Building a high rise, or other large buildings, is typical for urban areas. High-rise buildings are rapidly becoming a developing nature of urban zones due to increased population and businesses. The core of high-rise buildings is one of the most important elements in such gigantic structures. Fast and efficient construction of the concrete core of a high-rise building is essential to maintain phased progress on other parts of the building. Formwork is one of the most important factors in determining the success of a construction project in terms of speed, quality, cost and safety of work as it accounts about 40% of the total project cost of the structure. To minimize the costs the contractor needs to complete the project as soon as possible and the client wants the building to use the building as early as possible for the intended purpose. In high-rise building construction the most efficient way to speed up the work is by achieving a very short floor cycle. That directly depends on the selected formwork type for the construction.

The development of formworks is parallel with the growth of concrete construction throughout past few decades. With the development and increasing of population people tend to construct high-rise buildings and construction of a tall building was not easy at the early days. With the development, the man made the tasks easy by inventing new machinery and new techniques. One such area related to high-rise construction is the type of the formwork used in the construction. At the early days people used conventional type formwork where the timber planks were supported on timber columns. With the advancement of the science man used plywood instead of timber planks and pipe supports with various kinds of jacks instead of timber supports. Then the man invented small units of formworks when the same structure is repeating such as slab forms, flying forms for the walls etc. finally the greatest invention came for the complete system. At the beginning the system was made out of steel and which was very heavy. Then the man paid his attention towards reducing the weight of the formwork system. Now the materials for formwork have extended to aluminium, plastic, fiber glass etc.
But still the aluminium panel system formwork is not much explored in developing countries and most of the contractors do not like to shift to the latest technology as they have the doubt of facing losses in the project and they are very much familiar with the existing formwork type, the modern conventional type. At the same time contactors have a false belief that aluminium panel system formwork is only suitable for very tall buildings which are having thirty to forty storeys. Though the aluminium panel system formwork reduces the project duration and hence the total project cost, the formwork system is a bit expensive. So this research was carried out to analyze the cost for each formwork type and compare the values obtained for the total project cost when different types of formworks are used in the construction project and find the least no. of storeys sufficient to use the system formwork in the construction project.

Another important aspect in a high-rise building construction with reinforced concrete structures is form work effective management systems to reduce the duration and cost of structural frame work and subsequent activities. A concrete curing management system by adapting a ubiquitous computing environment has been developed by researcher’s as a method for effective quality management, which is also discussed here.

**Various Work Packages and Work Flow Pattern of a High Rise / Mid Rise Building**

A Typical master program comprises five primary work packages as shown in Figure 1.

```
Figure 1: Typical Master Program for High Rise Buildings
```

Management strategies for defining these stages as construction packages have been proposed to reduce time in the overall construction duration. If the construction durations of every phase can be estimated reliably and objectively in the design stage, time uncertainty will be minimized in the construction stage.

The researchers found that the seven most important variables affecting the time schedule of this type of structures are:

1. Area of external cladding
2. Height of the building
3. Ratio of total gross floor area to the number of stories
4. Type of foundations
5. Information flows between architect/engineer and contractor
6. Presence/absence of precast facades; and
7. Type of scheme adopted

Form work system and its usefulness to optimize the construction schedule and speeding it up falls in the type of scheme adopted category. This is a very important aspect to speed up the construction as now a days there are projects which achieved 3 to 6 days of floor cycle by adopting light assembled form work system.

**Available Formwork Types for High Rise / Mid Rise Buildings**

When a project is considered the material requirement is unique as it depends on the design. But the labor requirement and the duration of the project are totally depending on the technologies and the construction methods used in the project. One of the most time consuming activities in a high-rise / mid-rise building construction project is the construction of the main structure. At the same time it requires more labor. But when the latest technologies are used it can reduce both the time and labor requirement in constructing the main structure. In a high-rise building projects formwork plays a major role as it directly affect the floor cycle and hence it will reduce the time taken to construct the main structure and because of that the total duration of the project will go down drastically. Commonly available formwork system includes:-

**Conventional Type of Formwork**

This is the most traditional type of formwork and this uses timber, bamboo, masonry and carpentry to complete construction. Low initial cost, low experience factor and low weight are some of the advantages while high floor cycle, poor finish, and high labor requirement are the disadvantages of this formwork type. This formwork type is still in practice in two – three storey building construction projects.

**Modern Conventional type of Formwork**

Modern conventional type formwork is as much the same as the traditional slab formwork method and the only difference is that steel props and various types of jacks (U jacks, T jacks) are used as supports in the formwork instead of timber supports and ply wood sheets are used instead of timber planks on slab decks, beams and columns. The advantages of this type are low initial cost, low skilled labor requirement and can use in places where there are a lot of deviations in the structure.

