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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)

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 explicity 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 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 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 reuseable 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 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 concieved 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

10 Plastic Form Liners and Overlaid 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.

<u>Thermo Plastics</u> 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.

<u>Thermo Setting Plastics</u> 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.

<u>Elastomers</u> [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.