

Challenges in Making Concrete Economical

by Russell S. Fling

Synopsis: Economy in concrete construction is discussed in the light of 3 challenges:

1. The challenge of economizing design,
2. The challenge of economizing construction, and
3. The challenge of standardizing construction.

Procedures engineers may use to reduce the cost of construction are given. Suggestions for standardizing concrete construction include standards for concrete classes, column sizes, column spacing, column capitals, and tolerances.

Keywords: concrete construction; costs; economics; formwork (construction); framing systems; modular structures; standards; structural design; tolerances (mechanics)

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Russell S. Fling graduated from Ohio State University in 1949 and founded the consulting structural engineering practice in 1953 that he headed until retirement in 1983. He has been active on many ACI committees and was President in 1976.

Design of concrete is an interesting exercise in predicting the behavior of a structure before it is built. Likewise, construction is an exciting activity. Design and construction with concrete provide a living for a large number of people. However, anyone who approaches his job with these objectives in mind will quickly find that the real purpose of construction is to provide the owner with a facility that meets his requirements at a price he is willing to pay.

Successful people -- architects, engineers, contractors and their suppliers -- must continually reexamine and improve their operations to serve the owner. What are the most expensive, most laborious, most difficult aspects of concrete construction and what can be done to reduce the cost, labor and difficulty? We are all here this week hoping to glean answers to these perennial but vexing questions.

Let us consider these questions in the light of three challenges facing the concrete industry today in its effort to reduce costs:

1. The challenge of economizing design,
2. The challenge of economizing construction, and
3. The challenge of standardizing construction.

THE CHALLENGE of ECONOMIZING DESIGN

Last year, I took a limited, informal survey of 32 practicing structural engineers and asked them to rank the difficulty of design in various structural materials and the ease or difficulty of various aspects of reinforced concrete design. All respondents agreed that concrete design is significantly more difficult than steel design. Almost all agreed that concrete design is more difficult now than when they started practice --

except those who started since 1977. The survey elicited comments such as:

- "The process is entirely too cumbersome."
- "Too many steps, too involved."
- "It is almost as if they were trying to make the Code difficult."

Clearly, there is widespread dissatisfaction with Code complexity and much room for meaningful simplification. A position inferred by several respondents has been stated explicitly in private conversations: the complexity of ACI318, Building Code Requirements for Reinforced Concrete, is driving many engineers to recommend other framing materials whenever they have a choice. This is not in the best interest of the concrete industry (or industries, if you prefer).

Summarizing survey results, there are four areas of design especially in need of simplification. In declining order of difficulty, they are:

1. Torsion - - engineers still don't understand it,
2. Deflection - - accuracy of results don't justify extensive calculations,
3. Two-way slabs - - too many steps require too much bookkeeping and risk of arithmetical error, and
4. Column slenderness and interaction between moment and axial load - - most troublesome, takes the most time.

While economizing design is an important subject and interesting to those of us involved in design, it is not one of the primary subjects of this conference. I'll leave it then with a comment by Prof. Siess, past President of ACI and past Chairman of Committee 318, who said it is easier to simplify use of the Code than it is to simplify the Code. We can all do the former but few of us can do the latter.

THE CHALLENGE of ECONOMIZING CONSTRUCTION

What changes in design techniques will result in more economical buildings? What construction procedures reduce the cost most while maintaining quality? These are important questions architects, engineers and contractors must answer to remain in business. We will hear much discussion related to

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these issues during this conference.

Most often, construction simplification starts in the design office. The architect must design a building that permits a modular structural system amenable to low cost solutions. Even on monumental buildings the design team should conserve costs within the bounds of the special design requirements.

Architectural layouts should permit uniform spacing of columns and uniform story heights for the most economical structure. And, since a uniform column size and shape throughout the building is most economical, architects should incorporate identical columns in the design. Most other details of a structural frame do not affect architects, so they show little interest in them.

Since structural engineers layout the framing system and suggest ways to modify the architectural design to reduce costs, they are most responsible for an economical frame. How can they fulfill this duty responsibly? Let us review the well known ways. Engineers should:

1. Study all reasonable framing schemes and select the most economical scheme that best meets design objectives.
2. Use one, and only one, framing scheme for a building. If a project includes several buildings, consider the same framing scheme for all buildings.
3. If a framing scheme is directional (for example, ribbed slabs), span all members in one direction.
4. Use conventional framing schemes or present them to contractors in conventional terms. Workers are more efficient doing what they know well.
5. Keep the floor framing system shallow to avoid interference with mechanical trades.
6. Minimize the number of column, beam and slab sizes, that is, their concrete outlines.
7. Use as few concrete mix designs as possible.
8. Write careful, unambiguous specifications limited to requirements for the subject project only, giving the contractor as much freedom as possible

to innovate and use economical materials and methods of construction.

Contractors translate the designer's ideas into a finished concrete structure. In doing so, they have many opportunities to minimize costs and strong incentive to do so since low bid wins the job in most cases and low cost keeps the contractor solvent, ready to bid the next project. Unfortunately, both designers and contractors sometimes feel only contractors have control over construction costs. Everyone should avoid the attitudes this narrow view fosters.

When they have the opportunity, contractors should suggest to designers reasonable options that meet design requirements while reducing costs or offering other advantages. And certainly contractors never need to be told to search for ways to reduce costs while meeting requirements of contract documents! They have done so for years. Some of the innovations developed since I started my design practice are concrete pumping, flying forms and rebar mechanical splices to name just a few. We will, no doubt, hear of many new innovations and new developments in the next few days.

THE CHALLENGE of STANDARDIZING CONSTRUCTION

We should consider economizing on a much larger larger scale than simply lowering costs on individual projects. The latter efforts take place within the limits of industry practices which themselves are subject to improvement. Some practices facilitate economical construction and some do not.

For example, standard metal buildings are very economical because they are standardized. Spans are standardized at nominal 10-ft. increments, bay widths are standardized at nominal 2-ft. increments, and heights are similarly standardized. The actual width, length and height of the building has been established to use wall and roof materials as well as structural materials to best advantage considering stock sizes, fabrication and erection details. Customers must accept standard dimensions to gain the advantage of lower cost.

Perhaps the concrete industry has sold the concept of flexibility of form too well for too long and overlooked too easily the benefits of

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standardization.

Some elements of concrete construction have been standardized. For example, the number of stock rebar sizes has been reduced to nine currently from eleven within my memory and from dozens only 60 years ago. Only two grades of steel are standard currently, down from three or more in my memory. And all rebars now meet one specification for deformations when formerly each manufacturer had its own standard. Metal pans for ribbed slabs were standardized to only a few sizes about 40 years ago. In actual practice, only two or three sizes are in widespread use today. Clearly these standardization efforts have benefitted the entire industry.

Concrete construction could benefit from further standardization, especially from standards that permit materials and equipment from one job to be used in another as if they were all one big job. In this way smaller projects can benefit from some of the economies of scale.

Potential New Concrete Standards

Concrete Classes -- I remember clearly the moment several years ago when I first realized that I had been specifying criteria that required over a dozen mix designs or more for each small project of a thousand cubic yards or less. We have made much progress in the last two decades in eliminating such excesses but more needs to be done. Each producing area should have standard concrete classes for a few of the most widely used concretes. For example, an area might establish three classes of concrete with strengths $f'_c = 3, 4$ and 5 ksi. A fourth class with durability requirements (air entrainment) and minimum strength (eq. $f'_c = 4$ ksi) will be required in most areas. Each class will have a few added requirements such as workability and maximum aggregate size.

With area standards, ready mixed concrete suppliers need only demonstrate their ability to produce concrete that will meet requirements of the standard class and of the project specifications. This may simply be submission of statistical data. Engineers would not need to review and approve mix designs, and ready mix suppliers could concentrate on maintaining quality of just a few mixes, costs would be lowered, and reliability increased.

Column Size - - If column sizes were limited to only a few, contractors and form suppliers could afford to supply low cost forms reusable from job to job. Rebar fabricators could standardize on tie sizes and field labor would have less time-wasting confusion in sorting out steel on the job. For example, the following 12 sizes would suffice for the vast majority of projects.

12x12	16x16	20x20	24x24
12x16	16x20	20x28	24x32
12x20	16x24	20x36	24x40

The list might be reduced to even fewer sizes.

The height of column forms might be standardized at 8, 10 and 12 ft. Ingenious contractors will devise ways to minimize the number of forms needed to meet all standard sizes.

Column Spacing - - If columns are spaced on standard increments of, say, two or four feet, it would allow use of standard slab forms based on the standard increment. I find it exciting to contemplate the release of creative energy of hundreds, maybe thousands, of formwork suppliers competing in a well-defined market for standard products.

Column Capitals - - Flat plates have a well deserved reputation for economy on many types of building construction, but they frequently require column capitals to keep shear stresses within limits. A few standard forms adaptable to all standard column sizes would suffice for the vast majority of buildings. For example, only two sizes of column capitals (square drop panels 4ft x 4ft x 6in and 6ft x 6ft x 8in) might be adequate for most structures.

The American Concrete Institute is a leader in suggesting methods of simplifying and standardizing formwork [1].

Tolerances - - Standard tolerances with two or three levels of quality are badly needed. It would enable contractors to put a price tag on tight tolerances. It would also protect a contractor so that he could lower bid prices if looser tolerances are satisfactory and if they are specified. Competent, well considered tolerances would serve as a reference for other vendors whose products are attached to concrete. If curtain wall or window vendors could rely on concrete tolerances, no matter

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how loose, and reduce the uncertainty of dealing with unexpected field problems, it seems reasonable to expect that the vendors could reduce their prices accordingly.

Reinforced concrete construction currently has the reputation of a high-quality product that is extremely flexible to meet any requirement conceived by an inventive architect. Perhaps it should also have the reputation of an especially low-cost product when standard sizes, dimensions and materials are used.

