CONVERSION OF LARGE CAST-IN –PLACE SHEAR WALL STRUCTURES TO PRECAST

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ABSTRACT

Many building and non-building structures have a structural system selected solely on the basis of the architect's or the Structural Engineer-of-Record's (SER) personal preferences. Those preferences are determined by past experiences and hence a sense of "comfort" with a particular structural system. Unfamiliarity with other systems, their potential and limitations, also plays a role in SER's preferences. One such system that is frequently overlooked by the SER community is precast concrete (PC). Not only can it meet the construction market's ever-increasing demands for faster schedules, less expensive products, and reduced field labor, it can do so in a creative and innovative way.

The paper also offers case studies from recently completed projects, one of which involved the cast in place (CIP)-to-PC conversion of a 12,000-seat auditorium for Brigham Young University in Rexburg, Idaho; a two level elevated parking structure over a retail store in Salt Lake City, UT, and storage tanks for liquid products (LP).

Keywords:

Precast Concrete, Structural Conversion, Emulative Design, Penalization, Planning, Shear Walls.

INTRODUCTION

In today's construction market, the need for fast and efficient construction methods is an increasing concern for owners. As a result structures that were originally designed as steel or (CIP) concrete are often converted to precast structures. It usually requires significant effort on the part of the precast producer to illustrate the benefits of using precast concrete to the owner, the architect, the SER, the general contractor (GC) and the other stakeholders.
For typical commercial or residential projects, the process is relatively straight-forward. For large-size projects, however, there are a lot of misconceptions about the PC capability and especially about its limitations. For the precast team to fulfill the promise of low cost, speed of construction, and quality products, many challenges must be overcome. This paper addresses the most important challenges associated with large-scale CIP-to-PC conversion projects. They are classified into three groups:

- Design/Logistics
- Production/Handling/Transportation
- Erection and Temporary Bracing

Strategies for finding various solutions to these problems are suggested. The focus is on unique structures with large walls, such as storage tanks, performing arts buildings and stadiums. The same approach may be applied to the conversion of conventional and frame-type buildings in a simplified form, although it rarely requires the elaborate decision-making process necessary for unique structures.

BEGINNING THE PROCESS

Precast producers offer their products on the premise that pre-fabricated components will help the contractor meet the increasing demands of the owner. With offsite fabrication of components, it is able to field-assemble structures in a much more efficient manner and with less waste than any on-site construction method. Structures typically constructed out of PC are projects that the SER or the Architect recognizes in the initial design phases as being a fit for precast based on past experience or a relationship with a PC company. There is still a common misconception, however in the design arena that for large projects such as high-rise construction or projects in high seismic regions cannot accomplish what CIP can. This prevents the initial design team from investigating PC as a solution and those structures are designed as CIP. Even in that situation, there is an opportunity for a PC producer to offer a conversion.

The process of conversions can be quick if you know what to look for and have a good understanding of what the contractor needs in order to have a successful project. Contractors who perform their own CIP work are much less interested in a precast solution than those who have a concrete subcontractor.

Large structures, unique structures, or structures with multiple levels of difficulty should be viewed as potential conversion projects. Structures that are tall and freestanding are ideal as contractors will have increased risk with these structures. Safety, time to construct, site lay-down and weather delays will all be reduced with a prefabricated system. Although PC systems have limits as to their height based on erection equipment, medium building height can easily be achieved by a conventional crane, while tower cranes can be used for hi-rise structures in planed far enough in advance. It may also be the case that the material of the original design can be used in combination with a precast system. The visual side-by-side comparison, as illustrated in Figures 1 and 2 demonstrates what the apparent advantages of PC are: minimal use of formwork, reinforcement, and CIP concrete on-site; no need of falsework.

Fig. 1

Fig. 2

Another aspect that offers a conversion possibility is a project in difficult geographic regions such as mountains. These projects pose a significant problem to the contractor as they will typically deal with delivery and logistical issues. CIP, for instance, in mountainous regions in the Western United States is a constant schedule risk. Depending on the time of the year the project may completely shut down. PC systems, fabricated off site in a controlled environment, can mitigate this risk. Using a staging area close to the job site where pieces can be stored until needed on the job site, reduces the risk of road closures due to weather. This provides the contractor with much better control over schedule during winter months, and less uncertainty of milestone dates.

