REPLACE AND HOLD IN PLACE WITH

TEMPORARY FASTENING.

REFERENCE:
"ALTON SLEEK TUBES, VOROS, DUCTS, "
ALTON BUILDING PRODUCTS, ALTON,
ILLINOIS.

PANSHIN, A. J., E. S. HARRAR, J. S. BETHEL,
"FOREST PRODUCTS," McGRAW-HILL
BOOK COMPANY, INC., 1962.

"SONOCO PRODUCTS FOR CONCRETE CONSTRUCTION, "
SONOCO PRODUCTS COMPANY, 1974.
"TODAY'S HARDBOARD, " AMERICAN HARDBOARD
ASSOCIATION, FORM NO. 400112,
Precast products are classified according to their demoulding process as either immediate or delayed. Immediate demoulding of products is done as soon as the compaction process is completed. The compaction process involves various applications of compacting force by means of spinning, vibrating, pressing, tamping, or combinations of any two of these. In most cases, demoulding involves extruding the concrete unit from the mold. If green strength is not high enough upon extrusion part of the mold may remain for support. Green strength should be sufficiently high to facilitate movement of the product without affecting the accuracy of the section.

Delayed demoulding involves removal of the products only after they have developed a high degree of strength. These products are cast in conventional horizontal and vertical positions. Because of better quality control conditions curing of these products can be accelerated by the following means: use of early strength mixes, preheating of the mix, and heating of the forms with steam, heat, or hot air. Demoulding can be accomplished in one-day cycles for most products. Delayed demoulding processes usually allow for a wider range of finishing techniques to be used. For this reason, architectural concrete products are usually fabricated in this way.

**HORIZONTAL CASTING**

**FACE UP**
FINISH SURFACE IS COMPLETED AFTER THE CONCRETE IS PLACED

ADVANTAGES: WIDE RANGE OF POSSIBLE FINISHES; EASE IN POSITIONING REINFORCEMENT, INSULATION AND SIMILAR ELEMENTS; GREATER CONTROL OVER FINISHING TREATMENTS—ONLY PRACTICAL METHOD OF MAKING SANDWICH PANELS

**FACE DOWN**
FINISH SURFACE IS EXPOSED AFTER THE MOULD IS REMOVED
MOST COMMON METHOD OF CASTING ARCHITECTURAL CONCRETE

**VERTICAL CASTING**

**SINGLE UNIT**

VERTICAL CASTING IS BEST SUITED FOR UNITS HAVING BOTH FACES SMOOTH

ADVANTAGES: LESS AREA TO HAND TROWEL, EASIER HANDLING ARRANGEMENT, MINIMAL REINFORCING IS NEEDED, BETTER CONTROL OF UNIT THICKNESSES, ADVANTAGEOUS FOR HEAT CURING, REQUIRES LESS FACTORY FLOOR SPACE

REFERENCE:
GAGE, MICHAEL. "GUIDE TO EXPOSED CONCRETE FINISHES." CEMENT AND CONCRETE ASSOCIATION, 1970, 158 PP.
CAST-IN-PLACE FORMING METHODS

STATIONARY DECK FORMS

COMPONENTS

DECKING - MAY BE RESIN IMPREGNATED PLYWOOD FOR A HIGH QUALITY FLAT SLAB, OR CONSTRUCTION GRADE PLYWOOD, IF FOR A RIBBED SLAB (DOMES OR PANS).

JOIST - MAY BE TIMBER OR STEEL, SPACED EVENLY TO PREVENT DEFLECTION OF DECKING. NOTE: CORRUGATED STEEL MAY BE USED IN PLACE OF JOISTS.

STRINGER - MAY BE TIMBER OR STEEL, SPACED EVENLY TO PREVENT DEFLECTION OF JOIST.

VERTICAL SHORE - ELEVATES OR LOWERS IN FINE INCREMENTS TO MEET HEIGHT AND ALIGNMENT REQUIREMENTS. SHORES COMMONLY AVAILABLE IN 10000 AND 15000 LBS/LEG CAPACITIES MUST BE SPACED TO SUPPORT THE LOADS OF THE CONCRETE, WORKMEN, EQUIPMENT & WIND.

FLOOR BEAM - DISTRIBUTES TOTAL IMPOSED LOAD INTO SURFACE BELOW.

MOBILE DECK FORMS

DECK PALLET AND SHORING

LIGHTWEIGHT SYSTEMS OF GANGED FORMS (AREA TO 2000 SQ. FT.) ALLOWS FOR A HIGH QUALITY FLAT SLAB, OR CONSTRUCTION GRADE PLYWOOD, IF FOR A RIBBED SLAB (DOMES OR PANS).

DECK PALLET ONLY

MOBILE DECK FORMS

DECK FORM SUPPORTS

ADJUSTABLE STEEL JOIST

LIGHTWEIGHT ADJUSTABLE JOISTS ELIMINATES LUMBER REQUIREMENTS AND DUE TO THEIR SPAN CAPABILITIES FEWER BEAMS ARE NEEDED. ERECTION AND STRIPPING TIME AS WELL AS LABOR NEEDS ARE REDUCED.

SOME TYPES MAY BE CANTILEVERED

AVAILABLE IN SIZES RANGING 4' - 20'

DECK PALLET BRACKETS

ROLLING SHORE BRACKETS ARE TEMPORARILY MOUNTED TO COLUMNS OR WALLS BY BOLTS. THE BRACKETS ARE ADJUSTABLE FOR MAINTAINING ALIGNMENT.

REFERENCE:
"ADVANCE SHORING," BEAVER-ADVANCE CORPORATION, PUBLICATION NO. 679-10M-175-SP.


"SYMONS CONCRETE FORMING SYSTEMS." SYMONS CORPORATION, PUBLICATION NO. 75-13, 1975.
Square and rectangular columns can also be formed by the three methods described for forming vertical surfaces. Round columns are typically formed by using fiberglass springforms and fibrous forms. Sectional steel forms are another alternative; however, they are not recommended for use with architectural concrete. Liners may be used in any of the column forms described.
CAST-IN-PLACE FORMING METHODS

WALL FORMS

VERTICAL STUD - HORIZONTAL WALER

HORIZONTAL STUD - VERTICAL WALER

POSITIONING OF THE FORM FACE PANEL USUALLY DICTATES THE SYSTEM USED

CONVENTIONAL WOOD FORMING SYSTEM

COMPONENTS

- SHEATHING
  - MAY SERVE AS ACTUAL FORM FACING MATERIAL OR AS A BACKUP FOR A LINER. LIMIT DEFLECTION TO 1/360 OF MEMBER SPAN FOR ARCHITECTURAL CONCRETE.

- FORM LINER
  - IMPARTS TEXTURE TO EXPOSED CONCRETE SURFACE AND SERVES AS AN ENVELOPE TO CONTAIN FRESH CONCRETE - MUST BE WATERTIGHT.

- INSIDE FACE
  - #8-8 GRADE PLYWOOD UNLESS FACE IS EXPOSED. MUST BE WATERTIGHT.

- TIE ROD
  - ACTS IN TENSION TO CARRY LOAD IMPOSED BY CONCRETE. SPACE UNIFORMILY TO PREVENT DEFLECTION OF WALERS.

- WALER
  - MAY BE OF TIMBER OR STEEL SPACED EVENLY TO PREVENT DEFLECTION OF STUDS.

- STUD
  - MAY BE OF TIMBER OR STEEL SPACED EVENLY TO PREVENT DEFLECTION OF FORM LINING.

- STRONG-BACK
  - USED WHEN SYSTEM IS VERY LARGE OR GANGED. MAY BE OF WOOD OR STEEL.

STEEL FRAMES WITH PLYWOOD PANELS

- MODULAR STEEL FRAME
  - ERECTED HORIZONTALLY OR VERTICALLY

- CONNECTIONS ARE PINNED TOGETHER TO ALLOW RAPID ERECTION AND STRIPING

- TIE ROD - LOCATED WHERE NEEDED

- WALER - SINGLE OR DOUBLE

- PLYWOOD INFILL PANEL

ALL STEEL PANELS

- BOLTED CONNECTION

- TIE ROD - LOCATION IS USUALLY DICTATED BY THE FORM SYSTEM

- MODULAR STEEL FORM PANEL - SMOOTH STEEL FACE. HEAVY DUTY SYSTEM REQUIRES FEWER TIES
WALL FORM CONSTRUCTION DETAILS

HORIZONTAL CONSTRUCTION JOINT

FIRST PLACEMENT
FORM MAY BE FLUSH OR EXTEND ABOVE RUSTICATION STRIP

SECOND PLACEMENT

CLAMP FOAMED SEALING STRIP BETWEEN RUSTICATION AND HARDENED CONCRETE

PARAPET
SLOPE PARAPET AWAY FROM FACE AND STEEL TROWEL TOP SURFACE. FRONT EDGE OF PARAPET MAY BE LEFT SHARP OR BEVELED. WHEN THE FORM EXTENDS ABOVE THE CONCRETE CARE MUST BE TAKEN TO OBTAIN A STRAIGHT EDGE.

VERTICAL CONSTRUCTION JOINT

FIRST PLACEMENT
FORM TIE

SECOND PLACEMENT
EXTEND FORMWORK PAST JOINT TO NEXT TIE POSITION

STOP END DETAIL
CHAMFERS ARE NOT REQUIRED

CORNER JOINT
TYPICAL METHOD

ALTERNATIVE
FORM TIE COMPRESSES JOINT. SEAL JOINTS WITH COMPRESSIBLE GASKETS, CAULKING OR JOINT TAPE

PANEL JOINT
SINGLE STUD

DOUBLE STUD - SPLINE JOINTS ONLY

SLOPED SURFACE FORMS
DESIGN SLOPED FORM SECTION SO THAT IT CAN BE REMOVED FROM THE MAIN BODY OF THE FORM AFTER CASTING (1-2 HR.) TO ALLOW STEEL TROWELING - AIR BUBBLES COLLECT OTHERWISE.

SLOPED SURFACES REQUIRE A GREAT DEAL OF LABOR TO FINISH PROPERLY.
FORM TIES

TIE CLASSIFICATION

FORM TIES (TIE RODS, TIE BOLTS) ARE CLASSIFIED BY THEIR USE AND THEIR LOAD-CARRYING CAPACITY. BY USE, TIES ARE GROUPED AS THROUGH TIES, HE-BOLTS, AND SHE-BOLTS. EACH TYPE IS DESIGNED FOR VARYING FORM CONDITIONS AND EACH WILL HAVE A DIFFERENT EFFECT ON THE FINISHED SURFACE. TIE STRENGTH WILL DEPEND ON THE FORM STRENGTH, TIE SPACING, RATE OF POUR, AND AN APPROPRIATE SAFETY FACTOR.

TIE STRENGTH DEPENDS ON THE STRENGTH OF THE FORM, TIE STRENGTH OF FORMWORK BEING CONSTRUCTED.

SAFETY FACTOR CLASS

<table>
<thead>
<tr>
<th>GRADE</th>
<th>USE</th>
<th>CARRYING CAPACITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5</td>
<td>LIGHT FORMWORK OR UNUSUALLY HAZARDOUS CONDITIONS</td>
<td>DUTY USE STRENGTH &lt; 5000</td>
</tr>
<tr>
<td>2.0</td>
<td>HEAVY FORMWORK</td>
<td>MEDIUM 5000 TO 12000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HEAVY &gt; 12000</td>
</tr>
</tbody>
</table>

SNAP-TIE

SNAP TIE BACK BREAKS: WITHOUT CONE 1/4", 1/2"; WITH CONE 1", 1 1/2", 2", LIGHT USE-STRENGTH OF 3000 AND 5000 LBS. (1.25 S.F.)

MAIN BODY OF TIE REMAINS WITHIN THE WALL. TIE ENDS ARE SNAPED OFF AFTER FORM REMOVAL. SPREADER WASHERS ARE PRECISELY LOCATED TO GIVE EXACT WALL THICKNESSES. SNAP TIES ARE INEXPENSIVE AND MAY BE USED WITH CONES. THIS TIE IS NOT RECOMMENDED FOR ARCHITECTURAL CONCRETE—SPREADER WASHING IMPRINTS CONCRETE.

SHE-BOLT TIE

SHE-BOLT DIAMETERS 3/8" TO 1 5/8" IN 1/8" INTERVALS. ALL DUTY USE-STRENGTH RANGE 4800 TO 48000 LBS. (1.5 S.F.)

THREADED ROD REMAINS WITHIN THE WALL. TIE ASSEMBLY MAY BE FED THROUGH FORM AFTER BOTH SIDES HAVE BEEN ERECTED. SYSTEM CAN BE USED TO REANCHOR FORMS. SHE-BOLTS CAN BE USED FOR VARYING FORM WIDTHS. HOWEVER, THEY DO NOT HAVE A POSITIVE SPREADER FEATURE.

HE-BOLT TIE

HE-BOLT DIAMETER 1/4" TO 1 1/4", MEDIUM AND HEAVY DUTY USE-STRENGTH RANGE 6000 TO 36000 LBS. (1.5 S.F.)

COIL TIE REMAINS WITHIN THE WALL. THIS SYSTEM CAN BE USED TO REANCHOR FORMS. DURING FORM CONSTRUCTION THE TIE CAN BE POSITIVELY ATTACHED TO ONE SIDE OF THE FORM PREVENTING REINFORCEMENT FROM COVERING THE TIE HOLE. SYSTEM MAY BE USED WITH OR WITHOUT CONES. THIS SYSTEM HAS A HIGH INITIAL COST FOR EXTERNAL HARDWARE.