Various companies have done various researches in the wood formwork and have come out with H beams and pressed shuttering plates.

(a)The H-Beam is a unique introduction in construction
industry to overcome the cumbersome process of procurement of timber. H-Beam is designed and fabricated at par with International Standards under strict quality control and Quality assurance to withstand various design loads during Construction of various activities. The members are made up of Solid Wood Panel making the web, and flange sections are made up of well-seasoned Spruce Wood that makes Timber H Beam stronger and durable. The flange and web of H-Beam are hot processed by the wedge technology that makes a versatile section by which the whole member gives us strong durable and higher load carrying capacity in various areas of construction Industry. Refer Figure 2 for H Beam application.

Semi System Formwork:
This is a more advanced formwork type than the modern conventional type as there are pre-fabricated formwork items. For example there are pre-fabricated formworks for slab panels and supports and other structural parts. There are several types of semi system formworks and is discussed as below:

(A) Fiberglass formwork: The use of fiberglass as a material to make forms for concrete work has increased rapidly within the past two years. Among the reasons are:
- Fiberglass forms provide a means of producing a concrete surface that is architecturally acceptable without rubbing and grinding.
- Special patterns and designs can be readily molded into the material.
- Large areas or sections may be made without joints or seams.
- When repeated usage is possible, fiberglass is often the most economical form material.

Perhaps most important one is fiberglass forms allow the architect complete freedom of design.

One advantage of fiberglass forms is it is possible to eliminate the joints or seams. Also when special conditions dictate building a form in sections, it is possible to join the units in such a manner that the several sections may later be sealed together with additional applications of resin and fiberglass to produce a seamless mold. Versatility is another advantage. Fiberglass panels can be 100 percent reversible in any situation. Fiberglass is also an excellent insulating material and is impervious to moisture; thus fiberglass forms provide built-in protection against temperature extremes. Although the first cost of fiberglass forms are relatively high, the durability of the material permits almost unlimited reuses. Consequently, wherever it is possible to make repeated use of the same form, the cost may be reduced substantially to a point that the material becomes the lowest cost per use of any form.

(b) Shuttering Panel made of Solid Wood have multiple layers (typically 3), with cross layers consist of two outer skins made of Spruce wood, oriented parallel to each other and one or more middle layer oriented crosswise to the grain direction of the outer skins. The build-up of the panels is symmetric to the middle layer. The two outer layers with aligned fibers and the middle layers are glued with waterproof bonding. This construction keeps the layers strongly bonded and gives more repetition along with high load carrying capacity. For construction use, the function of the Solid Wood shuttering panel is the same as Film Faced plywood. Refer Figure 3 for a typical 3 layered shuttering panel.
(B) Plastic Formwork: It comes as a individual structural elements like columns and walls. Various sized columns and walls are available in the market. The formwork is very easy to install and uninstall and has a very high repetitive nature. The ease of application makes it very useful where faster completion of work is a criteria. Refer Figure 5 for Plastic formwork in columns.

Figure 5: Plastic formwork in columns

(C) Fiber-reinforced polymer (FRP) formwork system: FRP formwork is used where unique configuration required for the arches and columns or any other structural parts. The FRP formwork pieces were produced using the hand layup method using molds fabricated by means of a computer numerical control (CNC) machine. On site, the size and weight of the formwork required the use of forklifts and scissor lifts for assembly. After the forms were assembled (Refer Figure 6) and the reinforcement was placed, selfconsolidating concrete was used to produce the required smooth, uniform finish.

Figure 6: FRP Formwork system

Aluminium Panel System Formwork:
System formwork has prefabricated modular components with casting panels. The system formwork can suit the required shape of concrete structure. The speedy and quality construction is the biggest advantage in this type while high initial cost is the main disadvantage and hence this is not economical to use in low-rise buildings. But this is the most economical form of formwork type to be used in high-rise building construction when it is having few (more that 10) typical storeys as it can be made in a single storey complete formwork set form and a faster floor to floor construction can be achieved. (Refer Figure 7)

Figure 7: Various Form work assembly system for High Rise Buildings

Jump Form System to Construct Concrete Core Walls of High Rise / Mid Rise Buildings
The use of a climbing formwork systems (Refer Figure 8) to construct the core walls of tall buildings has been successful in different countries in reducing construction times, primarily because the process become repetitive through the whole height of the building.