The design of large precast structures or structures located in high seismic regions are typically detailed with CIP in mind, i.e. emulating the behavior of code-accepted seismic force-resisting systems (SFRS) such as special shear walls and moment frames. Design documents such as guides (ACI 550.1R[1]) and standards (ACI 318[2]) are available to provide information on emulation and emulative detailing. PC designers are able to use the "Special Precast Shear Wall" category to meet the building code (IBC[3]) requirements. This can result in a significant cost savings to the job if the amount of steel is reduced. It allows the use of a response modification coefficient R provided in the design standard (ASCE 7[4]) referenced by the building code that is greater than R for intermediate SFRSs. The quality control process at PCI certified facilities allows for a more reliable execution of the placement of special reinforcement.

These types of conversions are presentable to the contractor in many ways. Contractors will typically invite suppliers into their office and go over bid documents prior to requesting bids; this is especially true if the contractor has a good relationship with the supplier. The meetings will generally occur prior to the formal pricing as a means to introduce the project scope to the supplier and review the schedule. These meetings are valuable for a PC producer as the contractor will typically divulge in what areas they are having problems. This would include schedule issues, supply issues, design issues, and cost issues. By seizing these opportunities, solutions in PC can be offered that may not have been previously investigated. Solving contractor's problems is one of the best ways to start the conversion process.

Once the contractor is willing to consider a conversion, it is time to evaluate the problem and come up with a solution. This is best done in the PC design office with production staff, engineering support, and field crew input. The goal is to have a comprehensive solution that includes a draft schedule, piece sizes, and budget numbers to present in a short meeting with the contractor. Although all solutions may not require the use of a three-dimensional (3D) model, the ability to walk through the structure can always help the contractor see the intent of the precast options being presented. Fig. 3 illustrate the extent of the design effort needed to ensure access, coordination with other trades, lack of spatial conflicts, and overall feasibility, should any of those aspects be questioned by the project team members.

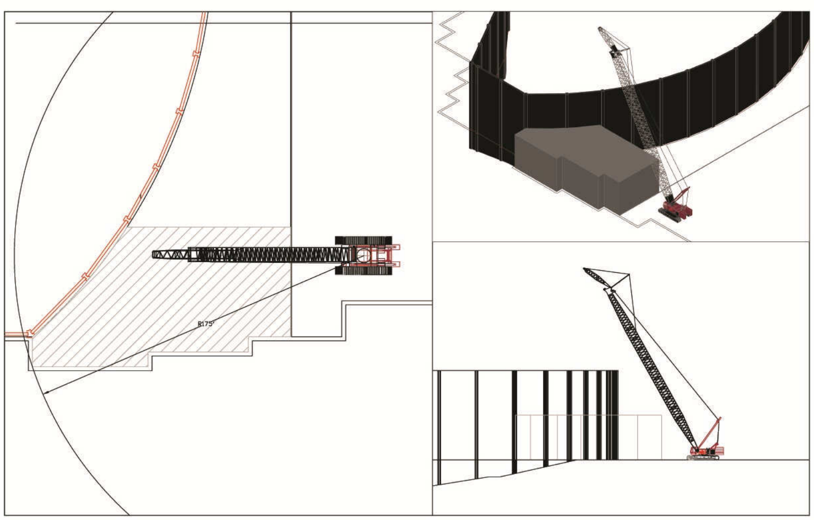

Fig. 3

If the initial take by the contractor is positive they will request more details to present to the design team and owner. This could include preliminary design, section cuts, connection sketches, and formal pricing. On complex structures this information will be taken to the SER for confirmation and approval. This potentially will require the PC producer to invest time and money in drawings and calculations. These documents are to prove the system will perform like the initial CIP design and that the SER's original design intent is not compromised or modified.