REFERENCE:

RICHMOND SCREW ANCHOR COMPANY., INC., BULLETIN NOS. 1, 2, 10. BROOKLYN, N.Y.
TIE SPACING MUST BE SUCH THAT FORM DEFLECTIONS ARE KEPT WITHIN ACCEPTABLE LIMITS. TIE STRENGTH, FORM STRENGTH AND CASTING RATE WILL AFFECT TIE SPACING. COMMON TIE LOCATIONS FOR PLYWOOD PANELS ARE INDICATED AT THE RIGHT. IN CASES WHERE VERY LARGE POURS ARE INCURRED THE SPACING OF TIES MAY BE CLOSER AT THE BOTTOM OF THE PANEL THAN AT THE TOP.

TREATMENT OF TIE HOLES WILL DEPEND ON THE TYPE OF TIE USED AND THE ARCHITECTURAL EXPRESSION DESIRED. SNAP TIES WITHOUT BACKBREAKS AND PENCIL ROD TIES REQUIRE THE CONCRETE TO BE CHISELED BACK BEFORE BEING CUT OFF, REPAIR IS EXPENSIVE. TAPER TIES AND SHE-BOLT TIES LEAVE A HOLE RELATIVELY CLEAN.

TIE HOLES MAY BE LEFT AS-CAST IF STAINLESS STEEL TIES ARE USED TO PREVENT RUSTING. IN MOST CASES TIE HOLES ARE FILLED WITH GROUT OR PLUGGED. IT IS RECOMMENDED THAT TIES LEAVE NO METAL CLOSER THAN 1 1/2" FROM THE FINISHED SURFACE.

SNAP-TIES CONES

CONE DIAMETERS
INSIDE 5/8" - 1"
OUTSIDE 3/4" - 1 1/2"

CONES ARE AVAILABLE IN WOOD OR PLASTIC

TIE HOLES TREATMENT

FLUSH, FILLED WITH GROUT

RECESSED

DEEP RECESS - UNTREATED

REVEALED

USE STAINLESS STEEL TIES

USE TAPER OR SHE-BOLT TIES FOR ACUTE ANGLES

REFERENCE:
"ACCESSORIES FOR CONCRETE CONSTRUCTION," DAYTON SURE-GRIP & SHORE COMPANY, CATALOG NO. 4-76B.
"CONCRETE FORMING SUPPLIES," ELLIS CONSTRUCTION SPECIALTIES, LTD.

TYPICAL TIE LOCATIONS FOR PLYWOOD

1/2 OR 3/4 PLYWOOD - 4'x8'

1/2 PLYWOOD ONLY

MANY CONTRACTORS PREFER USING 5/8" PLYWOOD, IN WHICH CASE THE TIE LOCATIONS SHOWN IN THE CENTER PANEL ARE MOST COMMON. HOWEVER, THE SAVINGS IN COST OF 5/8" PLYWOOD OVER 3/4" PLYWOOD IS NOT NEARLY AS GREAT AS THAT EFFECTED BY USING 3/4" PLYWOOD WITH LESS TIES NEEDED. IN ADDITION 3/4" PANELS ARE STRONGER AND LAST LONGER.
FORM REMOVAL

Removal of formwork for architectural concrete should be well scheduled to avoid variations in the color of the resulting surface. Different colors can be expected between two surfaces where the adjacent formwork is stripped at different maturities. It is important to understand the use of the term "maturity" in relation to concrete. Maturity is a product of the age, from time of placement of the concrete and its curing temperature. Therefore, two surfaces that are stripped at the same time may be different in color if one has cured faster as a result of increased temperature. This condition may exist on different faces of a building with varying exposures in which case color variations would be unnoticeable. This color difference would become less apparent as the concrete in both surfaces age. What is important is to maintain a degree of consistency in all procedures and since it is difficult to adequately evaluate curing it is recommended that stripping on the basis of age be the controlling factor.

After forms have been stripped they should be immediately cleaned and properly stored. Cleaning should be carefully done so as not to damage the form face and prevent reuse. Striking form surfaces with a hammer or scraping with metal objects to remove scale must be prohibited. Workmen should be advised as to proper procedures. After cleaning, surfaces should be lightly coated with an appropriate release agent whether they are to be used again or stored. Wood forms may have to be resealed after cleaning. Forms should be stored face-to-face and back-to-back to avoid damage to the form surface. If stored outdoors, forms should be slightly inclined to facilitate water runoff or preferably, covered.

Actual removal of the formwork requires a great deal of care as the concrete is at a time when it is most vulnerable to damage and shock. Prying or striking the form to facilitate release should be prohibited. Use of rubber or wooden wedges is recommended. Corners and sharp edge lines will require the greatest amount of attention to prevent chipping.
Concrete must also be protected from thermal shock to prevent crazing and cracks. Architectural surfaces should be protected from extremely low temperatures and from sudden temperature drop. It is recommended that cooling be limited to 40 degrees per 24 hours following necessitation of repeat application. "Cracking" of the form prior to complete removal has proved successful with wood forms in controlling the cooling process. It is recommended that at critical temperatures formwork with poor insulating qualities (i.e. metal, and plastic) to be of any use for curing must be enclosed in some insulating material such as polystyrene.

After stripping operations are completed the concrete must be protected from any damage that might be incurred throughout the remainder of the construction period. Corners and critical areas will need more than a mere reminder of their importance to workmen. Workmen must also be prohibited from writing on architectural concrete surfaces.

RELEASE AGENTS

The primary purpose in applying a release agent to form faces is to facilitate stripping of the formwork and to prevent likelihood of surface damage to both the formwork and the concrete. Careful selection of a release agent is important and investigations should include the following factors:

Compatibility of agent with form material and form sealer or curing agents.

Discoloration and staining of the concrete, effect on surface durability.

Effect of stripping time on ease of stripping and discoloration.

Effect of environment (hot, cold, etc.) on ease of stripping.

Uniformity of performance

Available quantities, the same agent should be used throughout the project.

Reduction of elimination of cleaning of forms between uses.

Storage life, effect of temperature extremes and various handling conditions.
The safest approach in release agent selection is to evaluate several types under actual project conditions. Contamination or dilution of release agents at the project site must be prohibited. Proper storage in a covered area is recommended.

Application of release agents should be in accordance with the manufacturers' recommendations on rate of spread and method of application. Forms should be cleaned before applying release agents. Previous build-ups of concrete, rust, scale, and dirt must be removed especially on forms where architectural surfaces are involved. Application may be by sprayer, roller, brush, mopping, or dipping. Excess material and puddles should be wiped off with squeegees or rags. With most release agents maximum performance and economy are gained by applying a thin film with a sprayer. Reuseable formwork should be coated after stripping and cleaning and preferably before erection. Coated surfaces should be allowed to dry before placement of reinforcing steel. Caution should be observed with certain types of agents that are effected by prolonged exposure to sunlight.

REFERENCE:
"MAGIC KOTE CONCRETE FORM COATING." SYMONS CORPORATION PUBLICATION 76-19, 1976
<table>
<thead>
<tr>
<th>TYPES</th>
<th>COMPOSITION</th>
<th>RELEASE AGENT</th>
<th>CONCRETE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neat Oils</td>
<td>Mineral, vegetable or fish origin</td>
<td>If used to excess mineral oil will cause staining, &amp; durability loss</td>
<td>Excessive bugholes, uniform in color</td>
</tr>
<tr>
<td>Neat Oils</td>
<td>with Surfactant Added</td>
<td>Excessive application will cause surface retardation &amp; color variations. Non-uniform distribution will cause color variation.</td>
<td>Fewer bugholes, good color consistency</td>
</tr>
<tr>
<td>Wax</td>
<td></td>
<td>Water insoluble, unpredictable when temperatures are under 50&lt;sup&gt;0&lt;/sup&gt; or above 80&lt;sup&gt;0&lt;/sup&gt;, excellent release</td>
<td>Uniform color, wax coats concrete and must be removed to properly finish surface</td>
</tr>
<tr>
<td>Chemically Active</td>
<td>Oil, fuel oil, kerosene, polyvinyl alcohol -- only for architectural concrete</td>
<td>Reacts with free lime to produce water insoluble soaps</td>
<td>Fewer bugholes, uniform color, excessive application, may cause spalling, dusting or increased permeability</td>
</tr>
<tr>
<td>Chemically Inactive</td>
<td>Uses hydrocarbon solvent</td>
<td>Water insoluble, good release</td>
<td>Fewer bugholes, uniform color</td>
</tr>
<tr>
<td>Water Soluble</td>
<td>Oil in water emulsion</td>
<td>Water soluble excessive application will cause dusting &amp; surface retardation</td>
<td>Fewer bugholes, Poor color uniformity</td>
</tr>
<tr>
<td>FORM MATERIAL</td>
<td>RELEASE AGENTS</td>
<td>FORM CONDITION</td>
<td>LIMITATIONS</td>
</tr>
<tr>
<td>-----------------</td>
<td>--------------------------------------------------------------------------------</td>
<td>------------------------------------------------------</td>
<td>--------------------------------------------------</td>
</tr>
<tr>
<td>WOOD Plywood</td>
<td>Most commercial oils capable of penetrating the wood</td>
<td>Surface should be slightly greasy to touch with no free oil</td>
<td></td>
</tr>
<tr>
<td>METAL Steel</td>
<td>Non-drying oil containing a rust inhibitor</td>
<td>Free of water</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>METAL Aluminum</td>
<td>Oil emulsions, lanolin, palm oil</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PLASTIC</td>
<td>Oil phased emulsion, high quality wax, non-staining fuel oil, silicones (during high temperature curing)</td>
<td>New forms may be used without release agent but will deteriorate rapidly. Use of release agent is recommended for all uses.</td>
<td>Avoid unsaturated oils, ketones, esters, acids, toluol, toluene xylanes, halogenated solvents</td>
</tr>
<tr>
<td>Reinforced/Unreinforced</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Foamed and Expanded</td>
<td>Lightly coated with castor oil, petroleum jelly, thinned with kerosene, paraffin, oil</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RUBBER</td>
<td>Castor oil, vegetable oil, lanolin, water-emulsion wax</td>
<td>Release agent may not be required if surfaces are clean and moistened with water before use</td>
<td>Avoid mineral oils, oil solvent based agents</td>
</tr>
<tr>
<td>FIBROUS</td>
<td>Oil emulsion</td>
<td>Treat with clear lacquer when using white cement, to avoid stains</td>
<td></td>
</tr>
<tr>
<td>Hardboard</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Tempered)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fiberboard</td>
<td>Paraffin base oil, grease with calcium stearate or aluminum stearate base</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
STRUCTURAL CONSIDERATIONS

Structural considerations are a major aspect in designing with architectural concrete; since concrete is a material capable of satisfying both building requirements of structure and enclosure. The building's appearance should flow from its structure and to be visually acceptable structural defects must be kept to a minimum. With proper planning the structure should be capable of withstanding service loads and stresses without such defects as cracking, spalling, or excessive deflection. Such defects can severely damage the architectural appearance of the building.

Cast-in-place concrete is a material which gains its structural integrity in the field under a varying range of conditions which are difficult to control. Unlike reinforcing materials and mixes which are tested beforehand, the final product resulting in the field cannot be tested before being put into service. Although concrete is a product of theoretical research and testing, it must stand the test of time to prove its integrity. During construction concrete members are being continually built upon which may overload them before they have gained sufficient strength. In the event of design errors it can be very difficult and expensive to remove members that are inadequate.

It is therefore very important that architects and structural engineers develop a close communication with one another from the project's inception. In the conceptional stages of design, engineers should provide the advice concerning the functional aspects of the design. It is important that the design concept reflect a clear understanding of structure and the material it is to be built from. If the structural system is inadequate or poorly designed it will create problems for the structure if in fact it can be built at all. Mechanical and electrical engineers must also be consulted and kept aware of the design progress. If construction is considered to be a problem, contractors should also be contacted for their advice. Thorough coordination of all disciplines during the planning stage is vital and can only lead to less problems during construction. Any changes in design or planning should be
closely monitored and made available to every one concerned to prevent an accumulation of errors that may be hazardous or irreparable. It is also advised that architects and structural engineers inspect project construction together so that resulting problems can be effectively solved without excessive time delays.

Before construction is started all drawings and calculations should be thoroughly checked and evaluated. The structure should be capable of responding to the extreme load conditions, especially where a high degree of uncertainty exists and therefore not designed just to meet code minimums. Carefully defined load criteria must be established and reviewed by all concerned. Soil conditions must be thoroughly investigated to determine a suitable means of supporting the structure. Foundation settlement is an especially critical condition that must be limited with architectural concrete to prevent unsightly cracks and structural deficiencies. During construction, erection loads must be carefully controlled. This is especially true for precast construction where structural members may be handled several times prior to final placement. With cast-in-place construction it is important that lower floors that have not developed design strength be properly shored before loading by continued forming and placing operations. Engineers should be consulted as to what load limits are for various conditions and what the results will be if such loads are incurred. Prior analysis of such suspected conditions should be conducted to insure the integrity of the structure, e.g. effects of construction loads on partially cured concrete, hot and cold weather concreting, inadequately supported compression flanges of beams, etc.

Engineering analyses should also investigate structural effects of building settlement, member deformation, concrete creep, temperature changes and stress losses resulting in prestressed concrete, all of which are capable of at least producing cracks unless controlled. Cracks may be limited by post-tensioning, inclusion of control joints, appropriate distribution of reinforcement, limiting flexural tension stress in reinforcement and use of special shrinkage-
compensating cements and low-shrinkage aggregates.

Integration of mechanical, electrical, and plumbing systems with the concrete structure should be closely investigated as to their feasibility. Openings created for passage of such systems must be carefully planned so as not to weaken structural elements. Expansion, construction, and control joints should be design located to effectively handle all temperature and shrinkage movements. Deflections in beams and spandrels should be kept within desired limits. Cambers should be created in all such sections to compensate for deflection and to overcome the effects of "optical sag" in long spans.

REFERENCE:
"AVOIDING GROSS ERRORS IN CONCEPT, PLANNING, DESIGN, AND DETAILING OF STRUCTURES."
AMERICAN CONCRETE INSTITUTE COMMITTEE 348, ACI PUBLICATION NO. 70-01, OCT., 1971.
Concrete floor systems may be cast-in-place, precast or a combination of both. Cast-in-place systems are divided into monolithic beam slabs and beamless slabs. The various systems are presented in the following pages with the intention of providing an overview of the alternatives and information concerning the capacity of each.