References:

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Producing Architectural Concrete Using Plastic Form Liners and High Density Overlaid Plywoods

by Jerome H. Ford

Synopsis: The density of well designed and compacted concrete directly reflects the density of the facing material of the Form Work. Therefore, high density plastics and high density overlaid plywoods produce the most consistent concrete color, texture and density over multiple uses providing a few do's and don'ts are considered. These do's and don'ts can be "consolidated" into the DESIRE OF ALL INVOLVED: designer, contractor and supplier, wanting to make it work and look good. All rules and regulations are worthless unless everyone involved is desirous of wanting to produce quality.

Keywords: architectural concrete; chemical analysis; form liners; physical properties; plastics, polymers, and resins; plywood

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INTRODUCTION

The production of concrete that is both structural and architecturally pleasing has been the objective of man since the earliest development of the use of concrete. This can be accomplished with the use of plastic form liners, and high density overlaid plywood provided a few rules and regulations are followed.

There are three types of plastic that are used as architectural concrete form liners: Thermo plastics, thermo setting plastics and elastomers.

Thermo Plastics by definition are:¹ "A high polymer that softens when exposed to heat and returns to its original condition when cooled to room temperature". The two thermo plastics that are widely used are PVC, poly vinyl chloride, and ABS, acrylonitrile, butadiene-styrene. There are two distinct differences between the two.² The coefficient of thermal expansion of PVC is three times that of ABS. The B of ABS is an elastomer which means that it is far more resilient than PVC.

Thermo Setting Plastics by definition are.¹ A high polymer that solidifies or "sets" irreversibly when heated. The most commonly used is glass reinforced polyester.

There are three phenolic overlays used in concrete form work: (1) 65% resin film, (2) 52% resin impregnated paper and (3) 35% resin impregnated paper. Either the resin film or the two impregnated papers are pressed onto plywood with controlled heat and pressure. The number of layers of either the film or the resin impregnated paper can be increased to produce greater durability and more resistance to abrasion and caustic attack. All are referred to as HDO or high density overlaid. The 35% resin impregnated is referred to as MDO or medium density overlaid.

Elastomers ² are all high polymers having the property of extensibility and elastic recovery, i.e. the ability to be stretched to at least twice their original length and to react very rapidly to approximately their original length when released. Polyurethane and PVC elastomers are most common form liner materials.

There are both absorbent and non-absorbent foams that can be used as form facings for concrete work. Neither foam absorbs water, but the absorbent form can absorb air which can greatly diminish air at the surface or bug holes from the concrete surface.

There are several other plastics used as forming materials. There are also wax impregnated papers used as foams.

The attached chart (Table 1) compares the chemical properties that effect concrete work: Hot and cold, strong alkalis, aromatic solvent-based retarders, and prolonged exposure to sunlight (ultra violet).

BB plywood and some of the polyurethane elastomers can react chemically with hot alkalis although usually action is not severe until temperatures exceed 140°F. Also, at this point the elastomer will begin to soften - see "melt point" in physical properties. To prevent this condition from becoming severe, strip the forms in 24 hours. Vibration can stimulate this action.

The PVC and ABS liners are soluble in aromatic based surface retarders.

All organic materials including plastics (plastics are organic material), can breakdown in prolonged exposure to ultra-violet light.² Generally this takes anywhere from several weeks to several months dependent upon the type of plastic, angle of sunlight and ambient conditions.

The attached chart (Table 2) compares the physical properties that effect concrete work: Compressive strength, impact strength, melt point, thermal expansion, water absorption, oil absorption (alaphatic), release agents, sharp corners and back drafts, insulation effect and density.

The thin hollow thermo formed plastics with a high degree of relief have potential deflection problems because of the lack of stiffness due to the shape. Internal back up should be used when there is potential for deflection due to deep shapes or high pressures. Most liners are rated at 1000psf. This hollowness also makes them susceptible to vibrator damage if contact is made and a greater compactive effort also stresses these materials more than lightly compactive applications.

The thermo setting plastics, especially when reinforced with glass, can easily be damaged from impact either by concrete or vibrator, or both.

Both the PVC and the PVC elastomer have thermal expansion co-efficients about twenty-four (24) times that of plywood. ABS and the polyurethane elastomers have approximately eight (8) times that of plywood. Adhesion to plywood greatly diminishes this effect.

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All plastics used as form liners can start to melt at the normal working temperatures of hydrating concrete (100-400°F.) The melt points of PVC and the PVC elastomer vary from just over 100 to less than 140°F. All the others have melt points very close to 140°F.

Fresh concrete contains water. Loss of this water at early stages of development can cause decreased strengths and produce a variety of surface discolorations.⁶ The control of this moisture loss is concrete curing. The most damaging effect caused by the loss of the curing water occurs in the first twenty-four hours. The effects of moisture loss after this initial twenty-four hour period is not as severe as was once considered.³ However, if the concrete is in an environment of high temperature, low humidity and high wind velocities, an improper development of desired properties can occur - see chart in ACI 308-01.⁴

When plastics are produced the densities are quite constant; however, some alteration in the density can take place with prolonged use of molds. The molds become slick and the density of the surface can be effected causing the release agent to be rejected. If this takes place the liner can stick. Generally speaking, if the liner is oiled the day concrete is placed, there is usually no sticking. If, however, a longer delay in this schedule is anticipated, measures should be taken to oil the liner in place. If release agents are produced with re-refined oils these can, and usually do, contain some aromatic solvents and can dissolve and soften the thermo plastics and can cause dimensional inaccuracies. Used oils generally contain sulfuric acid and this causes chemical action between concrete and the used oil used as releasing agent; it can also breakdown BB plywood. Vibration speeds up this action causing a greater degree of "softening" of concrete surface.

Light diffusion as an aesthetic property is greatly influenced by the sharpness of the detail. The elastomers are the only form liner materials that produce and will readily reproduce this sharp definition and the resultant aesthetic value.

The PVC, ABS and the fiberglass polyester can be thermal conductors.⁵ They are generally of little concern in either hot or cold weather construction. However, the elastomers are excellent insulators having from 10 to 13 in "R" value. With this high insulation effect, where thick walls are concerned, a mass concrete temperature condition can be produced if the liner is left in place for prolonged periods. Since the maximum heat of hydration occurs at approximately 72 hours after placement, stripping in 24 hours will virtually eliminate this potential problem. If there is no place to store forms, this effect will not occur provided the bond is broken between the liner and the concrete.

If plastic liners are left in place for more than 24 hours, the "green house" effect ⁶ can occur. The "green house" is caused by moisture coming out of the concrete and condensing on the dense surface of the liner which in turn draws out some of the excess free lime in the mix producing efflorescence. Vibration speeds this water movement to the surface. In most cases it takes more than 24 hours before the "green house" effect becomes objectionable.

The most difficult part of architectural concrete using plastic form liners is the prevention of surface irregularities.

Over vibration occurs when concrete is naturally fluid (high slump) or when a fluidifying admixture is used (super plasticizer) and the amount and intensity of the vibration is not adjusted for these two conditions.

Natural fluidity occurs when there is an over abundance of water or a high slump concrete. This can occur as a natural result of sand and aggregate gradation but is usually the result of too much water. Or as errors in the amount of moisture in the fine or coarse aggregate causing segregation. Vibration can increase the degree of segregation in these cases.

High range water reducers (super plasticizers) are, chemically, aggregate surfactants (surface acting agents) that lower the surface tension of the hard particles (sand, aggregate and in some cases cement grains). The duration of time that the lowering of the surface tension lasts is usually quite short or less than one hour. The degree of fluidity is dependent upon the quantity and the gradation of aggregates and the timing of the adding of the water reducer. Segregation is common if care is not take to prevent over vibration.

The timing of the introduction of the high range water reducer is critical to the performance of the admixture because if it is introduced into the mixture at a point when the cement paste begins to gel around the particles of aggregate. It is quite possible that the admixture does not mix and can more or less become "free" in the mixture. If the admixture contains free formaldehyde, it and oil-based release agents can cause the production of carbon dioxide gas which can take the form of anything from bug holes to scaling of the surface produced by the dissipation of this gas. Vibration causes this to increase if the "free" state occurs.

If a fluid mixture is vibrated intensely there is strong potential for segregation of the concrete mixture. Segregation is a breaking down of the mixture by gravity where the large (heavy) particles settle to the bottom and the fines float to the top producing a low strength non-durable concrete.

Under vibration is far more common than over vibration and it occurs on almost all jobs. It occurs from either poor vibration technique, a power source that is inadequate, or a mix design that will not compact.



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Bug holes are generally the result of improper mix design, inadequate vibration or release agent.

The two most important factors that influence the formation of bug holes are the water/cement ratio and the sand/aggregate ratio.

The effect of the water/cement ratio on the amount of bug holes is directly related to the sand to aggregate ratio because the water and cement have the capacity to coat each particle of both coarse and fine aggregate evenly. Consequently, if there is an over-abundance of fines to the coarse there will probably not be enough cement or water to coat every particle with sufficient cement paste, thus bug holes, and decreases in stripping resistance strength (tensile strength).

A natural mix (non-plasticized) with proper water/cement ratio and sand/aggregate ratio is virtually impossible to over vibrate.

Concrete requires proper consolidation. To properly consolidate, an interlocking (compaction) of coarse aggregate and the fines is essential.

Graded mixes of lower sand/aggregate ratios and higher fineness modulus sand can produce good compactable mixes provided their proportions are proper.¹¹ The local redi-mix supplier in conjunction with ACI and ASTM is the best source of this information.

Gap-graded mixes cannot consolidate as easily as a graded mix where normal placing and internal vibration techniques are used.

White concrete is the ultimate architectural concrete, and it is subject to the same surface irregularities as gray concrete.

Colored concrete should not be considered unless all form work can be full-liquid head pours. Colored concrete mottles especially if placed in lifts. They also tend to produce more surface irregularities than a similar configuration in gray cement.

Additives and admixtures can be great assistants to the problems of surface irregularities, they do require qualified personnel when used. Vibration can have either good or bad effects on certain admixtures or mixtures of admixtures.

Vibration is the most common method used to produce consolidation. If external vibration is considered, increased stress on both the form and the form liner should be considered. If properly considered the results of external vibration can be excellent. Vibration is a means to consolidation, and is probably the true art form in concrete work as it all has to be done by feel. Consolidation is so essential to good concrete work it is amazing how the vibration chores are often passed from man to man and usually these men are the lowest paid of all the concrete crew. Well compacted concrete is generally of higher strength and greater durability.

