Factors Affecting the Selection, Economics Involved in Formwork

Appropriate selection of a formwork system is a crucial factor in successfully completing most building projects. However, in practice, selection of an appropriate formwork system has traditionally depended mainly on the intuitive and subjective opinion of practitioners with limited experience. This paper discusses the guidelines on how to choose formwork, factors affecting the selection, economics involved in formwork and the present scenario of formwork in India. This article can assist engineers to determine the appropriate formwork system at the inception of future projects.

Formwork is a die or a mould, including all supporting structures, used to shape and support fresh concrete until it attains sufficient strength to carry its own weight. It should be capable of carrying all imposed dead and live loads apart from its own weight.

A formwork system is defined as “the total system of support for freshly placed concrete including the mould or sheathing which contacts the concrete as well as supporting members, hardware and necessary bracing”. However, “System” implies a fully compatible arrangement of formwork with a minimum of individual components with reusable elements intended to solve each forming task thereby rationalizing the forming work.

Formwork system is among the key factors determining the success of a construction project in terms of speed, quality,
A large proportion of the cost of formwork is related to formwork labour cost. Significant cost savings could be achieved by reducing labour cost. An exemplary comparison reveals that the additional concrete use of up to 15% is economical than the handling of angular forming areas, since their assembly is rather time-consuming and the cost per square meter is higher than that for a straight surface.

B) An Integrated Formwork/concrete Life Cycle

The process of providing formwork and concrete is highly integrated. In the figure 2, the left circle represents the formwork life cycle, while the right circle represents the concrete construction life cycle. The two intersection points represent the beginning and the end of concrete construction life cycle. It should be noted that the phases ‘cure concrete’ and ‘stripping of formwork’ are interchangeable depending on the type of structural element. For example, columns and walls are cured after stripping the forms while slabs and beams are cured before and then stripped.

C) Economy of Formwork and Significance

1. Economy in design of a concrete structure

   The architect or design engineer can also contribute much to reduce formwork cost by keeping the requirements of formwork economy in mind when one is designing the structure. At the time of design, consideration of the materials, methods that will be required to make, erect and remove the formwork. Avoid varying sizes in columns and beams; Usage of same sizes to the possible extent economizes the design permitting the reuse of formwork without alteration.

2. Economy in design, planning and building formwork

   In designing, planning and building formwork, the contractor should aim for maximum economy without sacrificing quality and safety. Short cuts in design or construction that endanger quality or safety may be false economy. For example, if forms do not produce the specific surface finish, much hand rubbing of the concrete may be required; if forms deflect excessively, bulges in the concrete may require expensive rectification measures.

A) share of Formwork Cost

In a typical multi-storey reinforced concrete building, formwork cost is the largest cost component. Formwork cost accounts for nearly 20-40% of cost of concrete and involves more than 60% cost of time. Overall formwork related cost have significant share ie.10% in the total construction cost.
Limit the size of formwork panels or systems to largest possible that can be handled at site.
- Standardize formwork making, erection and stripping to maximum possible extent
- Minimise the amount of components and accessories like nut, bolts, nails etc. to avoid risk of losing
- Create a material cost awareness cost of material consciousness in the personnel
- Control reuse and repetitions. Specially plywood and timber
- Standardize various formwork systems

coordination and cooperation between engineers, contractors are necessary to achieve the goals. Saving depends on inventiveness and knowledge of the contractor. Judgment in the selection of the materials and equipment, in planning, fabrication and erection procedures, and in scheduling reuse of formwork, will expedite the job and cut costs.

D) Various Formwork Systems

Formwork can be classified according to a variety of categories as follows: (Refer Figure - 3)

Classification according to sizes

- Small-sized formwork
- Operation by workers manually Wooden and aluminium formwork
- Large-sized formwork
- Crane facilities are required in the operation Reduce the number of joints and to minimize the number of lift Stiffening components -studs and soldier

Classification according to location of use

Various elements in the structure have specific design and performance requirements in the use of formwork. Some systems are more adaptive for specific location of use, such as

- Irregular frame structure – Conventional traditional timber form.
- Wall, Column – Girder form, Frame panel form, climb form or jump form
- Slab – Conventional timber form, Modular slab formwork, primary-and-secondary beam method, Panel form, Drop head beam- panel system, table form
- Repeated regular section – tunnel form, modular aluminium form
- Core walls, shells- Climbing formwork, Jump form and slip-form
- Precast structure- steel /aluminium mould forms