Monolithic beam systems are divided according to the reinforcement of the main structural members and the spacing of the beams. Reinforcement may be one-way or two-way within each structural element. Closely spaced beams such as those formed by steel and plastic pan forms are often referred to as joist or ribbed slabs. Beam and slab systems are relatively flexible in terms of their load and span capabilities. The beams may be varied in size to adapt to very long spans or excessively heavy loads or both. For this reason, span and load ranges have been omitted here and it is advised that the designer consult structural engineers for dimensions relating to specific projects.

Ribbed slabs are limited by their forming means (pans, domes, etc.) and ranges are given for typical situations. Beams are usually kept flush with the ribs, but by increasing the beam depth larger spans can be obtained.

Beamless systems consist of two-way ribbed slabs and flat slabs. Two-way ribbed slabs formed with metal or plastic domes are the most commonly exposed ceiling systems. Flat slabs are used where light loads are incurred while flat plate slabs with drop panels and column capitals are used where heavier loads must be supported without the use of a beam, (i.e. minimal floor depth). Flat slabs are usually the least expensive to form.

Precast floor systems allow for rapid building erection and reduced construction time. Tee sections and slab sections, cored and solid are commonly prestressed and available in either light-weight or normal weight concrete. When used for floor systems
(vs. roof systems) these sections are usually topped with normal weight concrete to provide continuity and to produce a flat surface on the cambered sections. Tee sections are usually employed where large spans are required, while cored slabs are designed for shorter spans with a minimal floor depth and a flat ceiling. Precast components are manufactured under strict supervision of the precast association to control tolerances and limit sectional variations.

Composite systems utilize combinations of precast and cast-in-place concrete with other various materials providing either structural reinforcement or void space for lighter weight slabs. These systems are usually quite heavy for their short span length and seldom are exposed architecturally.

Dimensions shown for each system are average ranges and should not be interpreted as the system limits. Systems using proprietary products are usually subject to the limitations of the standard available components although in certain cases manufacturers will fabricate special items.
FLOOR SYSTEMS
MONOLITHIC BEAM SYSTEMS
ONE-WAY BEAM AND SLAB

DEEP BEAM

SYSTEM IS USED FOR LARGE LOADS AND LONG SPANS.
LIMIT SLAB DEPTH TO 12".
INCREASE SYSTEM CAPABILITY BY INCREASING BEAM SIZE AND POST-TENSIONING.

FLUSH BEAM

WIDE BEAM ALLOWS FLUSH CEILING.
INCREASE BEAM WIDTH TO INCREASE CAPACITY.

MAIN REINFORCEMENT IN EACH STRUCTURAL ELEMENT RUNS IN ONE DIRECTION.

TWO-WAY BEAM AND SLAB

PERIMETER BEAMS

DEPTH OF SLAB LIMITS SPAN CAPABILITY.
LIMIT SLAB DEPTH TO 12".
SPANS ARE USUALLY SMALL FOR LARGE LOADS.

INTERMEDIATE BEAMS

LARGE SPAN CAPABILITY BY INCREASING SIZE OF BEAMS.
BEAM DEPTHS ARE KEPT UNIFORM.
LIMIT SLAB DEPTH TO 12".

MAIN REINFORCEMENT IN AT LEAST ONE STRUCTURAL ELEMENT RUNS IN TWO DIRECTIONS.

ONE-WAY RIBBED SLAB

FLOOR DEPTHS RANGE FROM 8" TO 24".
RIB MODULES RANGE FROM 2' TO 3'.
FORMED WITH PLASTIC OR STEEL PAN FORMS.

TWO-WAY RIBBED SLAB

FLOOR DEPTHS RANGE FROM 8" TO 24".
RIB MODULES RANGE FROM 2' TO 3'.
KEEP BEAMS FLUSH WITH CEILING.
INCREASE BEAM WIDTH TO INCREASE SPAN.
FORMED WITH PLASTIC OR STEEL DOME FORMS.
BEAMLESS SLABS

RIBBED

- SPAN RANGE: 25' TO 50'
- EXTENDED BY POST-TENSIONING
- SLAB DEPTH: 8" TO 24"
- RIB MODULE: 2' TO 8'
- COFFERS AROUND COLUMN ARE OMITTED OR REDUCED IN DEPTH TO ALLOW TRANSFER OF LOADS FROM SLAB TO COLUMN

FLAT PLATE

- CONCRETE COLUMN WITH DROP PANEL

- USED WHEN MINIMUM FLOOR TO FLOOR HEIGHT IS REQUIRED
- SPAN RANGE: 15' TO 35'
- SLAB DEPTH: 5' TO 12'
- WEIGHT RANGE: 60 TO 180 PSF

FLAT SLAB

- STEEL COLUMN WITH DROP PANEL & COLUMN CAPITAL

PRECAST SYSTEMS

SINGLE TEE

- SPANS TO 150'
- DEPTH: 12" TO 60"
- WIDTH: 4' TO 12'
- 8' IS MOST COMMON

CORED SLABS

- "FLEXICORE"
- SPANS TO 60'
- DEPTH: 12" TO 12"
- WIDTH: 12" TO 18"
- 8' IS MOST COMMON

- "SPANCRETE"
- SPANS TO 100'
- DEPTH: 12" TO 36"
- WIDTH: 4' TO 12'
- 8' IS MOST COMMON

- "SPAN-DECK"

CHANNEL + SLAB

- SIMILAR TO THE DOUBLE TEE SYSTEM
- INFILL SLABS MAY BE SOLID OR CORED

DETAILED INFORMATION ON LOAD AND SPAN CAPABILITIES CAN BE FOUND ON PAGES 110-111.

COMPOSITE SYSTEMS

4' FLAT SLAB, TOPPING

- WITH 2" TOPPING
- 15' TO 30'
- WEIGHT: 50 PSF
- RIB MODULE: 24"

- SPAN RANGE
- 6' TO 26'
- TOPPING DEPTH
- 2" TO 8"
- WEIGHT RANGE
- 50 TO 125 PSF

MASONARY UNIT TOPPING

- MASONARY UNIT SYSTEMS ARE USED FOR SHORT SPANS
- CEILINGS ARE NOT USUALLY EXPOSED
- SPAN RANGE
- 10' TO 30'
- TOTAL FLOOR DEPTH
- RANGE: 16" TO 24"
- MASONARY UNIT WIDTHS
- 12", 16", 24"

- "STEEL TRUSS, FIBER PAN FORM, TOPPING"
- SPAN RANGE
- 12' TO 20'
- SPAN RANGE
- 12' TO 20'
- WEIGHT WITH 2" TOPPING
- 75 PSF

REFERENCE:


"Omnia Concrete Systems," Inter-Omnia, Inc., Winston-Salem, N.C.
PRECAST COMPONENTS - SINGLE TEES

STANDARD SECTIONS

ALL SECTIONS ARE MANUFACTURED IN ONE FLEXIBLE MOULD. DEPTH AND WIDTH DIMENSIONS MAY BE VARIED FROM THE NOMINAL ONES INDICATED TO SATISFY SPECIAL DESIGN REQUIREMENTS. STEM DIMENSION MAY BE INCREASED TO 12" WHERE SPECIAL LOAD CONDITIONS REQUIRE ADDITIONAL SPACE FOR REINFORCING. WIDER SECTIONS ARE MORE ECONOMICAL FOR THE SAME LOAD OVER THE SAME SPAN. SINGLE TEES ARE AVAILABLE IN LIGHTWEIGHT AND NORMAL WEIGHT CONCRETE WITH AVAILABLE DEPTHS INDICATED FOR EACH.

WEIGHT & SPAN CAPABILITY

<table>
<thead>
<tr>
<th>WIDTH</th>
<th>DEPTH &amp; SPAN CAPABILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L - LIGHTWEIGHT CONCRETE</td>
</tr>
<tr>
<td></td>
<td>SPAN - EFFICIENT LENGTH FOR SECTION WITH STANDARD REINFORCING</td>
</tr>
</tbody>
</table>

REFERENCE:
"PCI DESIGN HANDBOOK." PRESTRESSED CONCRETE INSTITUTE, CHICAGO, ILLINOIS, 1972.
"SINGLE TEES." SAN-VEL CONCRETE CORPORATION, 1972.
MOULD FLEXIBILITY

DOUBLE TEE

- Nominal Width
- Variable, fixed Nominal Width: Variable

CHANNEL

STANDARD SECTIONS

4' Nominal Width

5'

6'

8'

10'

12'

12' 24" SPAN 34-56 WT. 597 896

10' 32" SPAN 52-82 WT. 641 891

6' 12" SPAN 20-36 WT. 299 499

12" SPAN 20-36 WT. 299 499

14" SPAN 24-44 WT. 319 519

16" SPAN 26-54 WT. 339

8' 12" SPAN 38-42 WT. 208 396

16" SPAN 42-54 WT. 254 442

20" SPAN 56-59 WT. 305 493

18" SPAN 30-56 WT. 358 558

20" SPAN 36-60 WT. 378 578

24" SPAN 40-74 WT. 418 618

32" SPAN 84-92 WT. 572 772

10' 32" SPAN 52-82 WT. 641 891

12' 24" SPAN 34-56 WT. 597 896

REFERENCE:
KONCZ, DR. ENG. TIHAMER. "MANUAL OF PRECAST CONCRETE CONSTRUCTION." VOLUME I. WIESBADEN UND BERLIN, 1968.
"PCI DESIGN HANDBOOK." PRESTRESSED CONCRETE INSTITUTE, CHICAGO, ILLINOIS, 1972.
**CORED SLABS**

**"FLEXICORE"**

<table>
<thead>
<tr>
<th>DEPTH</th>
<th>N</th>
<th>T</th>
</tr>
</thead>
<tbody>
<tr>
<td>6&quot; SPAN</td>
<td>24</td>
<td>43</td>
</tr>
<tr>
<td>WT.</td>
<td>20</td>
<td>68</td>
</tr>
<tr>
<td>8&quot; SPAN</td>
<td>31</td>
<td>25</td>
</tr>
<tr>
<td>WT.</td>
<td>57</td>
<td>82</td>
</tr>
<tr>
<td>10&quot; SPAN</td>
<td>38</td>
<td>30</td>
</tr>
<tr>
<td>WT.</td>
<td>61</td>
<td>86</td>
</tr>
<tr>
<td>12&quot; SPAN</td>
<td>44</td>
<td>35</td>
</tr>
<tr>
<td>WT.</td>
<td>74</td>
<td>99</td>
</tr>
</tbody>
</table>

**DESIGNATION**

N — NORMAL WEIGHT CONCRETE
T — (N) + 2" NORMAL WEIGHT CONCRETE TOPPING

**SPAN** — RECOMMENDED MAXIMUM FOR SECTION WITH STANDARD REINFORCING

**WEIGHT** — UNIT WEIGHT LBS./SQ.FT.
STANDARD 2" TOPPING IS ADDED IN WITH (T) SECTIONS

Precast prestressed hollow core slabs may be used for roofs and floor construction. Floor slabs are usually topped with 2" of normal weight concrete to level the upper surface of the cambered section. Hollow cores within the slabs can be used for mechanical distribution. Cored slabs are manufactured by an extrusion process on beds up to 600' long with widths and thicknesses as shown. After casting they are cut into desired length and can usually span up to 50'. Square and angular cuts can be made to satisfy design variations. "SPAN-DECK" is available with a smooth steel formed ceiling or a textured acoustical ceiling. Some manufacturers will fabricate slabs with an exposed aggregate surface on one side. Manufacturers should be contacted concerning local availability of each type.

REFERENCE:


BEARING WALL CONSTRUCTION

TYPICAL EXTERIOR WALL SECTIONS

SLABS SUPPORTED BY BEARING WALL SEATS IS THE MOST COMMONLY USED METHOD OF CAST-IN-PLACE WALL CONSTRUCTION. THIS METHOD ALLOWS THE USE OF DIFFERENT CONCRETES I.E., LIGHTWEIGHT CONCRETE FOR THE FLOOR SLAB AND NORMAL WEIGHT CONCRETE (POSSIBLY COLORED) FOR THE BEARING WALL. A DISADVANTAGE OF THIS METHOD OF CONSTRUCTION IS THAT THE FORM OPENING FOR THE BEARING WALL IS RESTRICTED, HAMPERING PLACEMENT AND VIBRATION. REINFORCEMENT RUNNING FROM THE WALL INTO THE SLAB MUST BE LEFT STRAIGHT (DUE TO FORMWORK) AND BENT AFTER STRIPPING. THIS CAN BE HAZARDOUS AS IT IS DIFFICULT TO BEND REINFORCING PROPERLY IN THE FIELD; INTO THE CORRECT POSITION AND WITHOUT CRACKS.

THE FLOOR SLAB IS EXPOSED ON THE EXTERIOR FACE WITH A CONSTRUCTION JOINT ABOVE AND BELOW THE SLAB, THIS METHOD USUALLY REQUIRES THE USE OF THE SAME CONCRETE IN THE FLOOR SLAB AS THAT USED IN THE BEARING WALLS TO OBTAIN A COLOR MATCH. IT IS POSSIBLE, ALTHOUGH DIFFICULT, TO USE TWO DIFFERENT MIXES SIMULTANEOUSLY IN PLACING THE FLOOR SLAB TO CREATE A PERIMETER COLOR MATCH. THIS METHOD OF CONSTRUCTION LEAVES THE FORM FOR THE BEARING WALL BELOW COMPLETELY OPEN FOR PLACEMENT. REINFORCEMENT CAN ALSO BE PREFORMED AND PROPERLY PLACED AS A RESULT. EXCESSIVE ROTATIONAL MOVEMENT OF THE FLOOR SLAB MAY CAUSE LEAKAGE THROUGH THE CONSTRUCTION JOINTS WHICH SHOULD BE CAULKED WITH A SEALANT.