External vibration is vibration of the form work or some part of the form work. This "shaking" of the form usually does an excellent job of consolidating (compacting) the concrete. It does necessarily induce considerably more stresses on the form work and it is generally accepted that you compensate for this by using a concrete density of 300#/cu.ft. in the pressure formula than the normal 150#/cu.ft.⁹

Internal vibration is accomplished with generally a hand operated vibrator that is inserted into concrete and withdrawn. Most manufacturers give the radius of effect of their tool and this is subject to both slump and maximum size aggregate and line voltage.

The size and capacity of the vibrator should be based on the recommendation of the vibrator manufacturer or ACI-309. As many of the form liner patterns have considerably more surface area than a flat form, oversize rather than undersize the vibrator. The manufacturers recommended radius of effect should be used to determine where the vibrator is inserted and the frequency of insertion. The placement of the reinforcing steel can sizeably change these dimensions and should definitely be considered.

Temporary electrical services can often produce low amperage . Low amperage renders most internal vibrators ineffective as consolidation tools. If extension cords are used the amperage should be checked at the tool as there can be considerable drop in many extension cords.

The radius of effect is usually available from the manufacturer but it can also be checked on the jobsite on a non-critical pour. When the radius of effect is established the center to center points of insertion can be established. The reinforcing placement may influence the spacing also and should always be adjusted closer rather than further apart. If reinforcing or other embedments are large (2" or greater) a test pour should be made to see what if any influence of vibration is accomplished on the opposite side of the reinforcing embedment from the insertion of the vibrator.

Revibration is vibration of concrete after it has been initially vibrated. This can often occur when the concrete in the lift to be vibrated has taken initial set.¹⁰

When the concrete to be revibrated has taken initial set it is essential to insert the vibrator in a manner that allows the vibrator to insert by gravity rather than forcing the vibrator head into the lift, as this merely drills a hole in the concrete and does not thoroughly fluidify the mixture so proper knitting together takes place. This necessarily has to be done by feel as it can't be seen and will require some experimenting to be perfected.

The speed of withdrawal of a vibrator either in normal vibration or revibration is dependent upon mix design, fluidity of mixture, air content and the desired degree of compaction required.

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or shaking action of the vibrator often renders better results than a smooth withdrawal, this also decreases a build up of pressure. Once the vibrator head breaks the top surface of concrete it is essential in most mixes to quickly withdraw the vibrator head as leaving the vibrating head at this point can very easily entrap additional air, rather than removing entrapped air.

The selection of a release agent in architectural work is as important as the selection of the forming system, for facing material, vibrator or mix design. The release agent is expected to allow the form facing material to release, not to stain the concrete, plus it is needed as a lubricant for the removal of entrapped air through vibration.

It is essential that the release agent serves as a lubricant for the removal of entrapped air in the vibration as it is to break the bond of the concrete and the form facing material especially in architectural concrete. The more water-insoluble the release agent the longer it lasts as a lubricant.

Releasing the concrete from the form should not be performed chemically, for the chances of mottling, dusting and other surface discolorations are greatly enhanced when the release agent reacts chemically with the concrete. The PH of the release agent is known but the PH of concrete is usually unknown. A chemically neutral non-staining release agent should be a primary consideration.

Well consolidated concrete, requires complete teamwork, cooperation, and the desire by all concerned to want to make it look good. This incorporates the designer, the contractor, the suppliers, and the entire work force.

The designer makes the initial decision to produce the structure. The more modular the design the better the potential for a good looking job. Modularity begins with design and the resultant form work with repeated usage will not only increase productivity, but also will produce good looking concrete.

It is the responsibility of the contractor to coordinate the design to the equipment and to the suppliers. This is difficult especially if there is one member of the team that does not cooperate. Many suppliers offer a great number of services on jobs of this nature, but often the contractor will price the suppliers out of this service.

Suppliers have as much influence on the outcome of a concrete job as either the designer or contractor. The most important suppliers are the redi-mix, forms, liners, release agents, and curing compounds. It is absolutely imperative that the suppliers of forms, liners, or other high density materials and release agents be compatible. If these suppliers are apportioned, because they are generally competitive enemies, the ultimate results will require a very close attention to the materials supplied, service proposed, and coordination between suppliers. The results are generally better when these three items are awarded to one

supplier. The supplier should never negotiate directly with the designer after a contract has been awarded.

Performance should be the prime objective of the designer, the contractor and the suppliers. Items of extreme importance in the performance are: Cold joints, reveals and wall intersections, and performing the necessary finish requirements.

Cold joints or flow lines should be eliminated even if it requires a design change. One point that can greatly decrease the potential for cold joints and flow lines is based in the basic engineering of internal vibrators. Vibration surge is always upward and conservatively at least at a 30° angle; it never surges downward. Consequently, the depth of insertion is critical and the proper method of insertion is imperative.⁷ Never force the vibrator into a hardened lift, allow the vibrator head to sink by gravity.

A projected reveal requires cutting of the form liner therefore, the height of all succeeding lifts should not exceed the one for which the liner was cut. Cutting, trimming, finishing of both form and liner is an extremely time consuming, and thus costly, procedure. An indented reveal can be produced relatively easily by a closure over the top of the liner that can easily be moved either up or down—not on an angle. It is important to order liner that is horizontally seamless to this maximum height if at all possible. Reveals can easily disguise color variations especially if the wall has both wall concrete and slab concrete, which usually vary in water/cement ratio which causes a vibration in color. The breaking up of the plane of the concrete can disguise this color variation.

The different legs of a wall intersection are almost always cast as a monolith. Assuming that the work in question is gang formed, the tolerance for level and plumb become critical for both inside corners and outside corners.

Because of the consistency of density of plastic form liners and plastic coated plywoods, and if a non-staining release agent that does not react with the concrete alkali is used, the water/cement ratio controls the concrete color. Therefore, the mix design should have local input and quality control both at the plant and the jobsite.

The water/cement ratio is the primary vehicle for the determination of concrete color. As the water/cement ratio decreases the color of the concrete becomes darker and also any variation in the lower water/cement ratio shows up much more dramatically (dark to light) than in higher water/cement ratios.

Local fine and coarse aggregate should always be selected provided there is sufficient supply.

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Once the acceptable workability level has been worked out and the water/cement ratio and sand/aggregate ratio established, the control responsibilities should also be established. The logistics of the formwork movement, release agent application to time of concrete placement, time of placement to time of stripping, and the time of stripping to the time of curing can all effect the concrete color. Consistency of these logistics not only produces excellent concrete results but also greatly improves form labor productivity.

Form work is the most important determinant in the producing of acceptable concrete work. The determination of whether to hand set or gang form should be of prime importance. If gang forming is established, the cycling of the reinforcing and the mechanical trades can greatly influence the eventual outcome both aesthetically and financially. Also, improper stripping techniques can greatly effect form work effectiveness especially if repair and refurbishing of either form or concrete are required after each strip.

Gang forming is the best method of forming architectural jobs. The size of the gangs should be easily determined by the design. The form design should be compatible with structures design. The tying system should also be compatible with not only the form design but also the structural design if at all possible.

Cycle of form work is the time that it takes to strip, reset and pour. The speed that the formwork reinforcing and mechanicals take greatly influences the eventual appearance of the concrete and it also probably is the greatest determining factor in establishing the contractors margin of profit.

Stripping is so essential to the eventual profit on the job that the best suggestion is a visit to a similar job in progress or establish meaningful test pours.

Test pours are essential to quality architectural concrete. Test pours are necessary because they allow the contractor the opportunity to actually perform all the necessary functions of onsite labor and use the required materials. Test pours establish mix design, vibration techniques, tie sizes and spacings, reveals and acceptable levels of surface irregularities. As a test pour accomplishes all of these it is well worth its cost, and usually, the experience gained more than offsets this cost. A test pour should always be as close to the maximum height of pour as practical. The width has less effect and the thickness of pour should be that of the maximum to determine necessary vibration and the effects of heat of hydration. The test pour should always be reinforced as closely to the maximum required on the job, as this has such decided effect on the amount and spacing of the vibration and the depth of lift. The test pour should as nearly as possible simulate job conditions.

The heights and thickness of the test pour should always be as close to job conditions as is possible. The width has little bearing provided it has a vertical joint in the sheet of liner or plastic coated plywood. Usually two sheets are more practical as the vertical joint is established without cutting. The more representative a test pour is of job conditions the better potential for good end results.

A test pour is one of the best vehicles for developing good job techniques. These techniques should carry through the rest of the job and if these are good techniques good quality concrete will be the end result.

Placement limitations are determined by the type and quantity of placement equipment and the amount of reinforcing or other imbedments as well as design.

Concrete placement equipment should be determined by the sizes of the pours and the capacity of the formwork. If the concrete is to be pumped, test pours are essential as many pump mixes are highly sanded and difficult to compact.

The size, quantity and spacing of reinforcing and other imbedded items can greatly influence the type of placement equipment, mix, design, vibration and other job conditions.

Pumping concrete from the bottom is a very effective means of concrete placement in some instances. It is far more effective in columns than in walls.

There are no ACI formulas for form pressure when pumped, but we use full liquid head plus a 50% of liquid head for pump surge. This is predicated on no obstructions to the flow or $P=225H$.

Liquid head refers to the pressure exerted by the liquid (concrete) for a given head (height) or ACI pressure formula for over 10' $P=150H$.

Surge is the pulsation of the pump or the piston or diaphragm action of the pump. The surge acts as the vibrator or compaction tool as the shocking of the concrete causes compaction and removal of entrapped air.

If the second lift is required it is very practical to pump through the concrete through a plastic (ABS or PVC) plumbers pipe to the next lift.

If the pipe in the above extends above existing lift it will mushroom or fountain thus entrapping air at the construction joint or top of existing column and bottom of second lift column. To prevent this an internal vibrator can be inserted in the pipe and the first concrete can thus be vibrated to break up the fountain and the resultant entrapped air. The vibrator only need be in this position until concrete exceeds the height of the pipe above the construction joint.