Classification according to materials of construction

- Timber: most popular formwork material -low initial cost -high adaptability to complicated shape-labour intensive and environmental unfriendly
- steel: hot-rolled or cold-formed sections heavy weight - suitable for large-sized panels
- Aluminium: stiff and light weight-higher material and labour cost-excellent finish
- Plastic: recyclable, tough, lighter weight
- Sacrificial concrete panels- Left in place formwork

Classification according to nature of operation

- Crane independent- Manually handled formwork -Self-climbing formwork
- Crane-dependent formwork
- Gantry, traveling and tunnel type formwork system

E) Evaluation / Selection Criteria for Formwork System

Earlier formwork was once built in-place, used once, and subsequently wrecked. The trend today, however, is towards increasing prefabrication, assembly in large units, erection by mechanical means, and repetitive use of forms. These developments are in tune with the increasing mechanisation of production in construction sites and other fields.

Formwork planning includes detailed layouts, cycle plans, calculation of optimum amount of material for the site, observance of fixed schedules and selection of the most appropriate and the most economic formwork system to be used at the construction site.

Different Parties involved in formwork selection

The proper selection of the formwork systems to be used in concrete structure is concern to all involved parties.

The following selection criteria have to be considered:

1) Geometry of building / structure

Internal layout

Some buildings may have very simple layouts with few in-situ walls and floor plates framed with regularly spaced columns, as seen in many commercial and office buildings. However, some developments feature very complicated load bearing internal walls that can make the casting process difficult.

Structural forms

Like internal layout, the structural form of buildings also affects the formwork options. For example, buildings with a structural core in the form of a vertical shaft limit the use of other formwork
systems other than those of a self-climbing nature. Buildings in flat slab design make table forms or flying forms the most obvious choice. For buildings with regularly arranged shear wall designs, the best selection is large-panel type steel forms or other types of gang forms.

Consistency in building dimensions

Some buildings may have non-standardised dimensions due to the architectural design and layout or to fulfill other structural requirements. These include the reduction of sizes for beams, columns and walls in high-rise buildings as the structure ascends. Formwork systems like the climb-form or steel form, may be quite difficult to use in such situations, due to the frequent adjustments of the form to meet the changes in dimensions may eventually incur extra cost and time.

Headroom

Higher headroom increases the amount (height) of staging required and can also create accessibility and safety problems. It can also make the erection of formwork, ensuring formwork stability and the placing of concrete more difficult.

Building span

Large building spans also create problems similar to those with high headroom situations. In addition, long-span structures generally have larger beam sections, heavier reinforcement provisions, or accompany post-tension works. This will further complicate the formwork’s design and erection process.

Repetitive nature

High-rise block-shaped structures usually require highly repetitive cycles and this is favourable to the use of formwork. However, the degree of repetition in building with very large construction area like a podium or underground structures such as basements is limited and the use of formwork, as an expensive resource, becomes very critical.

2) Project Planning/speed of work

The over-all construction sequence must be planned to use formwork in efficient manner and to permit the optimum investment in formwork to meet schedule requirements. Contractor should plan formwork and job sequence at the time of making a bid. Project planning such as the phasing or sectioning arrangement, integration of the structure, site layout and set-up arrangements or hoisting provisions and concrete placing facilities are influencing factors when considering formwork selection and application.

When working with buildings with large construction areas and horizontal spread, projects can be expedited by the introduction of additional sets of formwork, to create more independent work fronts. This will, of course, increase the cost of construction. For high-rise buildings, increasing the number of formwork used cannot always expedite the project, for the critical path still depends on the floor cycle. However, a properly selected, designed and arranged formwork system will increase work efficacy for each typical cycle. In some cases, adding half or a full set of formwork, especially for the floor forms, may help to speed up the cycle as the additional set can provide more flexibility when the form is struck at an earlier time.

3) Construction process, methods

For selecting formwork one must know the sequence of construction activities and methods to be followed. Construction method will always give idea about inter dependency of the activities, specifications and additional requirements in pour. This will enable us to workout appropriate system which fulfills the construction needs.

4) Site logistics

Exceptionally small or very large sites sloped or very crowded sites, proximity to sensitive structures, sites where other major activities are underway, or sites with many physical or contractual restrictions will increase the difficulty of working with formwork. There is no specific solution to improve the situation in general and problems are tackled according to individual circumstances.

Accessibility to work during the course of construction, accessibility problems may be created through segregation, temporary discontinuation, or blocking of the layout by the partially completed building or, in cases constructing a shaft-type core wall is constructed in an advanced phase, the shaft may stand independently for a long period of time before it is connected to the horizontal elements. Proper access to all components should be considered while planning a site layout.