SLABS CAST INTEGRAL WITH SPANDREL OR EDGE BEAMS IS A COMMON METHOD OF CONSTRUCTION ALTHOUGH FOR ARCHITECTURALLY EXPOSED SPANDRELS IT MAY NOT BE ADVANTAGEOUS. THIS IS DUE TO THE PROBLEM OF HAVING TO USE ONE MIX FOR THE SLAB AND THE SPANDREL, EITHER THE DESIRED MIX FOR THE EXPOSED SPANDREL FACE MUST BE SACRIFICED OR A MORE EXPENSIVE MIX THAN IS NEEDED FOR THE SLAB MUST BE USED. AN ALTERNATIVE TO THIS METHOD OF CONSTRUCTION IS TO CAST THE SPANDREL FIRST, IN SIMILAR MANNER TO THE BEARING WALL IN (1) AND THEN CAST THE SLAB. PLACEMENT OF REINFORCING IS HOWEVER EASIER WITH INTEGRAL BEAMS AND SLABS.

SLOPED WINDOW SILLS MAY BE CAST-IN-PLACE OR PRECAST CONCRETE. BETTER RESULTS MAY BE ACHIEVED WITH SUCH SECTIONS BY PRECASTING. OBTAINING COLOR UNIFORMITY BETWEEN THE PRECAST WORK AND THE CAST-IN-PLACE WORK SHOULD NOT BE A PROBLEM. THE WINDOW FILLER MAY BE CAST INTEGRAL WITH THE SILL SECTION DEPENDING ON THE INTRICACY OF THE SHAPE.
REINFORCED CONCRETE JOINTS

JOINTS IN CONCRETE ARE NECESSARY TO PROVIDE POINTS OF RELIEF FOR BUILT-UP STRESSES AND TO SERVE AS STOPPING POINTS BETWEEN DAY-TO-DAY POURS. THE AMOUNT OF CONCRETE CAPABLE OF BEING CAST AT ANY TIME MUST BE CONSIDERED IN PLANNING THE LOCATION OF JOINTS. THE MOST COMMON STRUCTURAL DEFECT IN CONCRETE IS CRACKING USUALLY CAUSED BY DRYING SHRINKAGE OR THERMAL STRESSES. THE MOST EFFECTIVE METHOD OF CONTROLLING CRACKING IS TO PROVIDE CONTROL JOINTS WHICH INDUCE CRACKING IN DESIRED LOCATIONS. LOCATION OF CONTROL JOINTS IN WALLS OR FLOORS WILL DEPEND ON THEIR PHYSICAL SIZE, AMOUNT OF REINFORCEMENT, AND SEVERAL OTHER FACTORS; HOWEVER, LOGICAL LOCATIONS DictATED BY MODULAR FORMING PANELS CAN OFTEN PROVIDE THE BEST SOLUTION. VERTICAL CRACKING IS THE BIGGEST PROBLEM IN WALLS AND IS BEST CONTROLLED BY JOINTS OCCURRING AT LEAST AT MID-SPAN BETWEEN BAYS. VERTICAL CONTROL JOINTS IN LONG WALLS MAY OCCUR AS CLOSE AS 15 FEET OR AS FAR APART AS 30 FEET DEPENDING ON CONDITIONS. HORIZONTAL CONTROL JOINTS SHOULD BE LOCATED AT THE BOTTOM OF BEAMS, TOPS OF FLOORS AND AT THE BOTTOM AND TOP OF ALL WALL OPENINGS, AS WELL AS INTERMEDIATE HEIGHTS IN TALL WALLS. IRRESPECTIVE OF THE TYPE OF JOINT EMPLOYED, RUSTICATIONS FOR EACH MAY BE DETAILLED SIMILARLY. CRACKING Seldom OCCURS IN COLUMNS DUE TO THE USUAL ABSENCE OF TENSILE STRESSES.

CONSTRUCTION JOINTS

WALL SECTION 1

FLOOR SECTION 2

CONSTRUCTION JOINTS ARE USED TO DIVIDE A STRUCTURE INTO SEGMENTS THAT CAN BE CAST MONOLITHICALLY WITHOUT "COLD JOINTS". ALL REINFORCING CROSSES THE JOINT AND DOWELS ARE USUALLY ADDED. KEYED JOINTS MAY BE FORMED INTO THE CONCRETE BUT ARE USUALLY OMITTED IN FAVOR OF DOWELS, ESPECIALLY IN THIN SECTIONS. IN SPANNING ELEMENTS, JOINTS ARE LOCATED AT THIRD POINTS. RUSTICATION STRIPS MAY BE USED ON EXPOSED SURFACES FOR APPEARANCE OR WITH CAREFUL ATTENTION TO FORMWORK BUTJ JOINTS CAN BE USED.

EXPANSION JOINTS

WALL SECTION 5

FLOOR SECTION 6

EXPANSION JOINTS ARE USED FOR VERY LONG BUILDINGS OR FOR BUILDINGS OF DIFFERENT MASSING, I.E., A TOWER AND A LOW RECTANGULAR EXTENSION. THEY ARE USED WHERE LARGE DIMENSIONAL CHANGES OCCUR AND WHEN PROPERLY DETAILLED CAN BE USED FOR ANTICIPATED DIFFERENTIAL SETTLEMENT BETWEEN TWO ELEMENTS. NO REINFORCING CROSSES AN EXPANSION JOINT. COMPRESSIBLE FILLERS ARE CAST-IN-PLACE BETWEEN ADJACENT SECTIONS. WATERSTOPS MAY BE INCLUDED WHEN NECESSARY AND ALL JOINTS SHOULD BE CAULKED WITH SEALANTS TO PREVENT PASSAGE OF MOISTURE.

CRACK CONTROL

FLOOR SECTION 7

DESIGN DEPTH

ADDITIONAL COVER

KEEP RUSTICATION DEPTHS IN BEAMS AND SLABS MINIMAL AS THE ADDITIONAL CONCRETE COVER WILL ACCENTUATE CRACKS OCCURRING ELSEWHERE

FLOOR PLAN 8

COLUMNS BEARING ON GROUND SLABS WILL CREATE CRACKS IF SETTLEMENT OCCURS. RECTANGULAR OPENINGS IN SLABS WILL ALSO CRACK FROM THE CORNERS. CONTROL JOINTS CAN BE USED TO PREVENT THESE CRACKS AND SHOULD BECOME A DESIGN FEATURE AS WELL.

EXTERIOR WALL ELEVATION 9

WHEN HORIZONTAL REINFORCING IS INTERRUPTED BY OPENINGS, THE INTERRUPTED STEEL SHOULD BE PLACED 1/2 ABOVE AND 1/2 BELOW THE OPENING. THIS MAY NOT ALWAYS BE POSSIBLE ARCHITECTURALLY, IN WHICH CASE DIAGONAL REINFORCING IS USED AT THE CORNER AS SHOWN. CONSTRUCTION JOINTS SHOULD ALSO BE LOCATED ABOVE AND BELOW THE WALL OPENING.
REINFORCEMENT

When sizing concrete members, designers should always keep in mind the process of placing concrete. Adequate work space must be maintained to consolidate fresh concrete. The amount and location of reinforcement can have significant influence on placement. Not only does the reinforcement take up space, but it divides the space within the member into a series of grids through which the concrete must pass. When specifying slender columns and walls it is advised to first determine if consolidation will be a problem. If so, an alternate method of construction should be sought. The first step in designing concrete members is to establish sizes utilizing optimum amounts of reinforcing for various load conditions. Intersection of structural members such as columns and beams should also be carefully designed as they are usually quite congested with reinforcing. Where conditions dictate a large amount of reinforcing for a given area, bundling of the reinforcing bars may provide some relief. Mixes with smaller coarse aggregates may be used if the design will permit. It is not advised that smaller vibrators be used in congested areas as their effectiveness is limited and the intended result may not be achieved.

Reinforcing is required to be supported and properly spaced within concrete members. Materials used in supporting reinforcing should be stainless steel to prevent rusting in exposed concrete. Steel bolsters and chairs used in supporting reinforcing bars above horizontal forms may occasionallly have plastic-coated feet to prevent rusting. Care should be taken with their use as some plastics may not be durable if exposed to weather or sunlight. When specifying bolsters and chairs a sufficient quantity should be required to support the weight of the reinforcing without causing damage to either the form face or plastic feet.

Bolsters or chairs should never be used to space reinforcing in vertical surfaces; however, some form of sideform spaces may be required to maintain minimum concrete cover. Wire used in tying reinforcing bars together should have the ends bent back from form surfaces. Any wire clippings found on horizontal surfaces should
be removed prior to the concrete placement to prevent rusting or exposure in the event of surface treatment.

When galvanized reinforcing steel is placed close to nongalvanized metal forms, the concrete may have a tendency to stick to the forms. This may also happen if nongalvanized reinforcement is used close to galvanized forms or form liners. A two percent solution of sodium dichromate or a five percent solution of chromic acid (chromium trioxide) solution applied as a wash to the galvanized surface has satisfactorily passivated the metal to prevent reaction between the zinc and alkaline fresh concrete. Addition of chromates to the concrete cannot be recommended as their effect on concrete performance is not yet fully known.

**MINIMUM BAR SPACINGS**

- **Flat Surface**
  - S - LARGEST OF
  - \( H \) 1.25 \( \times \) BAR DIA.
  - 1.50 \( \times \) MAX
  - AGGREGATE SIZE

- **Profiled Surface**
  - S - LARGEST OF
  - \( H \) 2\( ''\)
  - 1.25 \( \times \) BAR DIA.
  - 1.25 \( \times \) MAX
  - AGGREGATE SIZE

- **To Be Treated**
  - S - DEPTH
  - OF TREATMENT
  - (Bushhammer Blast, etc.)

ACI ALLOWS 1/2" TOLERANCE FOR DIMENSIONS INDICATED ABOVE.

**MINIMUM WALL THICKNESSES**

- **Single Wall Reinforcement**
  - CASTING SPACE
  - 2'' \( \times \) 4''

- **Double Wall Reinforcement**
  - CASTING SPACE
  - 2'' \( \times \) 5'' \( \times \) 2''

CASTING VALUES ARE RECOMMENDED MINIMUMS TO FACILITATE PLACEMENT

HORIZONTAL BARS PLACED ON OUTSIDE FACE OF VERTICALS

VIBRATORS USED ONLY WITHIN CASTING SPACE

CUT SHORT OR WRAP TIE WIRE AROUND BARS

ACI ALLOWS 1/2" TOLERANCE FOR DIMENSIONS INDICATED ABOVE.
6

MATERIALS
CEMENTS

The definition of materials as used in concrete shall include cements, aggregates, admixtures, and mix water. These materials are the same for both precast and cast-in-place construction. The proportioning of these materials for architectural concrete is covered under the section entitled "Mixes."

The cement paste used in concrete may be any of several materials: slake lime, plaster, epoxy resins, etc; however, the most widely used and available is Portland cement. Portland cement is a product obtained by pulverizing a clinker with the addition of gypsum. A clinker is produced by burning in a kiln a proportioned mixture of lime, silica, alumina, and iron components. During the burning process the components release oxygen and fuse to form Portland cement. Gypsum is added to the cement to retard rapid setting. By varying the quantities of components used in producing the clinker and varying the amount of gypsum used, several types of Portland cement are obtainable. Generally, five different types are produced, meeting certain physical and chemical requirements for specific purposes. The American Society for Testing and Materials (ASTM) provides for Types I, II, III, IV, and V in ASTM C150. The letter "A" after a number designates air-entraining Portland cement.

<table>
<thead>
<tr>
<th>TYPE OF CEMENT</th>
<th>USE</th>
</tr>
</thead>
<tbody>
<tr>
<td>I, IA NORMAL</td>
<td>General construction where special properties are not required</td>
</tr>
<tr>
<td>II, IIA MODERATE</td>
<td>General construction where moderate resistance to sulfate attack is required</td>
</tr>
<tr>
<td>III, IIIA HIGH-EARLY-STRENGTH</td>
<td>General construction where rapid strength development is required</td>
</tr>
<tr>
<td>IV LOW HEAT OF HYDRATION</td>
<td>Used in massive construction where low heat of hydration is slowly dissipated</td>
</tr>
<tr>
<td>V SULFATE RESISTANT</td>
<td>Used in special construction where resistance to severe sulfate attack is required</td>
</tr>
</tbody>
</table>

REFERENCE:
Also available are several special cements that have been specifically graded for varying applications. White cements and shrinkage-compensating cements are two that have architectural applications.

Selection of a specific cement will depend upon the nature of the construction; however, most architectural applications utilize Type I and Type III cements, both of which are also available in white or color.

Type III cement is manufactured by the same process as Type I, but is specially graded and ground to a fineness to insure more rapid strength development. The following Table* indicates the variations between Type I and Type III cements.

<table>
<thead>
<tr>
<th>Type of Portland Cement</th>
<th>Compound Composition, Percent**</th>
<th>Fineness, Sq. cm. Per g.***</th>
</tr>
</thead>
<tbody>
<tr>
<td>C₃S C₂S C₃A C₄AF</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>50 24 11 8</td>
<td>1800</td>
</tr>
<tr>
<td>III</td>
<td>60 13 9 8</td>
<td>2600</td>
</tr>
</tbody>
</table>

** The compound compositions shown are typical.

*** Fineness as determined by Wagner Turbidimeter

Type III cement has proved useful in construction where speed of erection, quick reuse of formwork and reduction of cost for labor, curing and overhead are important. During cold weather concreting high-early-strength cement is especially advantageous in permitting early reuse of forms and savings in the cost of artificial heat and protection. In precast plants, Type III cements allow for faster reuse of molding equipment and increased resistance to handling damage. High-early-strength cement has also proved more effective in producing watertight concrete. Although Type I and Type III cements are similar

REFERENCE:
* HIGH-EARLY-STRENGTH,” PORTLAND CEMENT ASSOCIATION, PUBLICATION NO. IS053.017, 1968
in composition, they should not be used interchangeably where color uniformity is critical.