20 Plastic Form Liners and Overlaid Plywood

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CHEMICAL PROPERTIES

	<u>THERMO PLASTIC</u>		<u>THERMO SETTING</u>		<u>ELASTOMERIC</u>	<u>PLYWOOD</u>	
	PVC	ABS	Fiberglass Reinforced Polyester	Phenolic Plywood Overlay	PVC Elastomeric	Urethane Elastomeric	BB Plywood
Alkalai, Strong Ph 11+							
Cold 32°F/40°F							
Hot 140°F+							
Aromatic Surface Retarders							
Sun Light-Prolonged							



MODERATE POTENTIAL PROBLEM

SERIOUS POTENTIAL PROBLEM



Ford

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PHYSICAL PROPERTIES

	<u>THERMO PLASTIC</u>		<u>THERMO SETTING</u>		<u>ELASTOMERIC</u>		<u>PLYWOOD</u>
	PVC	ABS	Fiberglass Reinforced Polyester	Phenolic Plywood Overlay	PVC Elastomeric	Urethane Elastomeric	BB Plywood
Compressive Strength							
Impact Strength							
Thermal Ex.							
Melt Pt.							
Water Absorption							
Oil Absorption/Rejection							
Sharp Corners							
Back Drafts							
Insulator R Value							
Density							



MODERATE POTENTIAL PROBLEM



SERIOUS POTENTIAL PROBLEM



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Architectural Concrete: New York Exposition and Convention Center

by Eliot Locitzer

Synopsis: Architectural concrete was selected as the material for all the prime public spaces in the New York Exposition and Convention Center. A construction oriented design provided the basis for high quality formwork and finish on a fast-track, construction-managed, and government-owned job. Drawings, specifications, and on-site inspection requirements for a large scale, architectural concrete building are discussed using this job as an example. Construction progress is highlighted with particular emphasis on formwork in the context of architectural design, sequence of construction, re-bar design, and quality control.

Keywords: architectural concrete; concrete construction; formwork (construction); quality control; reinforced concrete; reinforcing steels; structural design

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Eliot Locitzer, a registered architect, worked as a Resident Architect at the New York Exposition & Convention Center. Mr. Locitzer lectures on the subject of Architectural Concrete.

INTRODUCTION

The Convention Center Building Type

The New York Convention Center will be New York City's entry into the lucrative convention market. The Center will consolidate many of the City's smaller convention facilities and enable New York City to compete with other major cities for the convention business.

City convention centers, as a building type, however, are often massive, uninviting and out of scale with their urban environment because the use requires vast unobstructed floor space enclosed by opaque walls. To address this problem and enliven the design, certain key elements of the building structure were focused upon and selected to receive special architectural detail. These were:

1. the building skin (curtain wall)
2. the roof, ceiling, and wall supports (space frame)
3. the columns (steel clad precast concrete)
4. the service and circulation cores (architectural concrete)

There is a distinction to be made here. The first three elements are manufactured and/or prefabricated in factories; well-controlled, remote environments where the products consistency and quality result from its constant reproduction. Concrete work, the fourth building element to receive special architectural attention on the job, is quite different in its production demands, requirements for control, and final presentation - different because it happens all at once. Concrete is man, material, and machines assembled together on a specific site for a brief period in time, often under adverse environments to produce a shape and function unique to the site and building program. The first three elements are largely prefabricated from discrete parts and can be easily unbolted and replaced if an error is uncovered. Architectural Concrete is many parts simultaneously cast together in place. Errors, for one thing, are far too costly to forgive or correct.



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Most of the Architectural Concrete work at the Convention Center is contained in the "East Cores". These East Cores (Figure 1) form a massive building that in turn is enveloped by a glass skin. They are located between the public concourse and the exhibition halls and they contain elevators, escalators, stairs, utility closets, bathrooms, and small offices that overlook the exhibition spaces beyond.

The site, program, and design were firmly established. The main assignment then was to place 10,000 cubic yards of concrete with the highest quality finish on a fast-track basis for the State of New York. Sixty-five (65) separate contracts were awarded by the public bid process and simultaneously coordinated with the concrete work by the Construction Manager, HRH Construction Company. The following describes the effort.

DESIGN

Construction Orientation

Bearing in mind the history and environment of concrete work in large cities, the Architect, I. M. Pei, laid down precise criteria with a construction orientation and made sure that these criteria would be clear to the bidders. With drawings such as this (Figure 1), contractors can conceptualize the job progression from start to finish. Its ironic that often the clearest three dimensional renderings are never seen by the people that physically build the buildings. Plans, typical sections and details are at times so abstract that the man in the field loses the whole picture and has only an idea of where he is headed. To address this problem, special sections of the specifications and drawings were devoted to Architectural Concrete.

Architectural Concrete Working Drawings

These drawings suggest the sequence of work the designer envisioned when he laid out the patterns of formed surfaces. Note how in Figures 2 and 3 the walls are articulated by vertical boards and the spandrel beams finished with horizontal board forms. The placement of slabs are suggested to be separate from walls and beams. Slab edges are shown as finn form to emphasize this suggestion. A typical wall elevation (Figure 4) shows the exact location of tie holes, rustication joints, construction joints, and embeddments as well as the extent of the various form surfaces. The work was detailed and specified so that the risk of producing poor quality is reduced. In this way, a design with

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construction orientation realizes the relationship between the shape of the placement to its quality.

The drawings also demonstrated how a ganged form system could be applied to the job (Figure 5). Note how the sizes of panels were coordinated with the length of walls and the corners of the structure - the entire building was broken down into modular parts. Where there were more intricate details, suggested formwork details were drawn. Figure 6 shows a possible formwork assembly for the intersection of three Architectural Concrete walls with a 135° outside corner. Figure 7 shows a possible formwork assembly for a 45° corner. Note that the internal ties are located along lines to resist the radial pressure of concrete's liquid head. Corner forms are tightly squeezed to preserve alignment and prevent leakage.

During estimating and bidding, the Contractor had these drawings in hand and was able to put in a reasonable price for the work. As you will see in the description of the actual job progress, the contractor did not always follow the architect's suggestions but was able to produce the results. The dividing line between contract documents and contractor 'means and methods' was protected by issuing these drawings as supplementary information. This methodology afforded the contractor the necessary latitude while guaranteeing to the Owner that the desired appearance would be obtained.

Architectural Concrete Specifications

A special section of the specification was devoted to Architectural Cast-In-Place Concrete. Submittals were required for all the materials to be used including:

- a. Cement
- b. Fine Aggregate
- c. Coarse Aggregate
- d. Cast Concrete Finishes
- e. Gaskets
- f. Form Contact Materials (fiberglass, finn form, edge grain, douglas fir)
- g. Forms for rustication joints
- h. Reinforcement supports (plastic tipped, hangers, and tie wire - coated)

These preliminary steps give the Architect the opportunity to be assured by the contractor that the work will be done with acceptable materials. Execution of the formwork, including tolerances, placement of reinforcement with respect to the finish surface, placement timing of concrete, curing, temporary protection, and final cleaning are all described in this Architectural Concrete Specification.

Shop Drawings and Mock-Ups - Non-adversary relationships

The contractor was required to prepare shop drawings of formwork reflecting how he intended to meet the requirements of the Contract Documents. Pre-construction conferences were held and a consensus was reached regarding gang forming and quality control. This was also the time when the team of Architect, Engineer, Construction Manager, and Contractor formed a "non-adversary" relationship that carried through the job. There certainly were problems but they were worked out without polarization and personality conflicts.

The final preliminary step was a mock-up to be built off-site. This gave the contractors' men the opportunity to explore the most important aspects of the architectural requirements. Typical corners, beam bottoms, board and fin formed finishes as well as the hardware (rebar supports, galvanized tie wire, form ties) were incorporated to familiarize the workers with the work. The mock-up served as a practice run for concrete placement and subsequent removal of formwork, a precautionary expenditure that was worthwhile given the \$30,000,000 contract.

Coordination and Composite Drawings

As described earlier, the East Cores functioned as service and circulation cores. Composite drawings prepared by the construction manager established the location of sleeve embedments and hanging loads that had to be coordinated with the reinforcing steel layout. There was also a dense concentration of conduit in the slab (due to the Electrical Closets being in the East Cores) that had to be coordinated with placement of the reinforcing steel.

CONSTRUCTION

On Site Representation - Friendly, Fair, but Firm

With approvals of prefabricated building element samples such as curtain wall and additional spot checks, the Architect can be reasonably assured that the factory production techniques will reproduce the quality of these samples for the remainder of the job.

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Day to day aesthetic control by the Resident Architect of cast-in-place concrete is essential because architectural forms, structural reinforcing, and the open-air environment are constantly changing.

Such a commitment was made on this job and it proved to be the key quality control factor. Quality control is achieved by assertive but non-antagonistic representation.

East Cores - Horizontal Erection Sequence

Prior to construction, there was special thinking about how to build a structure of this size. The Architect sub-divided the 1,000-foot-long structure into identical modules (East Cores) and repeated them seven times across the site. Modular building elements afforded maximum re-use of formwork.

The Contractor, Julius Nasso/S & A, Joint Venture, decided against building floor-to-floor (typical of high rise construction in Manhattan) because it would spread large crews over 1,000 feet to install the same wall simultaneously in seven separate locations. The Contractor successfully developed a cycle of moving and re-using modular wall forms horizontally across from East Core to East Core. This cycle opened areas up for other trades on a normal basis, minimized fluctuations in staffing, and contributed to a steady flow of production. In this way, the unusual dimensions of the building were addressed in both the design and construction process.

These buildings had to be supported by four (4)-foot-thick pile caps and piles because the site was created by successive landfilling operations during the growth of Manhattan Island. The gang form was built on site. The 3-1/8" x 3/4" vertical edge grain douglas fir boards were soaked in a cupranol preservative, installed tongue and groove and then coated with a thin cement slurry. The slurry on the boards insured that the finish cast from "new" boards would be indistinguishable from boards re-used several times. The 9/16-in. tie holes indicated on shop drawings were then drilled from the contact surface side (to avoid splintering). The steel reinforcing cages were installed with close attention to the requirement for 2-inch coverage between the reinforcing steel and concrete finish. The architectural finish panels were set up first to allow alignment and inspection and the form was closed up with non-architectural panel. In most cases, the slab was separated from the spandrel beam placement and articulated by a finn-formed edge. The wall dowels must be very accurately placed to maintain concrete cover over reinforcing steel and alignment of edges and surfaces. Successive spandrel and wall panels were built on the ground and hoisted in place. Concrete was pumped into place.