5) Climate condition

Formwork systems are sensitive to weather conditions. Typically, in vertical forming systems, the newly placed concrete is supported by the wall already cast below it. The lower wall section must get the sufficient strength to support the fresh concrete above. The rate of strength gain of lower wall is influenced by the ambient temperature, moisture content, and the freezing and thawing cycles.

Another factor that affects the economy of the selected system is the effect of stopping formwork activity and concreting because of extreme weather conditions. In the case of a slip-form, the work is usually continuous, 24hrs around the clock. If the slip-form stops because of weather conditions, it may impact structure as well as cost.

6) Labour efficiency

Considering the availability and qualification of the work force, improving labour cost efficiency is a major factor, especially in markets experiencing a building boom. Here, the qualification of workers tends to be low in relation to ever higher demands posed by construction methods.
7) Cost of formwork system

This is a vital factor for deciding formwork system as one must know the capital provision for formwork in the project. It is always beneficial to work out these details at the time of bid. Cost is influenced by three components;

Initial cost or make-up cost:
Includes cost of transportation, materials, assembly and erection.

Reuse cost of formwork system:

The formwork system cost goes on reducing as we increase reuse of same. The re-use for traditional timber formwork is usually limited due to the durability of the plywood sheathing. The optimum number of uses for timber form usually ranges from 12 to 14. Thus, it is still sufficiently economical to use timber formwork for high-rise buildings at heights in accordance to the multiple of the usual re-used times. Although the metal form can be re-used many times, the high initial cost of providing the form often discourages its selection, especially when there is no need to reuse them too many times, for example in a low-rise development. A careful balance between cost, speed, performance and the quality of output should be properly considered when making the selection.

8) Maintenance & storage cost:

It includes cost of stripping, repair, storage, etc. Formwork materials are a valuable asset of company. If proper care is taken during handling and storage, much return is obtained on the investment. Formwork needs to be handled correctly, maintained, repaired if necessary and finally, cleaned regularly. Avoiding damage reduces costs incurred. Proper storage of formwork materials gives easy reconciliation, faster retrieval of material, better space management and avoid unnecessary expenditures, improve safety at work place.

9) Availability of lifting devices (Crane time)

Many factors should be considered before employment of a construction plan and the selection of the right formwork system. These include considerations of whether there will be lifting appliances provided for the erection of formwork; whether these appliances will be able to access the work spot to assist in the operation as the structural works proceed; whether any special equipment will be required for striking the forms; and how the removed formwork panels can be transported to other spot to continue work.

Characteristic to high rise building sites is the confined and congested space availability for working. Crane time and space is regularly limited. In general, reinforcing (rebar) activities are most critical, since lifting the reinforcement to building level is the most crane- time consuming job of all. Thus, the capability of formwork to rely less on or be used independently of crane time is critical in high rise construction.

10) Simple logic of the system

Formwork system ought to be self-explanatory to use, this automatically eases the usage for the engineers/supervisor and also the labour who are end users of the system.

11) Working safety

Formwork should be self-securing with safe access and working platforms. Thus, it is not left to the end user whether they takes safety measures or not. Creating a safe work environment for the entire work force involved in the construction process, has become the pivotal issue in emerging construction markets.

12) Special requirements on Concrete surface/finish

Fair-faced concrete demands very high quality formwork in terms of surface treatment of the panels, tightness of the formwork joints and in dimensional accuracy. Requirements are slightly relaxed where the concrete surface is to be finished at a later stage.

13) Area or volume of cast per pour

The optimum volume of cast per pour depends on the types of formwork used, the particular elements of structure to be placed, the actual scale of work, and different levels of provisions of plant facilities. Usually a volume of concrete ranging from 60-200 cubic meters per pour can be comfortably handled in most
site environments. It also depends on whether the concrete to be placed is for the vertical elements only or also includes the beams and slabs, as a means of saving an additional phase in the overall work cycle.

14) Involvement of other construction techniques

Tensioning and prefabrication activities are often involved in construction. This may create certain impacts on the use of formwork, especially where precast elements are to be incorporated during the casting process. Provision should be made for temporary supports or slot spaces and box out positions in the formwork for the precast elements, or extra working space for placing stressing tendons and onward jacking.

15) Provision of construction joints in structures

Many times a large number of construction joints are inevitable in a large structure because of the subdivision of works into effectively workable sizes. The provision of construction joints can challenge the output and affect the quality of the concrete. Careful selection should be made to ensure a particular formwork system can satisfactorily allow such arrangements.

16) Inventory- The fewer, the better

The most frequent time & cost consuming activity of formwork assembly is the loose and small components/accessories. The lesser inventories will help to reduce risk of losing parts and provide ease in construction.