When specifying a cement, if color uniformity is crucial it is important to indicate not only the cement type, but the mill brand, specific mill location, and specific batch. Due to the number of components used in cement production there are many variables which can affect the cement color. It is also important to realize that cement color has a significant effect on the color of the finished product, although the volume of cement in a mix is small in comparison to that of the aggregate. When possible it is best to require that all cement used in a project be from one raw material source; however, unless all the cement required for a project is purchased at one time, variations will occur due to raw materials being extracted from changing natural resources, and from the mill conditions effecting each cement batch.

After production cement may be handled several times before finally reaching its destination during which time handling and delivery equipment may effect its color qualities. Cement is shipped in bag or bulk form with most concrete plants receiving shipments in bulk by rail or truck. Assurance of uniformity in production and delivery may be next to impossible and can only be hopefully achieved if the necessary precautions required are made known to all involved. When requiring contractors to stockpile cement for the entire project, architects should be certain that the facilities for doing so are adequate so as not to cause deterioration or contamination of the cement, thus defeating the original intention. This precaution is seldom required due to the limited storage space available and the additional cost incurred. Most concrete plants are geared to the production of structural concrete and have designed their facilities to meet a high turnover of only a few cement types. Having to store (stockpile) a special architectural cement for the duration of a large project will greatly increase overhead cost if in fact, they were capable of storing such a quantity. Most plants do, however, carry white cement for architectural use in both precast and cast-in-place concrete.
White cement is a special cement made of selected raw materials containing minimal amounts of iron and manganese oxides which commonly produce a gray color. White cement is available in Type I, IA, III, IIIA and some manufacturers produce a special waterproof white cement by the addition of calcium, alumina or other stearates to the cement clinker. White cements will exhibit different color characteristics depending on their raw material source. Some have a buffish or cream undertone, while others have a bluish or greenish undertone, that can effect the desired concrete color. Ordering of white cement is perhaps a good example of where a one-time shipment would be preferable.

Buff, tan, and brown natural cements are also available from many manufacturing plants and are often used in architectural work. Colored cements are also available that have been produced by adding pigments to white cement during the manufacturing process. These cements usually have a wider color range than natural cements, but careful selection is advised as certain pigments may fade or "wash out" of the finished product in time.

Shrinkage-compensating and self-stressing cements are two types of special expansive cements and are classified according to the magnitude of their restrained expansion. Expansive cements increase in volume during the curing cycle placing the reinforcing steel in tension and the concrete in compression. Upon drying, a certain amount of the expansion is lost and depending on the original expansion, the concrete may be self-stressed which reduces or eliminates shrinkage cracks. Self-stressing concrete, when restrained, induces compressive stresses of a high enough magnitude to result in significant compression in the concrete after drying shrinkage is completed. Shrinkage-compensating concrete, when restrained, induces compressive stresses which approximately offset tensile stresses in concrete induced by drying. To offset compressive stresses in either type of concrete, the concrete must be adequately reinforced. Without restraint offered by the reinforcing no stress will be developed.

REFERENCE:
The compressive stresses induced by self-stressing cements usually range from 100-1000 psi while shrinkage compensating cements are about 25-100 psi.

For architectural applications, shrinkage-compensating cements have been most successful in eliminating shrinkage cracks and improving watertightness. They are available in Types K, M, and S through several manufacturers. The chemical composition of these three cements is similar to the composition of Portland cement except for higher sulfate and alumina contents. Strength characteristics and durability of expansive cement concretes are similar to those of Portland cement concretes.

REFERENCE:

"NEW MATERIALS IN CONCRETE CONSTRUCTION." UNIVERSITY OF ILLINOIS AT CHICAGO CIRCLE, DECEMBER 1971.
AGGREGATES

Aggregates used in concrete are inert materials that occupy approximately 75% of its bulk and may be either natural or artificial. Coarse aggregates are usually natural gravel, crushed gravel or crushed stone. Fine aggregates consist of natural sand, or manufactured sand. Artificial aggregates include expanded shales, slates, clays and slag; glass and ceramic materials. Fine and coarse aggregates are graded according to their size, with the fine aggregates passing a sieve opening of 3/8" x 3/8". According to their shape, coarse aggregates are also graded as rounded, irregular, angular, elongated, or flakey. Irregular, angular, and rounded aggregates coming from natural gravel or a crushing process usually provide the best workability, compaction and concrete density. Fine aggregates (sand) should be cubical in shape for the best workability. Sliver particles tend to interlock requiring more water to maintain workability. Fine aggregates should also be free of dust which requires a high water content that may cause excessive cracking. Stone stands produced by crushing rock may tend to have excessive dust and also coarse particles which may cause harsh mixtures.

Aggregate grading and particle shape should be kept constant for uniform workability and density. The coarse aggregate is the highest quality material in the concrete mix and the one that contributes the greatest strength. Coarse aggregates are subdivided according to their density as lightweight or normal weight and are used in non-structural lightweight concrete, lightweight structural concrete and normal weight structural concrete.

Lightweight aggregates used in non-structural concrete consist of two general types and are primarily used for their thermal insulating properties. Such concrete is usually unexposed to weathering. The first type is prepared by expanding products such as Perlite and Vermiculite which produce concrete weighing from 15-50 PCF. The second type is prepared by expanding, calcining or sintering such products as blast-furnace, slag, clay, shale, slate, diatomite, fly ash and others which produce concrete weighing from 45-90 PCF.
Lightweight aggregates used in structural lightweight concrete are the same as those used in the second type for lightweight non-structural concrete. Natural materials including pumice, scoria, and tuff may also be included as lightweight structural concrete aggregates. Structural lightweight concrete weights range from 80-115 PCF.

Aggregates used in concrete should demonstrate good weathering characteristics, freedom from impurities which may affect strength and color, physical and chemical stability at high temperatures, expansion characteristics consistent with the other concrete elements, chemical inertness with Portland cement, resistance to oxidation, and should be inexpensive and available in large quantities. All aggregates used in concrete, especially those exposed, should come from one source to assure quality and color uniformity. Uniformity in color of the fine aggregates is usually more important in terms of the finished product than that of the coarse aggregate. Any aggregate taken from a "local" source that does not have a proven record of performance should be laboratory-tested for quality assurance.

Exposed or facing aggregates require greater consideration than those unexposed. Exposed aggregate finishes may call for a single aggregate size or for gap grading of the aggregate to insure uniform exposure. Aggregates used in conventional mixes are uniformly graded blends of aggregates ranging from 3/16" to 1 1/2" and larger; whereas, gap grading includes only those aggregates in a short size range such as 1 1/2" to 3/4", 1" to 1/2", 3/4" to 3/8", etc.

Soft non-durable aggregates including limestone and other high calcium materials are usually not suitable for exposed surfaces. Facing aggregates should also be examined for the occurrence of iron-base materials which react upon exposure and cause staining.

REFERENCE:
"CONCRETE AND MINERAL AGGREGATES." AMERICAN SOCIETY FOR TESTING AND MATERIALS, ANNUAL BOOK OF ASTM STANDARDS, PART 14, 1975.

PFEIFER, DONALD W. "FLY ASH AGGREGATE LIGHTWEIGHT CONCRETE." PORTLAND CEMENT ASSOCIATION, PUBLICATION NO. RD003.01T, 1969.

When variations are likely to occur in the shape or color of aggregates taken from the same source, provisions should be made for stockpiling.

The selection of aggregates is also critical in the production of white concrete. Due to the greater difference in color between the white cement and aggregates, the white cement has less ability than gray cement to form an opaque film over the aggregates and prevent the aggregate color from showing through. Light color, coarse aggregates are preferable to dark aggregates for this reason. Aggregates should also be examined as with exposed aggregates for particles with an iron-oxide content as prevention of staining is especially important. Stockpiling of aggregates in clean areas set aside for such purposes is recommended. Covering of the stockpiles to prevent contamination is also advisable. The fine aggregates used in white cement contribute significantly to the overall color. Natural sands are usually light yellow and may darken the concrete if maximum whiteness is desired. Crushed stone aggregates such as limestone (dolomite or calcite) and quartz give the best results.

When selecting aggregates such as for white concrete, the economics in relation to the building application should be carefully investigated as certain types may be very expensive. Most concrete producers prefer to use local aggregates with which they are familiar and know can be readily obtained. Unless special aggregates are available through local truck delivery, architects are advised to use special cements to obtain color flexibility, as they are easier and cheaper to obtain.
Admixtures are materials other than water, aggregate, or cement that are used to modify fresh concrete for one or more of the following purposes.

- Increase workability without increasing water-cement ratio
- Accelerate setting time
- Increase strength
- Retard or increase initial setting
- Retard or reduce heat development
- Modify rate of bleeding
- Increase durability to extreme conditions
- Control expansion caused by alkalies
- Decrease capillary flow of water
- Produce cellular concrete
- Improve penetration and pumpability
- Reduce segregation
- Prevent settlement or cause expansion for blockouts
- Increase bond of concrete to steel
- Increase bond of old and new concrete
- Produce colored concrete
- Prevent fungus growth
- Inhibit corrosion of embedded metal
- Decrease unit cost of concrete
Admixtures are generally classified as air-entraining agents, accelerators, retarders, water reducers and pozzolans. Admixtures can be introduced into a cement mix in the form of a commercially available chemical, a proprietary admixture or a special cement in which the material was added during production. When using admixtures in connection with architectural concrete, testing should be conducted to determine what effect, if any, the admixture will have on the color strength and durability of the finished product. The best method is to conduct comparative tests of two or more admixtures of the same type with a test sample not having an admixture. Results must be interpreted carefully.

Air-entraining agents are generally added to all exterior concrete to improve resistance to freeze-thaw cycles (durability) in severe weather zones. Concrete exposed to such conditions should have between 3 and 6% of air by volume. Air-entraining agents usually account for a certain amount of strength loss, but due to improved workability the water-cement ratio can be reduced, thus compensating for the strength loss. Air entrainment used in architectural concrete mixes with high cement factors and large quantities of sand can result in a mix that is very cohesive and difficult to compact. If air entrainment is required for weathering purposes, the minimum percentage allowable should be used. If the concrete is not going to be exposed to weathering, air entrainment should be avoided.

Accelerating admixtures are used to increase the rate of hardening and to hasten strength development at low temperatures. Calcium chloride is commonly used for this purpose and has the advantage of increasing workability and cohesiveness; however, it also contributes to the corrosion of metal and tends to darken and mottle the concrete surface. Excessive use may impair durability. For these reasons it is not advised that calcium chloride be used for architectural concrete.

Set-retarding agents are used to retard or control the initial set of concrete so as to minimize cold joints, lift lines, and extend
placement time. Their use is especially valuable in warm weather where it is desirable to maintain constant consistency of concrete delivery from each truck. They are often used to prevent segregation in mixes that have a high coarse aggregate weight in relation to the cement-sand paste weight. The water reducer minimizes the need for water, thus keeping the specific gravity of the parts in the range of the coarse aggregate. Caution is advised in their use as high dosages may cause set, cracking or discoloration problems.

Water reducing admixtures are used in concrete to reduce the amount of mix water needed, and are occasionally used in conjunction with retarders and accelerators.

Pozzolans or mineral admixtures are added to increase workability; however, they sometimes darken the color of concrete. Fly ash aggregate produced as a result of burning pulverized coal in power plants is a commonly available material.

Other admixtures are available which are designed as plasticisers, waterproofing agents, and gas forming agents. Use of these materials must be carefully considered as to their effects on the mix design and final product appearance.
COLORANTS

Pigmented admixtures or colorants are used to vary the color tone of architectural concrete. Pigments used for this purpose are finely ground natural or synthetic mineral oxides that provide a wider range of color selections than colored cements. Natural oxides may contain inert substances that have no color value, but tend to dilute the richness of the color. Synthetic oxides are practically "all color" in their chemical composition and usually have more attractive colors, greater permanence and better performance.

Synthetic iron oxides are available in reds, yellows, and blacks. Red hues range from yellowish "terra-cottas" to bluish "burgundies", yellow hues range from "cream" to buff colors and blacks range from a light gray to charcoal. Shades of brown or tan may be obtained by proper proportioning of the three "basic" colorants.

Chromium oxides are readily available for producing various shades of green. For special projects where cost is secondary, consideration should be given to such pigments as hydrated chrome, oxide green, nickel titanate yellow, and cobalt aluminate blue.

Inorganic and organic dyes such as water-dispersible carbon black, water-dispersible phthalocyanine greens and ultramarine blues have been used successfully although experience has been limited. Most other organic and inorganic dyes should be strictly avoided especially phthalocyanine blues and inorganic chrome greens.

The color shade obtained in concrete will depend upon the quantity of colorant used. This quantity is expressed as a percentage of the dry cement content by weight and usually is limited to a 10% maximum (ACI). Amounts greater than 5% seldom produce further color intensity while amounts greater than 10% are detrimental to the concrete strength. Dyes are usually used
in quantities of less than 1%. The normal level of colorant in concrete generally has little or no effect on ultimate strength.

Any pigments used in concrete should be stable in the presence of alkalis in the cement, light-fast, chemically inert in service and unaffected by curing at high temperatures. Color fading and "washing-out" with time have been the biggest complaints with pigmented admixtures. A disadvantage of pigmented admixtures during mixing is that it is difficult to obtain color uniformity when they are added at the mixer. Preblending with the cement is an alternative solution. Dyes on the other hand, may be added to the mix water assuring greater uniformity.

The best quality results for color concrete are usually achieved by using colored cements. Pigmented admixtures usually produce more intense colors when added to white cement.