A conversion can also be done by bidding value engineering (VE) alternate. Most contractors will not use a VE price in the hard bid, but will keep it aside for discussion after award. Upon award, the process of investigation by the contractor will begin. Should the project be over budget, or have schedule problems, then a VE proposal would be investigated. Because this is a hard-bid conversion, the luxury of time is no longer available. Typically, the schedule will begin prior to bidding out the project, and thus the conversion process will need to be fast and efficient, so impacts are minimal. Keeping data from past conversions can be crucial to making this happen as many details of conversions, especially in high seismic areas, will be repeated, with minor adjustments to fit the project scope currently being investigated.

While discussing potential conversions with clients, it is wise to keep all ideas open as possibilities even ideas that may at the time seem a bit farfetched. These ideas may eventually lead to open discussions that build into a solution that makes the project feasible. The construction community is always looking for the edge that puts them on the path to selection by the owner. Partners who can deliver cost saving in the structure are valuable assets.

DESIGN TEAM CONSIDERATIONS

When converting a project from steel or CIP to PC, the project schedule is the most important challenge. Reducing the time required to complete the task will assist in the process. At the time the conversion is approved, the precast team is actually in a very difficult position; until that point, there has been a fully designed project with construction schedule parameters already established. Now the precast team needs to quickly deliver a concept design, which at the same time is detailed enough to provide definitive answers to questions regarding the time frame for the complete PC design, production, and erection. A seamless integration into the existing schedule is vital, so the precast team will not be perceived as hindering the construction progress. The PC team may be at a disadvantage if design changes are required to accommodate the proposed PC system. To avoid this drawback, the team must communicate the pros and cons to the owner and contractor, make sure they understand the benefits of the conversion, and help them implement the necessary changes. The importance of a realistic assessment of the time required at each stage cannot be overstated, since commitments to the project schedule are legally binding and carry large penalties if not met.

It is critical that the PC producer or the consulting engineering company be experienced in conversion projects. Precast producers have in-house engineering departments that are highly skilled and experienced in the design of PC structures and components. Conversion projects however, require an expanded set of skills, working knowledge of other structural materials, and the ability to perform more global analyses. Some of these analyses require sophisticated software, which is typically used by larger and more specialized structural engineering firms. Although these firms offer specialized services, it is more important that they have participated in similar projects. Understanding why problems occurred in previous projects and being able to prevent them from reoccurring in later projects is a more valuable asset than technical capabilities. Integration with the PC producer's internal engineering department during the conversion design allows standard procedures to be strictly followed. Retaining an outside consultant requires an additional layer of communication and coordination. During the short period of time allotted for conceptual design, the PC producer and the consultant need to review and agree on many issues. Maintaining a check list is one way to organize and track concerns and solutions.

While member size, weight, casting and handling procedures are the primary focus of initial discussions, there are other subtle matters that can be easily overlooked. If these subjects are not dealt with in a timely manner, they often result in re-work and delays and may strain relationships within the PC team. The examples below outline a number of primary coordination topics:

- Decision-making hierarchy
- Communications protocol
- Graphic standards
- Clearly defined roles and responsibilities
- Full understanding of the scope of work and deadlines

The following are examples of coordination topics relating to materials:

- Items that require long lead times
- PC producer's preferences on embedded hardware suppliers
- PC producer's preferred reinforcement patterns and release strength
- PC producer's prestressing and post-tensioning capabilities
- Use of proprietary technology

It is important to document and notify members of the project design team of any changes that could impact pricing. During complex design-build projects, it is common that owners initiate changes to improve areas such as design functionality, appearance, future tenant requirements, and revisions to the mechanical systems. Usually, there is a protocol established to compensate all affected designers and subcontractors in terms of cost and schedule time. However, a series of seemingly minor changes may have a cumulative effect and jeopardize the efficiency of the proposed PC system. One typical example of this is the continuous addition and enlargement of openings in floors and walls. A point is reached where repetitive members cannot be used, unique solutions are required (including custom forms), the PC system becomes complex, and efficiency is reduced. Those inexperienced in the use of PC may not realize that a minor alteration made by the architect could have a profound impact on cost and schedule. Design changes and scope “creep” are an unfortunate reality and the ability to address these issues with a flexible attitude is highly regarded by everyone involved in the construction process.