The Drum - Coordination of Reinforcing Steel with Architectural Concrete

The center piece of the Great Hall is an Architectural Concrete Drum with a cantilevered slab extending out in a radial direction thirty-five feet at its furthest point. Most of the structural concrete is exposed; the inside and outside faces of the Drum Wall are board-formed, beam bottoms and slab edges are finn-formed.

Weidlinger Associates, the Structural Engineers utilized a computer to design the most efficient layout of reinforcing steel. The clear space between #11 "L" bars was less then two inches at the top of the wall. The Engineers also required the cantilever to be poured monolithic with the fifteen (15) foot high wall. There appeared to be no room to insert the concrete discharge hose down to the bottom of the wall (to prevent segregation and the formation of voids). To solve the problem, the bars were clustered and openings in the cage were created to drop the pipe to the bottom of the form.

The Contractor was concerned that depositing concrete along the entire 125-foot circumference might create noticeable diagonal deposit lines. Concrete deposited at the start of the circle would be setting for at least twenty minutes before the pump returned again to the point of initial placement. This in effect would be a discontinuous placement in an Architectural Concrete wall. To avoid this potential problem, the Contractor divided the 560 cubic yard drum and cantilevered slab into four quarters, each 140 yards in volume. The quarter section allowed one pump to continuously fill the wall and slab in 5 hours without deposit lines.

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SUMMARY

Each of the special conditions and problems unique to the Architectural Concrete job were approached by a design sensitive to construction techniques and resolved by a contractor's commitment to quality. Architectural Concrete depends on follow-up by the Architect in the field and close supervision by the contractor. Concrete is a labor intensive industry and successful execution depends more on the workers (carpenters, laborers, engineers, and masons) than in any other industry.

The future of Architectural Concrete is bright as indicated by the experience at the New York Exposition and Convention Center.

Architectural Concrete was preferred over granite, tile, and drywall by the Architect, Owner, and Construction Manager because it is aesthetic, cost effective (combines structure and finish), immediately available, and quickly constructed.

The Concrete Industry can now expand further and compete with off-site manufacturers by providing more construction oriented design and more on-site quality control.

END

CREDITS

Owner:

Convention Center Development Corporation
Mr. Thomas F. Galvin, President & Chief Executive Officer

Architect:

I. M. Pei & Partners, Architects and Planners
Mr. James I. Freed, Partner In Charge

Engineer:

Weidlinger Associates
Mr. Matthys Levy, Partner In Charge

Architectural Concrete Formwork Drawings:

Kelly-Hough Associates
Mr. Reginald Hough, Partner In Charge

Contractor:

Julius Nasso/S&A Concrete
Mr. Nicholas Grecco, Project Superintendent

Construction Manager:

HRH Construction Company
Mr. Frank Ross, Project Coordinator

Graphics:

Mr. Carlos Ferre
Mr. Bernard Forte

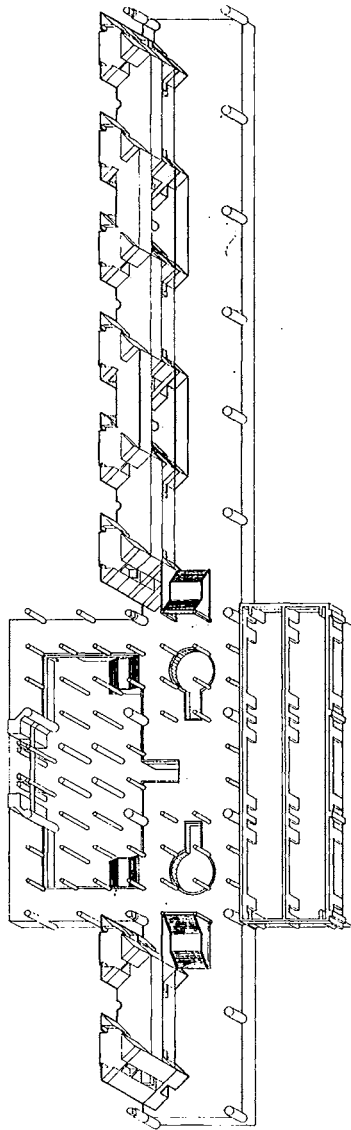


Fig. 1--Axonometric of East Cores

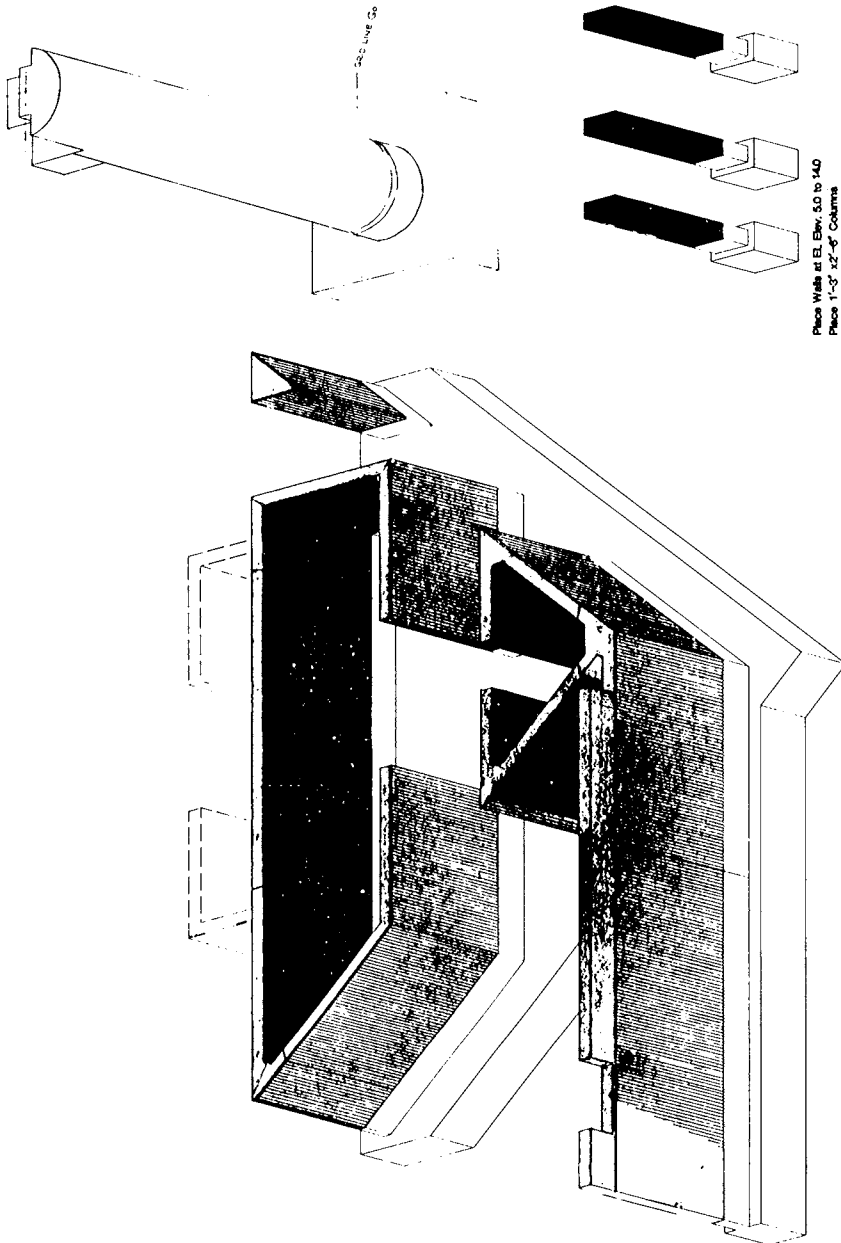


Fig. 2--East Core - wall lift

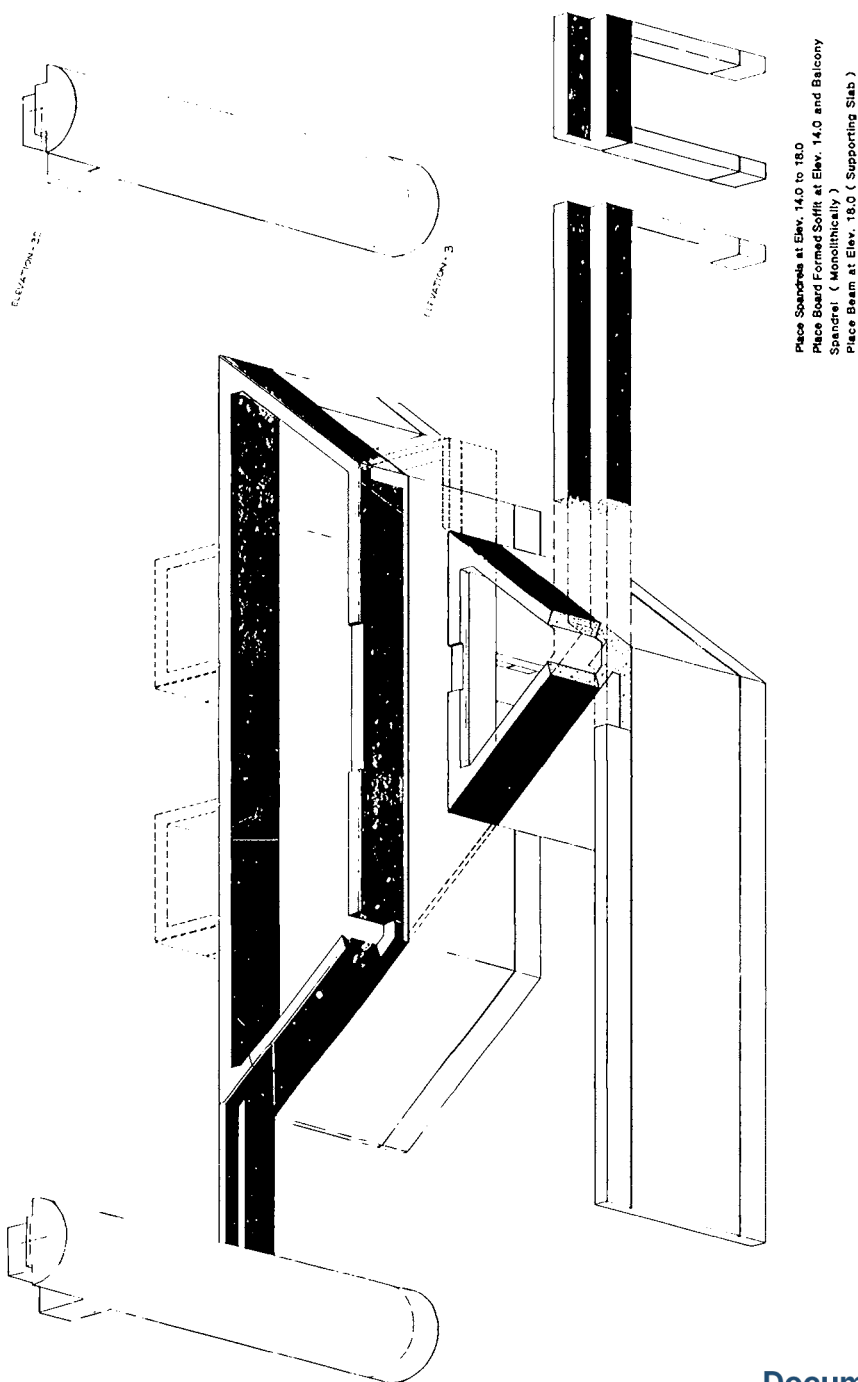


Fig. 3--East Core - spandrel lift

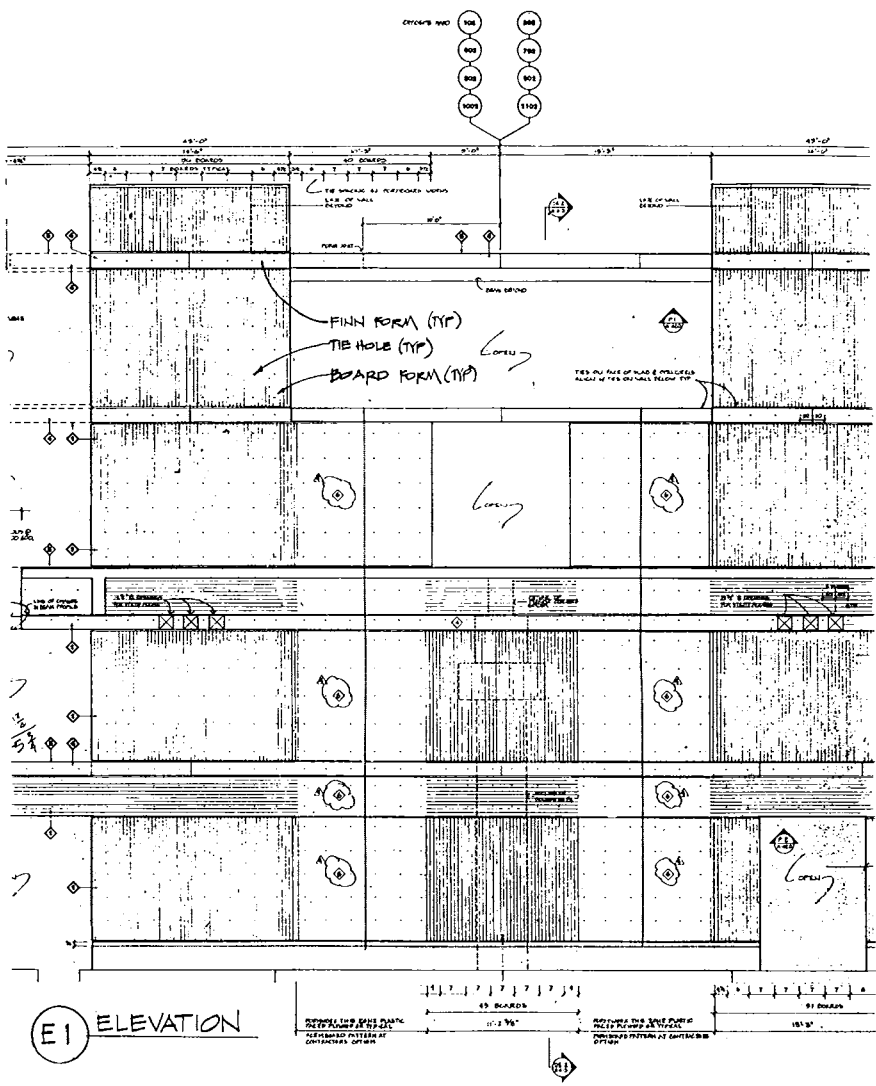


Fig. 4--East Core - wall elevation

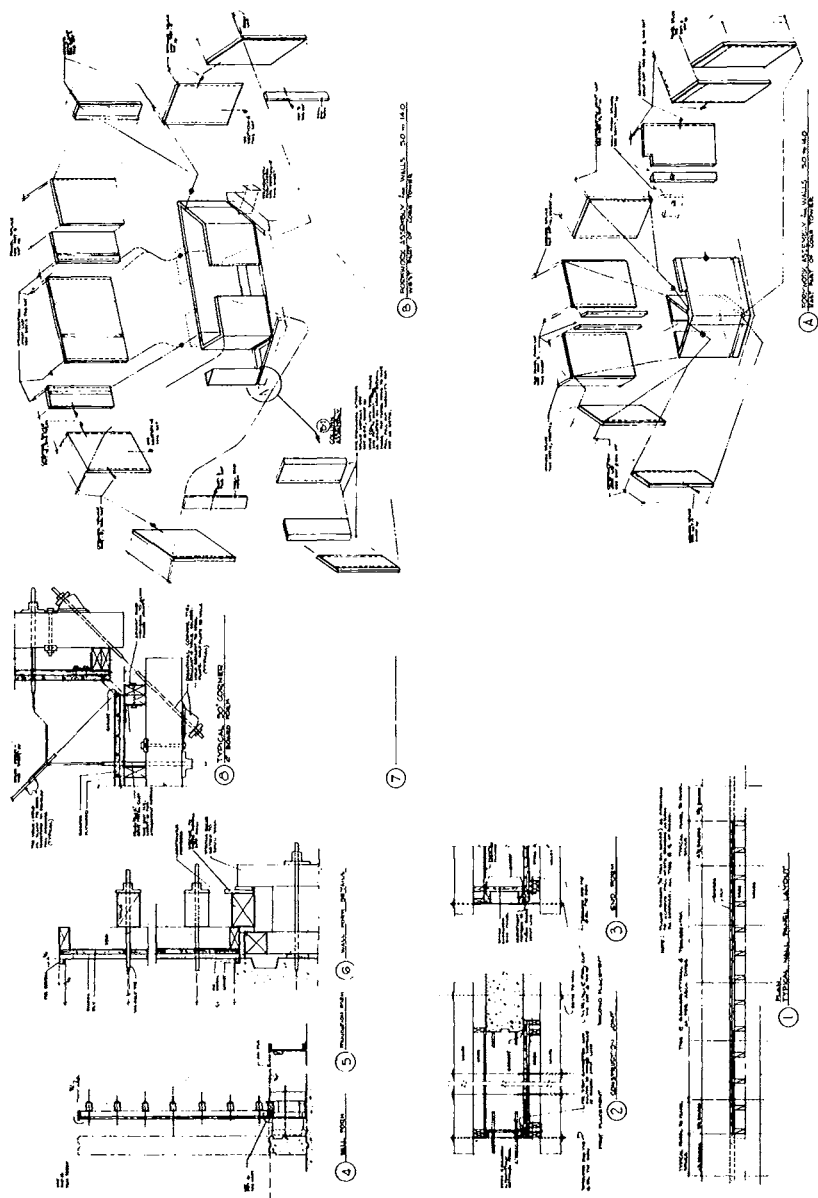


Fig. 5--East Core - suggested formwork sequence

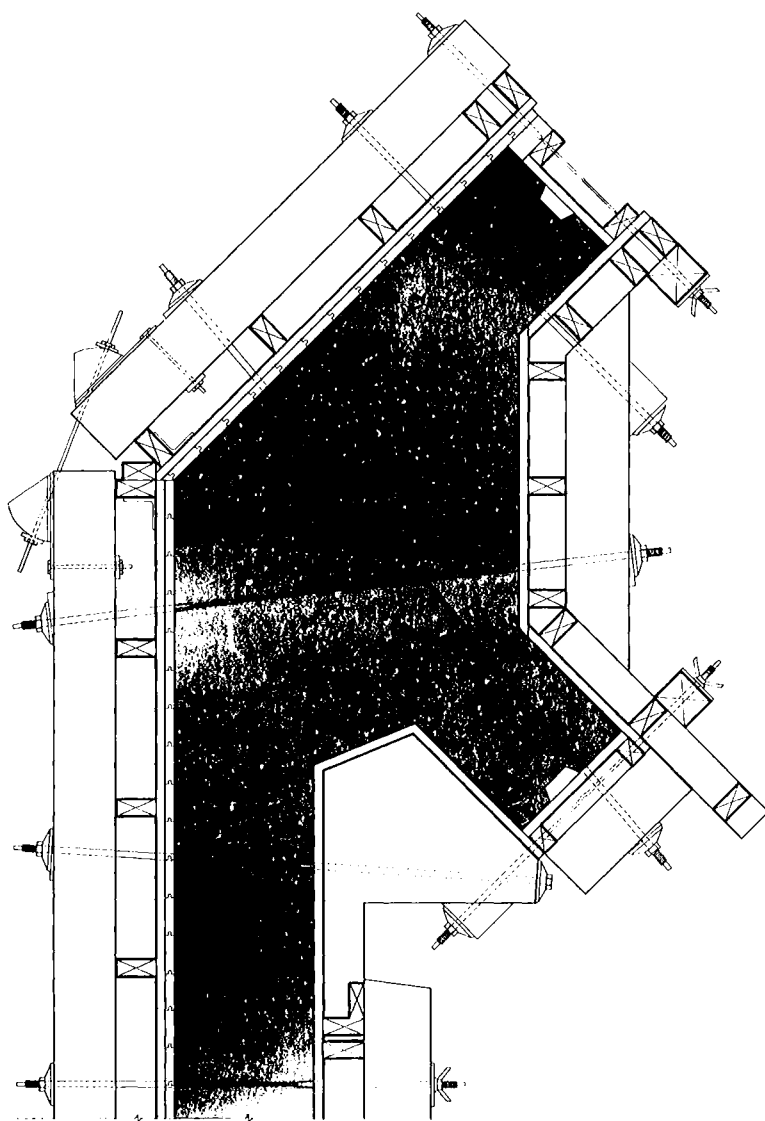


Fig. 6--East Core - suggested corner formwork, 135 degrees

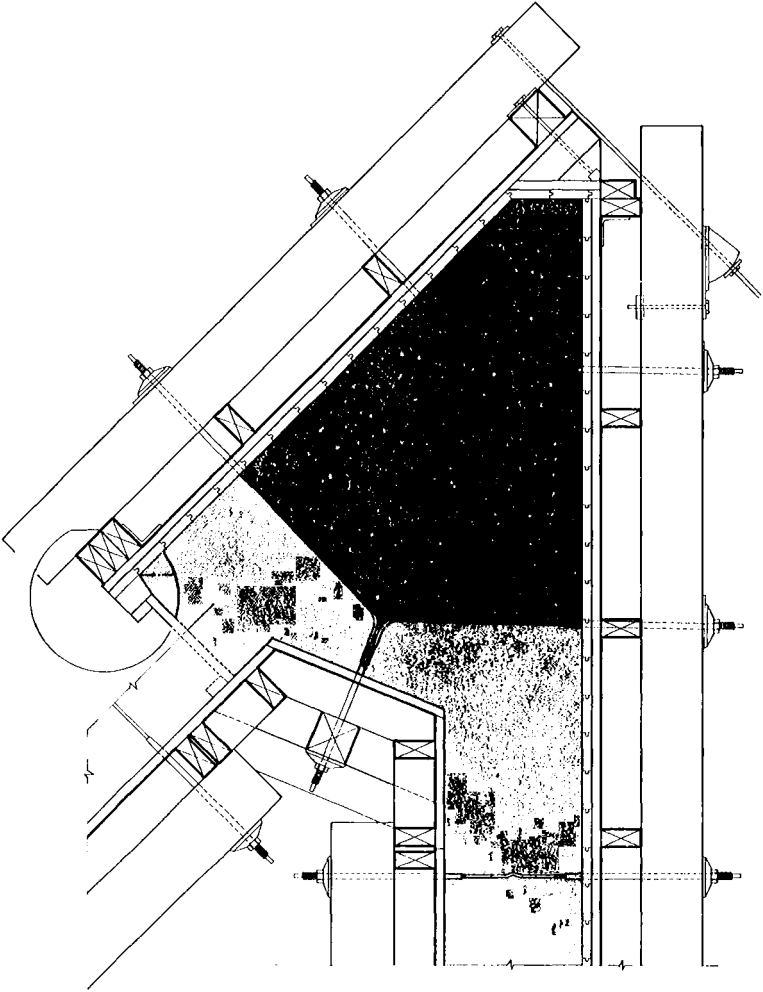


Fig. 7--East Core - suggested corner formwork, 45 degrees

Designing with Plywood — Considerations for Selecting and Using Plywood Correctly for Concrete Forming

by John V. Gould

Synopsis: There are four different basic types of plywood most commonly available to the concrete form industry: sanded (non-overlaid), high density overlay, medium density overlay and imported Finnish birch. The differences and important factors needed to help the specifier select the right one and use it correctly have not always been well understood. This paper discusses some of the important considerations:

- Surface characteristics imparted to the concrete.
- Number of reuses, economy, relative cost on a per-use basis.
- Strength and stiffness and use of load-span tables.
- The importance of proper edge sealing and form release.

Keywords: costs; formwork (construction); parting agents; plywood; pressure; strength; stiffness; surface defects

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There are many different concrete form sheathing materials, the principal ones being plywood, steel, fiberglass, aluminum and lumber boards. The most commonly used of these is plywood because of its cost, workability, good strength-to-weight characteristics, efficient sheet sizes providing large joint-free areas and general familiarity to the contractor. While all types have their place this paper will deal only with plywood and the relative merits of the four major categories:

- 1.) Sanded, non-overlaid plywood, commonly referred to as BB Plyform.
- 2.) Medium density overlay (MDO).
 - a. Standard one-step MDO
 - b. Special two-step MDO where the plywood blank is sanded before overlaying.
- 3.) High density overlay (HDO).
- 4.) Imported overlaid birch plywood (usually from Finland).

The standard overlay connected with these categories is a thermosetting phenolic impregnated fiber sheet cured under heat and pressure, usually about 5 to 12 mils thick.

Each of these types of plywood has distinct attributes and is a logical selection for a certain set of conditions. The purpose of this presentation is to help you make the best choice considering cost as well as the quality of the resulting concrete; and also help the contractor use it to best advantage.

SURFACE CHARACTERISTICS IMPARTED TO THE CONCRETE

The major factors to look for here are:

Uniformity, Mechanical Transfer of Patches, Grain and other Defects

The top choice here is imported Finnish overlaid birch although this is very expensive.

Where surface characteristics dominate the decision, two-step medium density overlaid plywood (where the plywood blanks is sanded before overlaying) is a close second and in fact superior in one characteristic, its ability to impart a matte finish to the concrete. Many architects specify this for architectural concrete because it is not so slick, provides good uniformity and helps the concrete to accept paint and coatings well.

It is important to specify a concrete form grade of MDO because the standard paint grade MDO used by the sign industry and others will not hold up well in concrete forming use. This is true of both the two-step (mentioned above) and the standard one-step MDO concrete form (mentioned below).

High density overlay (HDO) is also a good choice for providing a smooth concrete surface with minimal mechanical transference. However, we sometimes see the faint outline of grain and patches. Nevertheless, HDO is the durable work-horse panel for commercial construction in which good quality, though not perfect, concrete surfaces are expected.

Standard MDO (1-step) concrete form is next in this regard. In fact it should be noted that all overlays are head and shoulders above sanded, non-overlaid plywood in the characteristic of uniformity of surface.

Sanded plywood is at the bottom of this list but, of course, is widely used where the surface characteristics are not that important, e.g. foundation walls, utility structures and surfaces that are to be covered with other materials, such as brick, plaster or sprayed acoustical ceilings.