When specifying an admixture a complete description should be outlined including the manufacturer, the trade name of the product, and the areas of intended use. During use the manufacturers' recommendations should be strictly adhered to concerning mixing colorants. Admixture brands should never be changed during any construction where color uniformity is critical.

**MIX WATER**

Water suitable for drinking may be used for architectural concrete. Water containing rust or iron compounds may cause stain on light or white concrete and should be avoided.

**REFERENCE:**

"ADMIXTURES." FRANK O. DAVIS COMPANY, PLAINFIELD, NEW JERSEY, 1976.


GAGE, MICHAEL. "GUIDE TO EXPOSED CONCRETE FINISHES," THE ARCHITECTURAL PRESS, LONDON, 1970.

BATCHING AND MIXING

BATCHING

Batching of concrete mixes involves the actual process of "weighing out" of the ingredients prior to mixing. To produce concrete of uniform quality and color each batch must be accurately proportioned from batch to batch. Facilities for material weighing and dispensing are usually inspected on a regular basis to insure accuracy; however, special attention should always be given to the water-dispensing mechanism. Slight variations in the amount included in the mix often causes discoloration in the finished product. Mixes with a larger water-cement ratio are almost always darker than those with a lower water-cement ratio made with the same cement. This consideration is especially crucial for the production of white cement concrete.

MIXING

Mixing of proportioned ingredients requires as much special attention as other aspects of production where quality and color uniformity are important. The mixing time for each batch should be the same and it is best that this be specified. Mixing time should be sufficient to provide a uniform distribution to cement throughout the mix and should be extended to guarantee this uniformity. Although proper mixing is essential, differences in mixing time will also produce color variations in the finished product. Water added during mixing should be of such temperature that the resulting concrete temperature is kept between 65°F and 85°F. Concrete temperatures higher than 80 degrees result in faster setting time which produces visible flow lines and cold joints if the concrete placement is not properly scheduled.

Cement and dry admixtures, especially colorants should be thoroughly mixed with the aggregate prior to the addition of water to prevent streaking in the finished product. Wet admixtures should be added to the mix water to insure dispersion.

Special attention should always be given to the care and maintenance of the mixing equipment which should be clean and free
from contaminants such as grease, oil, rust and dried cement. Again, this concern is very important to the success of white cement concrete.

PROPORTIONING

The intentions of proper mix proportioning are to produce concrete of required strength without segregation and with finished surfaces uniform in color. Strength design is essentially a function of the water-cement ratio. Strength and durability are inversely proportional to the water-cement ratio which should not exceed 0.46 by weight. Preventing segregation in concrete requires a mix that has good workability and can be easily placed and consolidated. Workability is a function of the consistency or fluidity of a mix and for architectural concrete should not exceed a 4" slump. Workability is affected by the grading and shape of the aggregates, the water-cement ratio, the plasticity of the cement paste, the quantity of entrained air, and the inclusion of other admixtures. The consistency of admixtures for architectural concrete should be kept uniform from batch to batch to prevent color variations in the finished product.

Color uniformity in concrete is affected by many aspects of production; however, mixes for smooth surfaces should be rich in cement, high in fine aggregate (sand content) with continuously graded coarse aggregates. Rich mixes (high cement content) designed to assure color uniformity usually produces concrete exceeding requirements for specified strength. Mixes high in sand content tend to produce bugholes and may necessitate a reduction in the sand content to obtain color uniformity unless form surfaces, release agents, and placing procedures are capable of preventing or reducing bughole occurrence to respectable limits. Use of rich cement mixes with high sand content should be carefully evaluated in terms of cost and the tendency of crazing in concrete.

Gap graded mixes in which the coarse particles of sand and the fine particles of coarse aggregates are omitted are usually designed for exposed finishes where a high concentration of coarse aggregate at the surface is desired for uniform color and texture. Such mixes should have a fine aggregate to coarse aggregate ratio by weight of 1:2.5 to 1:3.
MOVEMENT AND DISTRIBUTION

Movement and distribution, placing, and consolidation of concrete are three distinct stages of production beyond mixing that require special attention if successful results are to be insured. Movement and distribution of concrete involves that process of moving the fresh concrete from the mixer to the form. Concrete may be batched on-site; however, most concrete is batched at an off-site plant, hauled to the site, mixed and distributed to the form. In this latter case, movement and distribution shall include both the movement of the dry mix and the distribution of the mixed, fresh concrete. Placing of concrete is the actual process of depositing the concrete within the form. Consolidation is the process of removing entrapped air from fresh concrete in the form.

Mixing and placing have been subject to a great deal of theoretical research and design. While hauling or movement and distribution is usually dealt with in a more general nature. In fact, it is a significant part of the overall operation in terms of the final cost, concrete quality, and contractors' efficiency. The intent here is to outline for the architect those elements of movement and distribution that contribute to concrete production efficiency and cost savings. While these elements are typically concerns of the contractor, it is important that the architect be aware of them as they may affect the project staging, completion time, and overall cost. At the present time the solutions available to satisfy the conditions of a contract are very broad in scope. They range from the humble wheelbarrow to the now popular mobile concrete pump. With constantly increasing labor costs, mechanized methods of handling concrete are most economical although occasionally simple manpower will prove more viable. Each case must be thoroughly investigated as to determine the most economical and efficient means of placement. In any event, an awareness of equipment characteristics and circumstances affecting handling will be essential.
Care should always be taken with whatever equipment is used to prevent contamination of the concrete mix by dirt, rust, foreign particles or other concrete mixtures. If methods of distribution are varied during construction of architectural concrete the uniformity of color of the finished product may be affected.

The following elements affecting movement and distribution are discussed below:

Circumstances Affecting Appropriate Methods
Temporary Works
Specifications
Selection of Ready-Mixed Concrete
Methods of Distribution

CIRCUMSTANCES AFFECTING APPROPRIATE METHODS
CHARACTER OF SITE
On Site Buildings--trees, ground conditions, seasonal, roads, land contours, access restrictions, noise level restrictions
Boundary Conditions--cranes swinging over adjacent property

AVAILABILITY OF PLANT
Capacity Rates
Supporting Equipment--delivery trucks, conveyor cranes, etc.

EFFECT ON PERMANENT CONSTRUCTION
Can a portion of the permanent construction be left out temporarily to allow efficient handling of equipment for the majority of the work?
Dismantling of equipment upon completion
CONTINUITY OF OPERATION
Weekly Requirements
Intermittent, continuous

SITE-MIXED VERSUS READY-MIXED CONCRETE
Does site and construction allow site mixing?
Is ready-mixed concrete a viable solution?
How is handling effected by either?

WORK SEASON
Time of year
Shutdowns caused by weather

TEMPORARY WORKS
DISTRIBUTION METHODS
Wheeled vehicles require adequate roads and surfaces.
Winter soil conditions may dictate temporary roads.
Barrows and prams used over areas of reinforcement
will require suitable staging.
Vehicle loads may impose additional requirements on
formwork.

SCAFFOLDING NEEDS
Bridges
Towers for Hoists—may be very elaborate for high-rise buildings

ACCESS OVER COMPLETED WORK
Bridging
On Actual Construction
Check to assure permanent work is adequate for temporarily
imposed loads
Provide temporary shoring
Over-design structure to handle loads
SPECIFICATIONS

TIME RESTRICTIONS
Time restrictions on the placing of concrete are very difficult to conform to and consideration should be based on the ability to adequately place and consolidate the concrete within the forms. This judgment may be best left to the contractor.

PLACEMENT RESTRICTIONS
Methods of handling should be discussed between the mix designer and the contractor to best develop a mix and a handling means that are compatible.

SELECTION OF READY-MIXED CONCRETE
The economic viability of ready-mixed concrete is undoubtedly linked with the cost of labor. In the United States the small site mixer has virtually disappeared and the site mix plants are used only on major contracts with high enough volumes of concrete to justify a plant similar to those of ready-mixed companies. It can be demonstrated in certain kinds of concrete work that merely on a cost basis—including mixing, hauling and placing—ready-mixed concrete is rapidly approaching parity with site mixing, and for small intermittent quantities it is demonstrably cheaper. The growth of secondary distribution systems—notably concrete pumps—has added additional thrust to the ready-mixed industry. The following factors should be considered when deciding to use ready mixed concrete:

QUALITY
Mix Uniformity
Color Uniformity

DELIVERY
Plant Capacity
Traffic Delays
Programmed Scheduling
Alternative direct discharge pours in the event of site distribution breakdown
HANDLING CONCRETE SUPPLIED
Secondary distribution means must be able to handle quantities supplied
Quantity of each delivery
Delayed standing costs

TEMPORARY WORKS AND ACCESS
Natural Ground Conditions--adequate for loads
Temporary loads--change with job progress, bridges, culverts

LOADING OF PERMANENT WORK--Structurally Sound
Specifications prohibit trucks crossing prepared foundations
---Additional Access Roads
---Secondary Distribution Means

VEHICLES ARE OFTEN REQUIRED TO DISCHARGE AT EDGES OF EXCAVATIONS
Temporary support for high surcharge load of full vehicles

VEHICLES TYPICALLY DISCHARGE FROM REAR
Adequate turning space near discharge point to avoid excessive backing

VEHICLE WASHDOWN AFTER DISCHARGE
Site drainage
Site damage
Blocking other arriving vehicles
METHODS OF DISTRIBUTION

Concrete's movement from the batch plant or truck mixer to the form may be by free or guided fall, powered lift, field transport, moving belt support, or pressurized flow. The restrictions affecting choice are time, cost, and site-access. The following methods are the most commonly used:

Chutes
Least expensive, least complex method of reaching lower elevation.

Drop Chutes
(Elephant trunks) rubber, plastic or steel chutes that attach to hoppers to guide concrete straight down without segregation. Used in tall wall forms.

Buckets
Used with cranes. Use is subject to limitations of crane and overhead restrictions. Available in bottom dump and lay-down type.
Capacity: 1 yd. bucket, 240 FPM crane:
73 yd./hr. at 50 ft. lift
36 yd./hr. at 200 ft. lift

Buggies
Motorized or manual barrows, require clear runways, ramps (5:1 slope max.) or hoists.
Practical Distance Range: Manual 200 Ft., Power 1000 Ft.
Capacity: Manual 3 to 5 yd./hr.
Power 15 to 20 yd./hr.

Conveyors
Cannot pass high vertical obstructions, but can go through windows, etc. 2:1 slope is limit both uphill and downhill. Requires longer set-up time than other methods.
Range: 2000 Ft.+
Capacity: 100-360 yd./hr.
Several restrictions regarding mix consistencies. May require slickline set-up for long runs—truck mounted units usually do not require such.

Range: Vertical 50-450 Ft.
      Horizontal 250-2000 Ft.

Capacity: 5-160 yd./hr.

Miscellaneous

Cable ways
Monorail
Helicopter
PLACEMENT

Placing concrete within the form should be done slowly in layers, varying in thickness from 12" - 18". The thickness varies on the width of the form and the amount of reinforcement. The concrete placement must be as near as possible to its final location with each layer being fairly level so that vibrators do not have to move the concrete laterally, which causes segregation. Each layer should be placed horizontally in uniform thicknesses with the proceeding layer being thoroughly consolidated. This helps to prevent segregation and sloping lift lines. Uniformity of aggregate distribution can be assured somewhat by using relatively stiff mixes (slump less than 4") of air entrained concrete. Concrete is best deposited into the form vertically, not at an angle, through elephant trunks or plastic chutes to avoid form splashing and segregation. Special care should be exercised to prevent splashing while concrete is being placed. This causes color and texture variations on the finished surface due to the spashed cement paste drying before the surrounding concrete is placed.

Concrete placed for slabs should always be dumped into the face of "in-place" material and never set in separate piles. On sloped surfaces concrete placement should begin at the bottom of the slope and work up. When using chutes or conveyors a short drop pipe should always be used at the end, which can easily be shifted or shortened to adapt to varying conditions. Conveyors should be equipped with wiper blades to keep the returning belt surface clean and free of build-up.

Use of buckets in conjunction with cranes is a very popular method of concrete movement. Discharging from buckets into chutes or elephant trunks is recommended practice, with direct discharge along the top of forms being allowed only when segregation will not occur. Buckets should be of the steep sided, bottom-dropping, type to facilitate the flow of low slump concrete. Use of two buckets per crane reduces waiting time.
When concrete is to be placed by means of a pump, appropriate equipment compatible with the mix should be used. Concrete pumps have many restrictions regarding their capabilities and an architectural concrete mix should never be designed to accommodate those restrictions. Pumps may require the use of retardant admixtures to prevent clogging and limitations on maximum aggregate size to facilitate pumpability. There are, however, many pumps which are capable of handling low slump, high coarse aggregate factor mixes. Architectural specifications regarding mix designs used with concrete pumps must clearly state what the priorities are.
CONSOLIDATION

Fresh concrete deposited in a form or a mould is usually honeycombed with entrapped air. Entrapped air is the incidental or accidental air voids in concrete, and does not include air entrained intentionally for durability. Unless entrapped air is removed, the resulting concrete will be weak, porous, non-uniform and poorly bonded to the reinforcement. The mix must be consolidated (densified) if normal results are to be expected. Consolidation of concrete can be accomplished by several methods and techniques depending on the workability of the mix, placing conditions, and the degree of deaerification desired. Elimination of entrapped air throughout the mass and a minimum of surface voids are especially important for architectural concrete.