F) The Current Situation in India

In the past, India had been lagging behind over the other advanced countries in applying advanced and safe concepts for formwork in reinforced concrete construction resulting in a poor surface quality, wastage and low productivity of the people involved in concrete construction. This unfortunate situation continued for a long time because of availability and use of very cheap unskilled labour and very few skilled personnel who have had professional training for formwork jobs.

With increasing demand and competition and reducing project completion times, there have been significant developments in the construction industry in terms of experience and mastering of the required managerial, construction or engineering skills for handling very large and complex projects. At the same time, the motivating factors highlighted above have created an eagerness and readiness within the industry to advance. From the building construction point of view, the use of better formwork systems can satisfactorily allow such arrangements.

- Similarly, traditional systems can hardly satisfy current safety and environmental standards.
- The accumulation of experienced crews makes the application of more sophisticated formwork systems more reliable and economical.
- Many developers view the application of innovative technology in the construction process as a positive image-building factor.

G) Major Systems Dominate Today’s State of Art Formwork Approach in High Rise Construction

- Slab edge protection by screens, providing a safe working environment on the construction levels
- Modular slab formwork, operated independently of the crane time, adapted flexibly to different building geometries and floor layouts
- Undisturbed shoring for slab with drop beam systems
- Frame formwork for columns and walls
- Crane dependent climbing formwork for shear walls/mega columns
- Crane independent climbing formwork for core

H) The Potential and Limiting Factors of Innovative Technologies in the Built Environment of India Potentials

- The public’s expectation (government, developers, building users) are rising all the time.
- More stringent regulations have been imposed to control the performance of the construction industries.
- Accidents are costly, especially where human casualties are involved (both for the reasons of compensation, image and government records).
- The development or importing of advanced technology have become more common and market affordable.
- The industry is gradually accepting the production of higher performance buildings involving a more expensive resource input.

Limitations

- Insufficient research and development in most contracting firms or other supporting units.
- Lack of working space on construction sites (both on-site and off-site work areas).
- Training opportunity (including on-the-job training) is still limited for both the professionals and other workers.
- No guarantee of a consistent market environment for the development and continual application of innovative technology in construction (learned skill and experience will lose eventually).
- The extensive use of cross wall design especially in most residential buildings and small-scaled projects makes the use of more innovative formwork system less feasible.
- The exceptionally large scale and complex nature of projects in terms of the site condition as well as structural and building design confine the application of more advanced and sophisticated formwork system.
I) The Industry or Individual Corporations May Consider for the Following Measures:

- Explore ways to streamline and re-engineer the work structure at both industrial and corporate levels.
- Invest steadily in the human resources development and to train competent and high quality staff with the required attitude and readiness to work in the new environment.
- Invest steadily in the research and development of technologies that are particularly suitable for the built environment of India.
- Strengthen the linkages among government departments, developers, consultants and contractor firms in the promotion, development, cooperation and implementation of more innovative projects.
- Government or other institutions may consider providing funding to support research and development for the exploration, recommendation or setting up of guidelines and standards in the application of newer technology and work systems in construction.

Conclusion

1. Selection of formwork system, is highly dependent on individual site/project environment
2. Economy of formwork can be achieved with seamless collaboration between owner, architect, designer teams and contractor. And it can aid in the effective use of advance formwork systems
3. The structural form of the building is one of the critical factors to determine the choice of formwork
4. System products can contribute much in the success of formwork application

Formwork Standards

<table>
<thead>
<tr>
<th>Indian</th>
<th>International</th>
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<tbody>
<tr>
<td>IS 14687-1999</td>
<td>ACI 347-04 Guide to formwork for concrete</td>
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<tr>
<td>IRC 87-1984</td>
<td>ACI 347.2 R-05 Guide for shoring / reshoring of concrete multi-story buildings</td>
</tr>
<tr>
<td>IS 2750-1964 (1995)</td>
<td>ACI SP-4 Formwork for concrete</td>
</tr>
<tr>
<td>IRC 87-1984</td>
<td>BS 5975-2008 British standard code for practice for temporary works procedures and the permissible stress design of falsework</td>
</tr>
<tr>
<td>IS 2750-1964 (1995)</td>
<td>DIN 4420 &amp; 4421 German standard for formwork</td>
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<tr>
<td>IRC 87-1984</td>
<td>DIN 18218 Pressure of fresh concrete on vertical formwork</td>
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<td>IRC 87-1984</td>
<td>CIRIA Report 108 Concrete pressure on formwork</td>
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References