It is important to recognize that many types of mechanical transference such as plywood patch outlines, penetrate deeply into the concrete surface because of differences in hydration rates at the panel-concrete interface. Sandblasting and various other forms of texturing will generally not remove

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the appearance of the outline of the patch, since the discoloration will often penetrate more than 1/4".

Paintability

When the concrete is to be subsequently painted or plastered, a key consideration is the use of a proper release agent. While this is a long and complicated subject outside the scope of this paper a couple of points can be made as it applies to specifying the right plywood. Many plywoods are manufactured with pre-applied release agents and, where field painting is a factor, specifications should avoid any release agent containing silicones, paraffins or waxes. Chemically reactive release agents are preferable to the common pale oils.

Also matte surfaces such as provided by medium density overlays help the acceptance and adherence of coating without sandblasting or other preparation. Ultra smooth or slick surfaces can inhibit good coating adhesion.

Bug Holes and Honeycombing

"Bug holes" result from trapped bubbles of air, water or excessive release agent against the form surface. Proper selection of the concrete mix, the release agent and proper vibrating are probably the most important factors in controlling "bug holes". However, on vertical surfaces the smoothness of an overlaid plywood with some porosity seems to be a factor as well. The fiber sheet overlays (especially MDO) have some porosity which allows air to escape. A quote from the Cement and Concrete Association of England reads "blow holes are invariably present to some degree with impermeable form-face material". Also a reasonably smooth surface allows air bubbles to slide up to the surface better than rough surface when vibrated.

The more serious condition of honeycombing can occur because of inadequate vibrating and also because of excessive grout leakage at poorly fitted joints. Leaked grout can be replaced by air bubbles which create pockets in the concrete surface. Therefore, tight fitting or sealed joints are important, and well manufactured plywood with square edges will help the contractor a great deal in this respect. A squareness tolerance per PS-1 should be specified.

Pillowing and Excess Deflection

Probably the most common cause of pillowing on vertical forms is the excessive pour rate that results from new methods of pumping and placing (dumping) large amounts of concrete in a short time. The designer will often specify a pour rate of four or five feet per hour, but the effective pour rate in any minute may be several times that. From a structural breakage point of view plywood is conservatively designed so that structural failure are extremely rare. However, there is very little conservatism built into the deflection design so we do see quite a bit of pillowing.

There are many ways to tackle this problem. One is to specify a stronger and stiffer grade of plywood (see discussion below on this subject). Another, obviously is to position the supports closer together. The second most common cause of pillowing seems to be the use of plywood in the wrong direction across the supports. Normally the face grain direction is about 50% stiffer and stronger than the cross direction. See discussion below under strength and stiffness.

Also refer to the section below on edge sealing and edge support which describes a common cause of excess deflection on horizontal pours.

Dusting

Dusting or a granular surface can be caused by many conditions including the concrete mix, the release agent, curing agents, the weather, dirt, etc. However, one factor that relates to the selection of plywood is the species. A non-overlaid larch for example, which contains a high content of wood sugar can cause a serious dusting problem. If dusting becomes a problem due to the wood, overlays are the best answer.

NUMBER OF REUSES - RELATIVE COST ON A PER USE BASIS

It is virtually impossible to spell out the expected number of reuses from a given panel material, since every contractor handles the material so differently. For example, we know that some engineered systems users have reported up to 200 uses with HDO, but we also know of cases where HDO has been used only two or three times because it was cut up, damaged or simply because of the planning of the job.