Workability is that property of fresh concrete which determines the ease with which it can be handled, consolidated, and finished. It is affected by the grading, particle shape, and proportions of the aggregate, the cement content, admixtures used, and the consistency of the mix. Consistency is the ability of freshly mixed concrete to flow, and largely determines the ease with which it can be consolidated. After materials and mixed proportions have been chosen the primary control over workability is through changes in consistency affected by changing the water content. Consistency is measured in terms of slump. Measurements of slump as related to consistency are as follows:

<table>
<thead>
<tr>
<th>Consistency</th>
<th>Slump (In.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extremely Dry</td>
<td>--</td>
</tr>
<tr>
<td>Very Stiff</td>
<td>--</td>
</tr>
<tr>
<td>Stiff</td>
<td>0 - 1&quot;</td>
</tr>
<tr>
<td>Stiff Plastic</td>
<td>1 - 2&quot;</td>
</tr>
<tr>
<td>Plastic</td>
<td>3 - 4&quot;</td>
</tr>
<tr>
<td>Flowing</td>
<td>5 - 7&quot;</td>
</tr>
</tbody>
</table>
Stiffer and dryer mixtures (less slump) will require greater compactive efforts to properly consolidate. As the water content of such mixes is increased to improve workability, the quality (strength and durability) decreases; however, excessively dry mixes may be difficult to adequately compact.

Workability of mixes is also affected by placing conditions such as high temperatures, delays, false sets, etc., which necessitates additional consolidation efforts. Successful results in the finished product will require a mix suitable for the form conditions and consolidation techniques appropriate for the consistency of the mix after placement.

Actual methods of consolidation vary depending on the type of construction—precast or cast-in-place—but, in general the most widely used method is vibration. Vibration subjects the fresh concrete to rapid vibratory impulses which "liquify" the paste and greatly reduce the internal friction between the aggregate particles. Vibration is especially adapted to stiffer consistencies associated with architectural concrete and may be either of the internal or external type.

Internal vibrators are inserted vertically at uniform spacing into the fresh concrete after each lift. The distance between insertions will depend on the properties of the mix and the effectiveness of the vibrator. The area visibly effected by the vibrator should overlap the just-vibrated area. There should be a row of insertions within 6" of the form face; however, if the concrete is to have an exposed aggregate finish the vibrators should be kept at least 3" away from the face. This is to prevent pockets of fine materials from collecting near the face which may also produce a darker color in the unexposed concrete. The vibrator should not be inserted within two feet of any unconfined edge as it will cause the concrete to move laterally producing segregation.
The vibrator should penetrate rapidly to the bottom of each lift and at least 5" into the preceding lift if there is one. It should then be held stationary for a period of time—usually 10-30 seconds and then withdrawn slowly to effectively insure consolidation. Harsh mixes such as those that are gap-graded will require more powerful vibrators and longer vibration times.

When air voids at form surfaces are to be minimized the time of vibration must be increased and the vibrator should be placed closer to the form (minimum 3"), with closer insertion spaces. Depending upon conditions it may be possible to insert a smaller rubber-tipped vibrator between the form face and the reinforcing to eliminate surface voids. This practice must be executed with extreme caution as the vibrator could mar the form surface and disfigure the concrete. In all practice, the vibrator should never be allowed to come in contact with the formwork.

Vibrations should be ceased when the cement paste level reaches the top of the aggregate. Excessive vibration beyond this point will produce an aggregate-free layer known as a "mortar lense" which will be a visible line between lifts. Abrasive blasting at later stages will exaggerate rather than diffuse this line. A remedy for this situation is to hand place aggregate of the same type used in the mix onto the layer of paste. This must be done directly after vibration and will require considerable care and uniformity in placement. The aggregates should fully penetrate the paste layer creating a homogeneous mixture. Mortar lenses can be eliminated in concrete columns by first placing the vibrator(s) in the form prior to concrete placement. The form is then filled to the required grade with the vibrators remaining idle; thereafter, the vibrators are turned on and slowly withdrawn. Experimentation on the mock-up or on unexposed columns should be conducted to determine the number of vibrators needed and optimum vibration time for specific conditions, including size of column, amount of reinforcing and mix consistency.
After several lifts of concrete have been placed and adequately consolidated there usually is a build-up of air voids within the last two feet of placement. This is due to the hydrostatic pressure of the concrete forcing the entrapped air in lower lifts upward, and the vibration of the upper lifts affecting the consolidation of the lower lifts. This concentration of entrapped air in the last few feet of a pour can be removed by revibration. This is a process whereby the upper few feet of the concrete, after bleeding, but before initial set, is vibrated again to further densify the concrete and reduce water pockets. Revibration is accomplished by allowing a "running" vibrator to sink by its own weight into the concrete and liquify it momentarily. Revibration also results in improved bond and compressive strengths. The best results are achieved with wetter mixes. Revibration should not be used where harsh, gap graded mixes are used to expose aggregate surfaces.

Spading is a manual method of consolidation sometimes used in conjunction with internal vibration techniques to improve formed surfaces. A flat, spade-like tool is repeatedly inserted and withdrawn adjacent to the form. This forces the coarse particles away from the form face and releases trapped air bubbles. This process requires considerable time to assure uniformity and is very labor-intensive.

External vibrators can be divided into three types: form vibrators, surface vibrators, and vibrating tables.

Form vibrators are external vibrators attached to the outside of the form or mould. They vibrate the form which in turn transmits the vibration to the concrete. Form vibration is recommended in areas inaccessible to internal vibration. Forms for external vibration must withstand repeated, reversing stresses induced by the vibrators. The forms should be of adequate thickness and stiffness
to withstand these stresses and yet uniformly transmit the vibrations over a considerable area. Special attention must be given to form joints to prevent leakage.

Surface vibrators are used for slab and horizontal surfaces and usually perform two functions: consolidation and leveling of the concrete, which assists in finishing.

Vibrating tables are used in precast construction and usually consist of steel reinforced tables with external vibrators rigidity mounted to the supporting frame. The table and frame are isolated from the base by steel springs or neoprene isolation pads. The table is part of the mould which transfers the vibrations to the mould and hence to the concrete.
Due to an intense concern for the visual appearance of concrete, especially vertical surfaces, defects must be minimized and controlled. Many defects result from insensitive care in the casting of concrete or simply a lack of experience on the part of the contractor and architect. Among the most troublesome defects are honeycombing, grout leaks, sandstreaking, variations in color, soft spots and surface voids. It is important to mention that some surface markings are considered typical of the material and will be tolerated or even desired; however, the importance of this discussion centers around proper consolidation of the mix and the development of a uniform surface. The primary concern for architectural concrete then becomes that of controlling surface voids (bugholes) which tend to concentrate in the middle and upper portions of a casting.

The following is a list of factors affecting surface voids and suggested remedies.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Suggested Remedies</th>
</tr>
</thead>
<tbody>
<tr>
<td>VIBRATION</td>
<td>Increasing the number of vibrator insertions is more effective than one insertion for a constant time period. Effective vibration testing leading to detailed instructions for workmen and the number and positions of insertions as well as vibration time.</td>
</tr>
<tr>
<td>MIX CONSISTENCY</td>
<td>Fluid mixes have fewer voids than plastic mixes; however, strength reduction becomes a critical factor. It is advisable that architectural concrete mixes be in the plastic range (slump 3-4&quot;).</td>
</tr>
<tr>
<td>LAYER (LIFT)</td>
<td>Thin layers have less voids than thick layers. A standard of 12&quot; has been established by the industry as optimum.</td>
</tr>
</tbody>
</table>
FORM MATERIAL

Research has indicated that there is a direct relation between form impermeability and the size and number of surface voids. Concrete in an impermeable form such as steel requires more consolidation than in a permeable one. Texture of the form surface is not considered to effect results.

RELEASE AGENTS

Release agents make the form surface more impermeable although only slightly, irrespective of the type of agent. Criteria for release agent selection should be based on release considerations and not on permeability factors.

CEMENT

Differences in cement brands, quality, and type should not create noticeable differences with respect to surface voids. Higher cement content in the mix helps somewhat in reducing surface voids and in decreasing segregation.

AGGREGATE

Better results are obtainable with a surplus of fine aggregate (less than .01" dia.) and less satisfactory with a shortage.

AIR-ENTRAINING

Air-entraining agents, producing smaller air bubbles, act as lubricants to larger accumulations of air thus reducing void formations. The consistency of mix will also show noticeable improvement.
CONCLUSION

Surface void formations on concrete surfaces can be influenced and controlled through several means available during the time of production. The following should be observed:

THOROUGH AND SUFFICIENT VIBRATION
Avoidance of Harsh Consistencies
Maximum 12" Lift Layers
Increased Vibration with Impermeable Forms
Surplus of Fine Aggregates (0.01")
Inclusion of Air-Entraining Agents
Curing is that process whereby concrete is allowed to reach a specified strength and degree of durability under controlled conditions. The presence of moisture at moderate temperatures is necessary for complete hydration of the cement. In practice, the only curing provided is often that by the formwork before it is removed. Before the formwork can be stripped the concrete must have sufficient strength to be self-supporting and resistant to mechanical damage during the stripping process. In many cases forms are stripped at an early "age," to allow reuse of the forms, and the concrete will need additional protection (curing) to effectuate strength development.

Concrete left "in the form" for curing may be subject to stripping problems if left too long. A bond may develop between the form face and the concrete surface making removal not only difficult, but expensive in terms of form damage or spalling of the concrete surface. This condition is especially critical with textured-absorbent forms.

It is important to note; however, that where color uniformity is critical the formwork should not be removed before four days following placement. If after this time additional curing is needed several options are available. An alternative to complete form removal is to "crack" the forms away from the concrete surface just enough to facilitate release and yet still offer the protection needed. Caution must be assured with this practice in that any form or portions of a form remaining in contact with the concrete will cause discoloration of that area in relation to the remaining surface. "Cracked" forms should also be covered to prevent air circulation from causing uneven or rapid curing.

Forms that are removed completely, whether curing is completed or not, should be stripped at constant times. Erratic stripping schedules lead to variations in concrete maturity which causes differences in color. Beams from which the vertical formwork is stripped earlier than the soffit section display a significant color difference.
Where additional curing is needed after form removal, the concrete will have to be protected from rapid moisture loss by evaporative winds or intense heat. Concrete that has been allowed to dry quickly will be lighter in color initially than concrete that has been kept moist. This difference in color may persist although it will become less noticeable in time.

Two methods of preventing this condition after form stripping are moist curing and membrane curing. Moist curing involves covering of the concrete with absorbent materials such as felt, straw, waterproof paper, etc., which are kept continually wet through the curing period. Plastic sheets may be used in conjunction with these materials or by themselves to prevent evaporation of moisture. Caution must be observed when using plastic sheets directly over concrete as color differences (mottled effect) will occur where the plastic contacts the concrete and areas where it does not. This is the result of a condition known as a "greenhouse effect." Moist curing can also be accomplished by ponding or continual sprinkling of the concrete surface with water. Curing water used in any form of moist curing should be nonstaining.

Membrane curing utilizes commercially available liquid compounds that are sprayed over the surface forming a moisture resistant barrier. These compounds may cause discoloration or staining and may prevent bonding of repairs as permanent coatings. Use of membrane compounds is best limited to architectural concrete where surface treatments such as bushhammering, or abrasive blasting will eliminate any surface variations. Membrane compounds should not be used with any form of white concrete. White concrete or light colored concrete shows the best results when moist cured using waterproof paper as a moisture barrier.

HOT WEATHER CONCRETING

Important consideration during hot weather or windy days is to protect and cure the concrete during the first few hours after placement. Rapid or nonuniform drying causes plastic shrinkage cracks and color variations. Curing practices should be started as soon as practical and may have to be started before the entire placement is
completed. Protection and curing are most critical where large areas are exposed, particularly horizontal slabs. Exposure to direct sunlight also allows the concrete to gain excessive heat, beyond its own heat of hydration, which causes expansion of the overall mass. When the concrete cools overnight contraction of the mass produces high tensile stresses which may cause cracks if the differential movement is great enough. It is therefore important to insulate exposed concrete from both excessive heat gain during the day and cooling during the night. Effective thermal insulation should be available for use in such conditions. Some contractors have also practiced adding ice to the mix water to keep the temperature within acceptable limits. It is important to note that hotter mixes allow more rapid evaporation of mix water than do cooler mixes.

COLD WEATHER CONCRETING

Concrete placed during cold or freezing temperatures is subject to impaired strength and durability unless certain precautions are followed. The temperature of the mix must be kept from freezing and preferably within prescribed limits during placement and curing. Architectural concrete should be kept above 45°F at all times during placement. The easiest way of producing warm concrete is to heat the mix water. The coarse aggregates may also be heated but that is usually more difficult than heating the water. Caution must be observed in this practice so as not to overheat the mix which causes loss of workability.

In addition to heating the mix water, the formwork and reinforcement should also be warmed prior to placement. Frost or ice should be removed from the reinforcement before each lift as the bars have a tendency to frost over quickly if the air temperature is below freezing, even though they were thawed out at the start of the work.

After placement, the concrete can be protected from freezing by hot air and steam heaters, protective covers and insulation. It is also important to note that concrete produces its own heat during hydration and that this heat can be utilized if sufficient insulation is provided. Heat of hydration should not be relied on as the sole source of heat where freezing temperatures are encountered. The ambient air temperatures surrounding the formwork
should be kept above 45°F throughout the curing process.

If the concrete is prevented from freezing until it has reached maturity and sufficient strength, it should be able to withstand freezing temperatures without damage as long as it is not saturated at the time of freezing. It is advisable, however, to protect new work from rapid temperature drops until such a time that its strength can be confirmed by test samples.

Warm concrete surfaces should not be exposed to cold air or cold water when the forms are stripped, as rapid cooling of the surface will cause differential temperature stresses resulting in possible cracks.

FINISHING

Following form removal and proper curing, most concrete surfaces will require some degree of finishing to repair damaged areas or variations in color or texture. Approved repair techniques should be developed on the mockup regarding method and acceptable finish. They should be well established in advance so that actual repair can be executed promptly and with assurance of desired results.

TIE HOLES

Tie holes should be plugged as soon as practicable to prevent corrosion of the tie and possible staining of the concrete surface, except where stainless steel ties are used. Materials used for plugging tie holes include cement mortar grout, epoxy mortar, plastic plugs, precast mortar plugs and lead plugs. Care should be taken to select a material that is nonstaining. When using wet materials care should be taken not to smear the face of the concrete thus creating color variations.