Basically it consists of a frame constructed from structural steel members over the score wall. Steel formwork panels
Formwork Systems

are hung from this frame, some supported on rollers. After the concrete walls are poured, the formwork is released and rolled back from the concrete face. Jacks then lift or climb the whole frame up one level. All the formwork panels are attached to the frame. This process takes approximately one and a half hours. The moulds are cleaned after being lifted out of the finished unit and then re-assembled. A thin layer of a steel mould-releasing agent is then applied by spraying it onto the surface of the steel mould in contact with concrete prior to reinforcing bar placement. Inspection of the moulds is then carried out. Once the climbing formwork is in its approved position, the next concrete wall is poured. The cycle continues, which is normally four days. Faster times have been achieved. However, the limiting factor to faster times is usually the construction of floor slabs, which usually are done as a separate process. Refer Figure 9 for climbing procedure.

Form Work Management Based On Ubiquitous Computing

Form work significantly influences successful project completion in high-rise / mid-rise building construction with reinforced concrete structures. One of the effective ways for reducing the form work duration is to strip the forms without delay when concrete placed in the form is sufficiently cured to stand by itself. In order to strip the forms at the appropriate time, it is important to estimate the concrete strength development at the early stage of the curing process. The concrete maturity method can determine the concrete strength more accurately and consistently than other conventional methods such as using test cylinders or a Schmidt hammer. A ubiquitous computing environment can facilitate the application of the concrete maturity method on the construction site, and a wireless temperature monitoring system has been recently developed in Korea. The system is discussed below.

Figure 8: Climbing Formwork System

Climbing procedure:

After pouring → move back formwork → lift climbing profile → lift bracket → close formwork and pour concrete

Figure 9: Climbing Procedure

Figure 10: Wireless temperature monitoring system
Wireless Temperature Monitoring System

Figure 10 shows the constitution of the wireless temperature monitoring system developed in Korea. The system transmits the temperature data measured from the sensors wirelessly in real-time into the personal computer in the site office, and estimates the maturity and concrete strength. The data are also stored in the computer server, and information is shared with related experts for technical support. However, there are some limitations on the application for form work management in a structural frame work in highrise building projects as follows:

1) time for installing the sensors and connecting wires with recording devices,
2) identification of the data into the PC in the site office, and
3) gap between the time when the estimated strength of concrete reaches the required standard and form stripping time due to a planned schedule in structural frame work.

However research have been carried out and the above bottleenecks were overcome. The research proposes a method which integrates a sensor and recording device with a form, and the sensor and recording device can be separated from the form in the case of a problem such as failure in the sensor or discharge in the recording device. The installing time may then be reduced considerably. Next, the construction manager can identify acquired data and estimated strength on the PC in the site office. However, this could cause proper and timely actions to be delayed according to the changes in the site condition, even though the system has the function of sending the warning message to the managers. Mobile devices, such as smart phones and web pads, can be offered as useful tools for timely management. Form stripping work could be delayed at the time when the required concrete strength is gained. This is because the time of resources input needs to be adjusted if the time taken to reach the required strength for form stripping is inconsistent with the time planned in advance. Thus, daily work management needs to be managed effectively through predicting the concrete strength development and form stripping time.

Considerations Required for Adoption of Formwork Systems

In planning for the adoption of handset system formwork for high-rise / mid-rise residential building construction, the followings consideration should be taken care of:

1. Building design must be frozen at early stage
2. Sufficient time shall be allowed for fabrication, factory pre-assembly and learning period for adopting necessary day cycle as required for the project.
3. Allowance should be made for change from typical floor to non-typical floor, such as refuge floor or plant rooms, and vice versa.

In order to shorten the learning period and smooth flow of works on site, full-scale factory pre-assembly is recommended for each set of system formwork prior to the delivery to site. In addition, an on-site mock-up is also mandatory to verify the integrity of the system formwork as well as for coordination among different trades. It is necessary to strike the beam and slab formwork earlier than the specified period to achieve the learning period to avoid any delay. The approval of such operation should be supported by concrete mix with early strength development. In addition, the formwork should be designed in a way to absorb the construction tolerance of the concrete flooring.

Conclusion

Buildings are becoming higher and higher nowadays in maximizing land use and investment return. Construction of residential developments are considered as focal point of the construction industry in view of its huge labor contents and turnovers evolved due to its own nature of works and investments involved from the investors. Investors tend to build everything possible in a small piece of land to increase their return from their investment in the quickest possible manner. Practitioners in the construction industry are looking for different means and methods in enhancing efficiency and meeting requirements from the statutory bodies and the Clients. All these will be met with if the construction is planned and achieved at a faster pace. Efficient formwork design and adoption helps considerably in achieving this target. However sufficient attention to be given in the safety aspect of the adopted system as this involves work at height.

Reference

1. Form Work Management Based On Ubiquitous Computing For High-Rise Building Construction Taehoon Kim, Hunhee Cho, and Kyung-In Kang School of Civil, Environmental and Architectural Engineering, Korea University, Seoul, Korea
8. http://www.siscon.co.in/slide/column20work.png