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Nevertheless, reuse is the key to cost saving, and it is often startling to note the dollars that can be saved if the right panel is chosen for multiple use and used in a way to achieve it. For example, if we consider only the cost of the panel material for simplicity (disregarding labor for the moment) consider a vertical pour that requires 30 reuses. If an HDO is used properly it can easily achieve that use factor.

For the purposes of comparison consider an HDO at a cost of approximately \$1.35/sq. ft. Compare this to BB Plyform at approximately \$.63/sq. ft. which for comparison might go approximately five uses. With these assumptions, the comparison becomes $\$1.35 \div 30 = 4.5¢$ per pour for HDO versus $\$.63 \div 5 = 12.6¢$ per pour for sanded plywood.

The following table gives a few typical examples based on the approximate price to a small contractor in the Chicago area and some assumed reuse factors.

Cost Per Square Foot (Approx. - will vary with area, size of job, etc.)

<u>Product</u>	<u>Your Cost Per Squ. Ft.</u>	<u>No. Pours</u>	<u>Cost Per Square Ft. of Pour</u>
BB Plyform	\$.63	$\div 5$	= 12.6¢
Standard 1-Step MDO (1)	\$.74	$\div 8$	= 9.2¢
2-Step MDO (1)	\$1.05	$\div 12$	= 8.7¢
HDO	\$1.35	$\div 30$	= 4.5¢

This cost saving can be even more dramatic if you reach for a higher number of uses with prefabricated engineered systems or gang forms. Therefore, it can be said it is very important to plan your job for multiple use and take the steps necessary to achieve it in the field.

-
- (1) Note that MDO is most commonly supplied 1-sided (although available 2-sided) while HDO and BB are commonly available 2-sided which can effect re-use factors if both sides are used. However, this author's experience is that the plywood is seldom turned over and re-used on both sides.

Some fundamental factors that affect reuse are:

1. Protection of the edges since the edges are usually where the panel breaks down and ultimately fails. For example, some systems manufacturers greatly extend the life of a panel by providing a steel framed edge.
2. Handling by the contractor, especially where the panels are lowered carefully from some height. A serious loss of panel life and quality is frequently noted where panels are dropped on a corner or an edge from one or more stories up. The method of stripping is also important. Recommendations for this and many other points are thoroughly covered in ACI literature, especially "Formwork for Concrete" by Mary Hurd.
3. Planning of the job, considering sizes, cut outs, holes, etc. Sometimes a contractor can use whole sheets by leaving an overhang instead of cutting to exact shape.
4. Reasonable protection during storage from both the weather and physical damage, lift trucks, etc.
5. Pour rates, piling loads on decks and other stress factors. Conditions have often been observed where a deck is designed for perhaps a 75 lb. dead load plus a 50 lb. live load, but several thousand pounds of re-bars or a compressor are placed on the area. Not only is this obviously extremely dangerous but it can cause fractures and distortions in the expensive panels.
6. Use of adequate and proper release agent. We have seen a great deal of plywood over the years that has been pulled apart simply because it was not oiled between each pour; or a poor release agent was selected which sat out in the sun for an extended period and evaporated.
7. Careful vibrating is important to avoid vibrator damage. While the overlaid plywoods are more resistant to vibrator damage than BB Plyform they can still be torn up by an overly aggressive vibrator operator.

While the above list of problems explains why it is impossible to give a simple list of expected reuse for different kinds of plywood, nevertheless it



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is important for the specifier to have some kind of guideline to help him select plywood for a given job. Therefore, the following table will give estimates of reuse (vertical uses) where the panels are used with care and will not be cut up for one reason or another:

Reuse Factors (vertical use)

<u>Type of System</u>	<u>HDO</u>	<u>Two-Step MDO</u>	<u>One-Step MDO</u>	<u>BB PLYFORM</u>
Prefab Eng. Sys. Up to 200	Up to 35	Up to 25	--	
Gang Forms Up to 50	Up to 30	Up to 20	Up to 10	
Job Built Up to 25	Up to 15	Up to 10	Up to 5	

STRENGTH AND STIFFNESS - LOAD SPAN TABLES

The designer often does not recognize nor take advantage of the substantial difference in load-carrying capacity of specialty overlaid plywoods compared to ordinary sanded BB Plyform. This is becoming more and more a factor with high rates of pour achieved with modern equipment. It is important that the designer obtain the engineering properties and load-span tables from the manufacturers as well as from the American Plywood Association of the ACI for comparison with standard sanded plywood. It should be noted that there can be as much as an 80% greater load carrying capacity in some cases. To illustrate the point the following are taken from some manufacturers' published data:

Example: Allowable pressure, 1/270, 3/4" supports @ 12" o.c.

(Face grain across supports, edge supported)

<u>BB PLYFORM</u>	<u>One-Step MDO</u>	<u>Two-Step MDO</u>	<u>HDO</u>	<u>IMPORTED BIRCH</u>
	(2)	(2)	(2)	(3)
735 psf	895 psf	1140 psf	895 psf	1225 psf

- (2) Figures published at the time of this presentation in October 1984. Higher pressure ratings are now being made available. Please consult manufacturer's current data. These numbers are presented to illustrate the point about large variations, especially compared to BB.

- (3) From "McFin Finnish Birch Plywood Panels for Concrete Formwork", Technical Bulletin No. 6-1980.

It should be noted that the overlay itself is a very minor factor in the higher strengths, which come primarily from the veneer thickness and species.

A very important consideration is that the face grain of the plywood normally must be oriented across the supports. If it is oriented incorrectly stiffness can be reduced by as much as half. To illustrate, using the example above, 3/4" HDO will carry 895 psf in its strong direction but only 425 psf in the cross direction under this set of conditions.

There is one exception to this. Many gang form systems are designed with support members oriented in the long (8 foot) direction. This results in the weak direction of normal plywood spanning across supports which often results in pillowing of concrete. To overcome this a special high density overlaid panel has been developed by one manufacturer with high strength in the cross direction (4). Also, imported birch is often designed with its higher strength in the cross direction which results from the cross orientation of the face grain and to some extent from the number of plies.

One other factor that affects deflection or stiffness is the number of plies. While more plies do not directly result in greater strength they do result in better dimensional stability, i.e. less tendency to warp; and warp can show up as an apparent deflection. Also more plies gives a better edge (refer to discussion below under edge sealing). It is recommended that 3/4" plywood be specified with 7 plies (1/2" and 5/8" normally have 5 plies).

EDGE SEALING AND EDGE SUPPORT

The edges are the most vulnerable part of the plywood form panel and one of the least understood requirements is proper edge sealing.

Based on our experience, the best edge sealer is a two-coat polyurethane system which should be specified. Cut edges and holes should be sealed in the shop or on the job. If this is not done you will see swelling, warping, buckling and general breakdown of the edges.

A particularly troublesome situation has been

(4) Simpson FormGuard X; also Symons DXB

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occurring in modern flying form systems where the edges are not supported. Water gets into the edges and causes a buckling effect which often results in deflections that are more than double the deflection due to structural load. This results in concrete ceilings with scalloped edges and offsets which may exceed the architect's specifications and can mandate very expensive patching and grinding.

The best solution is to support the edges with proper blocking in addition to a good job of edge sealing. In fact edge sealing should always be specified. Also taping the joints helps keep the water out as does a foam edge-tape gasket which is being used more and more where the architect wishes to minimize the various unsightly effect of joints, including differential hydration, fins etc.

Top quality overlaid plywood with two coats of polyurethane factory applied to the edge is a good start, but an additional suggestion can be made where extra quality is desired: Specify an additional coat of polyurethane edge sealer applied to the edges on the job.

This presentation only covers some of the considerations in selecting and using plywood in concrete forming. there are a number of sources of more detailed information. Some of the better ones that I am aware of are: the ACI "Formwork for Concrete" by Mary Hurd, the American Plywood Association "Concrete Forming" and "Plywood Design Specifications", various literature from the Cement and Concrete Association of England, your Portland Cement Association and Simpson Timber Company (5).

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- (5) American Concrete Inst., P.O. Box 19150,
Detroit, Michigan 48219.
Cement & Concrete Assoc., Fulmer Grange, Slough,
England SL24QS.
American Plywood Assoc., P.O. Box 11700, Tacoma,
Washington 98411.
Simpson Timber Company, 3rd & Franklin, Shelton,
Washington 98584.

Dowel Bar Substitution: A Hidden Strength

by Harry B. Lancelot

Synopsis: Dowel bar substitution is a new phrase but not a new solution. The technique provides a productive means of splicing across construction joints. Examples of the application are shown and discussed in this article.

Keywords: concrete construction; construction joints; dowels; formwork (construction); splicing

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INTRODUCTION

While concrete structures provide considerable artistic appeal and workability, forming costs tend to limit the degree of creativity. Forming costs may be as high as 60% of the in-place structure. These excessive costs are sometimes attributable to protruding rebar. This paper discusses a technique to improve constructibility by minimizing dowel bar projections. The technique is referred to as dowel bar substitution.

DISCUSSION

Protruding reinforcing bars may restrict access, cause personal injury, damage support equipment, compound concrete forming tasks, and require special administrative activities such as extra inspections and quality control support.

Reinforced concrete interfaces do not have to be complicated, tedious, or labor intensive. Figures 1 through 4 show typical sequences for achieving a reinforced concrete interface. Figure 1 illustrates the rebar splice receivers integrated into the rebar mat of the first pour. Figure 2 depicts the assembling of the dowel-in to the receiver interface. Figure 3 demonstrates the reinforced concrete interface of the second pour. Figure 4 shows the finished construction joint and reinforced concrete interface. The receivers may be attached to a keyway or directly to the bulkhead form face. Concrete forming and stripping is easily accomplished with routine activity.

Examples of dowel bar substitution applications are shown in Figures 5 through 13. Figures 5 and 6 show an example of dowel bar substitution being used to eliminate protruding dowels for connecting floor slabs to the slipformed core walls encompassing the elevator shafts and stair wells of the new Westin International Hotel in Boston's Copley Square. Figures 7 through 11 record the events of rehabilitating an old bridge using epoxy coated rebar. The technique