When using cement mortar grout the tie holes should be prewet with clean water and then a neat cement slurry bond coat should be applied. This aids in the bonding of the mortar grout. Epoxy mortar should be applied with a caulking gun in strict accordance with the manufacturers' recommendations. Plastic plugs are either wedged into the tie holes or held in place by adhesives. If cones have been used
with form ties they should not be removed until after mechanical surface treatments have been performed, thus preventing rounding of the edges. After treatment, if the cones cannot be removed without damage to the surrounding area, it is advisable to drill out the cone with a diamond bit tool. This may be the most economical method when uniform hole appearance is critical.

BLEMISH REPAIR

Repair of surface blemishes should be conducted as soon as possible after form removal to allow the repaired area and the surrounding concrete to age together. Troweling should be avoided since this makes the repair appear dark in color. Concrete repair should be cured as long as possible—at least several days. Where abrasive blasting or bushhammering treatments must be matched, experimentation should be performed on hidden or unimportant areas first. Light abrasive blasting may accentuate cracks or blemishes and should be performed cautiously. Where large cracks occur it is advisable to first fill them with epoxy which prevents rounding of the edges. After blasting, the epoxy fin can be broken off leaving a relatively unnoticeable line. When the appearance of as-cast surfaces is unacceptable it may be necessary to heavily abrasive blast the concrete to diminish cracks and other blemishes.

STAIN REMOVAL

The most common stain on architectural concrete is rust—usually caused by water washing rust from reinforcing bars (extending out of an element for connection to the next concrete element), by form hardware, reinforcing steel accessories or other ferrous materials carelessly left on top of surfaces. Exposed reinforcing steel can be coated with a slurry of neat Portland cement and water to temporarily prevent rusting.

Stains from various causes can usually be removed by commercially available stain removers; however, some alteration of the surface may occur. Experimentation should be conducted on areas less critical in appearance, to determine the best method and material to be used. The most effective method for rust stain removal is as follows:

REFERENCE:
"REMOVING STAINS FROM CONCRETE." PORTLAND CEMENT ASSOCIATION, PUBLICATION NO. 15142, O37, 1970
The rust stain should be soaked for 10 min. with a solution of 1 oz. of sodium citrate in 6 oz. of water. (Brushing the solution on at short intervals is satisfactory.) Then the surface is sprinkled with crystals of sodium hyposulfite and covered with a paste of fuller's earth and water. On a vertical surface, the paste is applied with a trowel, after the crystals have been sprinkled on the surface of the paste that will come in contact with the walls, so that they will be in direct contact with the stain. The paste is allowed to dry 10 min., then scraped off, and the treatment repeated if necessary. An alternative method is to use a saturated solution of sodium hyposulfite mixed with fuller's earth instead of the paste and crystals. However, considerable sulfur dioxide gas is generated, and this method should only be used outdoors. The surface should be flushed copiously with clean water upon completion.

Removal of efflorescence is best accomplished by dilute applications of muriatic acid (5-10 percent solutions) followed by a water spray to prevent surface etching. If acid treatments are not successful, use of detergents or a light abrasive blasting may be necessary.

For removal of other more serious stains the author recommends review of the publication, "Removal of Stains from Concrete," Portland Cement Association, which outlines detailed methods and precautions.

CLEAR COATINGS

Clear coatings are used when protection from atmospheric contaminants are necessary to the appearance of the building. Clear coatings are usually applied to surfaces to serve one or more of the following purposes.

1. To reduce attack of industrial airborne chemicals.

REFERENCE:
2. To inhibit soiling of the surface; however, some coatings have an affinity for airborne contaminants.
3. To facilitate cleaning of the surface.
4. To avoid darkening of the surface when wetted.

Smooth surfaces light in color usually are more susceptible to discoloration than exposed aggregate surfaces and will require coating. Tests have indicated that the best coatings consist of methyl methacrylate forms of acrylic resins which are resistant to ultra-violet radiation. Coatings based on polyurethanes, epoxies, polyesters and their combinations have a glassy appearance and tend to yellow or darken the surface of the concrete.

Joints should be caulked before application of coatings so as not to prevent bonding of the caulking compound. Care should be exercised when applying the caulking compound so that it does not smear the surface to be coated. Caution should be observed when applying coatings above flush windows as certain coatings wash down with time and may stain the glass.
TREATED SURFACES
Architectural surface finishes can be divided into two categories: as-cast—where the surface is left undisturbed after the forms are stripped, and treated—where the surface is abrasive blasted, fractured, ground, etched, chemically retarded or receives a combination of treatments. As-cast surfaces have been discussed in previous chapters; however, as a general review they should be uniform in appearance, flat, and free of major defects. To prevent flaws or discoloration the forms must have watertight joints and be constructed of materials that either resist water absorption completely or absorb it uniformly. Textures are created by form liners made of wood, plastic, metal, and rubber. Selection will depend on the finish desired. Flexible plastic or rubber liners should be used with deeply profiled surfaces to facilitate release during shipping. Quality control over operations affecting production is essential to assure uniformity of as-cast surfaces.

Treated surfaces are done so as to expose the fine and coarse aggregates. Each method of exposing the aggregates previously described creates a different appearance on the concrete surface and will impose certain requirements for the exposed aggregate in terms of shape, size, texture, and color. The greater the aggregate exposure the less important is the color of the cement matrix. Treated surfaces are susceptible to atmospheric pollution and consideration should be given to the color and shape of the aggregate as well as the cement matrix color. In areas subject to air pollution, round aggregates tend to collect dirt, eventually becoming darker than the cement matrix.

ABRASIVE BLASTING

Abrasive or sandblasting of architectural concrete surfaces is usually done to make the surface more uniform in color and texture, to dull the as-cast surface or to expose the aggregate. The depth of treatment will depend on whether the coarse aggregate is to be exposed or if the surface is just being lightly blasted to remove blemishes (fine aggregate exposed).
The best appearance of sandblasted surfaces is achieved by using a gap-graded concrete mix of low slump and adequate cement content. For example, the aggregate size might be confined to a range of 3/4" to 1 1/2" omitting sizes between No 4, and 3/4". The sand quantities are preferably quite low, approximately 25 to 30 percent of the total aggregate. The use of masonry sand, instead of concrete sand will be more pleasing in appearance. A mix of this type requires a cement content of about 565 lb. per cubic yard. The mix should also be air-entrained to improve workability and should have a slump between 1" and 3". In general, there are four classes of abrasive blasting producing surfaces categorized as (1) brush, (2) light abrasive, (3) medium abrasive, (4) heavily exposed aggregate.

Brush blasting is a fine sand scouring under low pressure to remove minor surface variations. Since the cement determines the overall color, a uniformly graded mix is suitable for a brush-blast finish. To prevent imperfections or marks in the concrete surface, form butt joints should be sealed with compressible fillers and not taped.

Light abrasive blasting of the concrete surface uncovers the fine aggregates as well as the edges of some coarse aggregates. The concrete mix should be conventional with about 10% more coarse aggregate than usual. Form joints may be taped to insure watertightness and most likely will disappear during blasting.

Medium abrasive blasting uncovers coarse aggregate around the edges which should protrude uniformly. A mix with a high coarse aggregate factor increases the likelihood of uniform distribution.

Heavily exposed aggregate finishes are produced by drastically eroding the surface to display the coarse aggregate. Gap-grading is best for gradation less than one inch maximum. Larger size aggregates are harder to handle and may segregate during handling and placing. For finishes requiring larger size graded aggregates, the aggregates should be preplaced and the grout added after.
Under this classification system, there is no established requirement for the total amount of matrix to be removed. Each class is related to the size of the aggregate involved. However, if required, the following approximate depths of exposure for each class may be used:

<table>
<thead>
<tr>
<th>Class</th>
<th>Depth</th>
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<tbody>
<tr>
<td>Class 1</td>
<td>(1/32 in. deep)</td>
</tr>
<tr>
<td>Class 2</td>
<td>(1/16 in. deep)</td>
</tr>
<tr>
<td>Class 3</td>
<td>(1/4 in. deep)</td>
</tr>
<tr>
<td>Class 4</td>
<td>(3/8+ in. deep)</td>
</tr>
</tbody>
</table>

(Measured from the original surface to the typical depth of mortar removal between pieces of coarse aggregate.)

Light abrasive blasting treatments require special effort by highly skilled operators as defects resulting from forming and placing (bugholes) are accentuated by such treatments. Additional thickness should be provided for treated surfaces to maintain the required minimum coverage over reinforcement. Abrasive blasting should take place as determined by scheduling, economics, visual appearance desired, and hardness of aggregate. Softer aggregates tend to abrade more when concrete strengths are high. If a greater reveal is desired, blasting should take place usually with the first 24-72 hours after casting and when the concrete strength is above 2000 PSI. Appropriate blasting times should be determined on the mockup and uniformly adhered to thereafter.

Materials used for abrasive blasting include silica sands, aluminum carbide, black slag particles, and walnut shells. The type and grading of the abrasive determines the surface treatment and must remain constant throughout the process. White cement should be treated only with materials that are non-staining.

Many community zoning laws require wet, abrasive blasting in order to maintain pollution standards. When this requirement must be fulfilled, the abraded mortar should be continually washed from the blasted areas to prevent staining.
FRACTURING

Fracturing of architectural surface is the process of chipping or spalling of the surface to expose the coarse aggregate and leave a roughened surface. Methods of fracturing concrete surfaces include: bushhammering, scaling, and tooling. Smooth and profiled surfaces (ribbed) are the most common formed surfaces to be treated by fracturing. Only the projections of ribbed surfaces are treated, leaving a surface of alternate rough and smooth areas. Orientation of equipment used in treating smooth formed surfaces must be kept constant if uniformity of appearance is desired. In some cases it may be necessary to specify that one equipment operator perform all treating operations in order to maintain uniformity.

Bushhammering is a manual or power operation with a multipointed tool that produces a varicolored broken stone effect with a moderate texture. Most bushhammering performed today is done with pneumatic tools fitted with various tool bits. The type of tool used will determine the surface effect desired. Most bushhammering removes approximately 3/16" of material, and additional cover will be required. To prevent loosening of the aggregate during treatment, the concrete should have a minimum compressive strength of 4000 PSI in a minimum age of 14 days. The best uniformity is usually achieved after 21 days on surfaces that are dry. An important consideration when treating smooth surfaces is proper handling of corners. Bushhammering usually produces jagged corners. It is recommended that either the treatment be held back 1-2" from the corner or that the corner be chamfered.

Jackhammering is a variation of bushhammering that uses a single point or a chisel tool to fracture the concrete surface.

Scaling is an operation that uses a chisel-equipped pneumatic tool that works over the surface without causing a deep etched or major texture change.

Tooling utilizes one or more mechanical fracturing devices that travel over the concrete's surface on a predetermined course, sometimes guided by jigs to produce a variety of patterns and textures.
GRINDING

Grinding of architectural surfaces is done primarily to expose the natural color of the fine and coarse aggregates and to produce a smooth surface similar to terrazo. Grinding is a very labor-intensive operation that is usually very expensive to perform especially on vertical or overhead surfaces. Final cost is determined by the hardness of the coarse aggregate and desired exposure.

CHEMICALLY RETARDED

Exposed aggregate surfaces can be produced by washing away the sand-cement matrix on the surface after form removal. In order to perform this operation, the surface skin is chemically retarded from setting by application of a retarder to the form surface prior to concrete placement. The overall effect depends upon the mix and its temperature, ambient temperature and absorption qualities of the form. Prolonged exposure of forms coated with retarder prior to placing may also affect the action of the retarder. Accelerators added during cold weather concreting may shorten the delay of set at the surface. Experimentation on areas of minor importance should be conducted to determine factors such as the effect of height on placement, form stripping times, and method of exposure. The recommended minimum strength prior to removal of the retarded surface should range from 1000-1500 PSI. Use of chemical retarders on vertically cast surfaces can be very difficult requiring thorough preplanning and stringent supervision. For these reasons it may be best to avoid the use of retarders for this purpose.

ETCHED

Acid etching is a process whereby the surface of the concrete is coated with a solution of muratic acid to bring out the full color of an exposed aggregate. Acid should be used only on surfaces that contain acid-resistant aggregates such as quartz or granite. Limestone, dolmites, and marble will discolor or dissolve due to their high calcium content. Acid washing is not recommended for vertical surfaces due to the hazards of application. Uniform application of the acid is difficult due to runoff.
Complete neutralization of the runoff is also difficult and may create problems at the ground level.

**COMBINATION TREATMENTS**

Combination treatment involves the application of more than one finishing technique. Such combinations usually involve creating a texture or profile via the formwork and treating the surface after stripping. Typical examples include: casting a striated surface and abrasive blasting, and reeding and chisel raking a surface.

The table on the following page outlines the relative significance of construction details on the result of various architectural surfaces. With a rating of "1", the degree of influence is high and careful control is critical to good results. With a rating of "4", the degree of influence is low and construction methods normally used for good structural concrete are sufficient.
## ARCHITECTURAL CONCRETE QUALITY

### Relative significance of construction details on the results

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<th>Concrete Mix</th>
<th>As Cast Finish</th>
<th>Distressed Finish</th>
<th>Influence</th>
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<td>Abrasive Blast</td>
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* Abrasive

REFERENCE:
The Construction Specifications Institute, Inc.,
1150 Seventeenth Street, N.W.,
Washington, D.C.
REFERENCES

10
ADDITIONAL REFERENCES


Knowles, P.R. "Composite Steel & Concrete Construction."


Waddell, Joseph J. "Precast Concrete: Handling and Erection." Iowa State University Press and American Concrete Institute, 1974.


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Sika Chemical Corp.
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San Diego, CA 92121

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The Tube Slab Company
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Hartford, CT 06105

Universal Form Clamp Company
1238 N. Kostner Avenue
Chicago, IL 60651

Western Wood Products
Association
Yeon Building
Portland, OR 97204
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