A design change usually requires an instant assessment of the cost and time impact on the PC delivery. Communication among the PC team is again critical. All members must provide feedback and best estimates in order to outline a cohesive response to the impact. Other effects of a design change include added complexity, the extra effort in quality control, the risk of errors and the potential cost of fixes, the additional stress on designers and detailers, and the learning curve for the erector. Most importantly, the impact on the schedule must be correctly estimated and substantiated. Good record-keeping can help avoid future disputes.

Effective communication between the production facility, the shipping company, and the erector will maximize the efficiency of fabrication, delivery, and the erection process. At the construction site design assumptions focusing on constructability are tested, and erection time estimates are proven to be correct or incorrect. The overall success of the project hinges upon whether the PC erection will meet the schedule deadline. The schedule is based on the erector’s best estimate at the time the conversion strategy is developed. It is dependent not only upon the number of PC pieces, but also on the complexity of those pieces, their connections, and temporary bracing. The timely delivery of all components and erection aids is crucial for the efficient utilization of manpower and equipment. The erection process is subject to a “learning curve.” More time is required initially to complete a process. After two or three repetitions the crew gains experience and finds more efficient ways to execute the action. A flexible shipping schedule accommodating the varying speed of erection must be negotiated with the shipping company up front. Additional trucks, trailers, and drivers may need to be available to manage delivery changes. Panel production must also meet the extra demand. An earlier production start date will increase the number of stored panels (queue) and compensate for the increased erection speed.

It should be noted that the PC erection process is comprised of many steps: stacking the panels, welding, bolting, grouting, reinforcing, forming, concrete casting, and a variety of other activities depending on the project. Each of these process steps requires a steady supply of auxiliary materials and components, and any shortages may stall the erection. Subcontracting items, such as ready-mix or concrete pumps, also complicates the process.

The most important factor in the successful erection of the PC system is the use of outstanding PC products that meet the tolerance requirements and design specifications verified by strict adherence to quality control. The same metrics for PC quality assurance must be applied to the site work as well to ensure a superior final product.

INSTALLATION AND FIELD WORK

Once the installation of the structure has commenced on site, the attention begins to shift from design and detailing to how it all fits together. The contractor, SER, and in some cases the architect will be on site several days during the start and have increased site visits during

the installation process. The design engineer for the PC structure needs to be available to respond to questions immediately. Pre-developing field repairs prior to onsite installation can pre-empt any project delay.
Supervision of the onsite crews is also another critical element required for successful installation of large PC walls. The tasks of tying rebar and pouring wet joints in the wall need to be supervised closely. A competent representative of the PC design engineer should be on site inspecting the reinforcement cages and erection process prior to any wet joints being poured. This also provides the project design team with confidence in the work being completed.

Projects that take several months to complete will need a number of walkthroughs with the project design team and SER. Questions about progress, repairs, and finishes can all be addressed as the project progresses. Large lateral elements become increasingly difficult to clean or repair as they become taller. Coming to an agreement about the overall acceptability degree of quality can prevent difficult discussions with the project design team later on.

CASE STUDIES

BRIGHAM YOUNG UNIVERSITY, REXBURG, IDAHO

This project was an emulative conversion of a 29.3 m (96 ft), 122 m (400 ft) long curved shear wall that supports 73m (240 ft) long trusses and two levels of balcony seating (Fig. 4). The wall was originally designed as 406 mm (16 in.) thick gang-formed CIP wall. The PC system was introduced to the contractor after conversations on how to support architectural carbon fiber reinforced panels to the CIP system. The contractor was having difficulty with the schedule of the wall pour. Located in the North Western United States it did not have a consistent supply of high quality ready mix concrete. It was the PC design team, in these meetings, that suggested the use of a prefabricated system, based on emulative design, to transform the project into a PC system with wet connections.

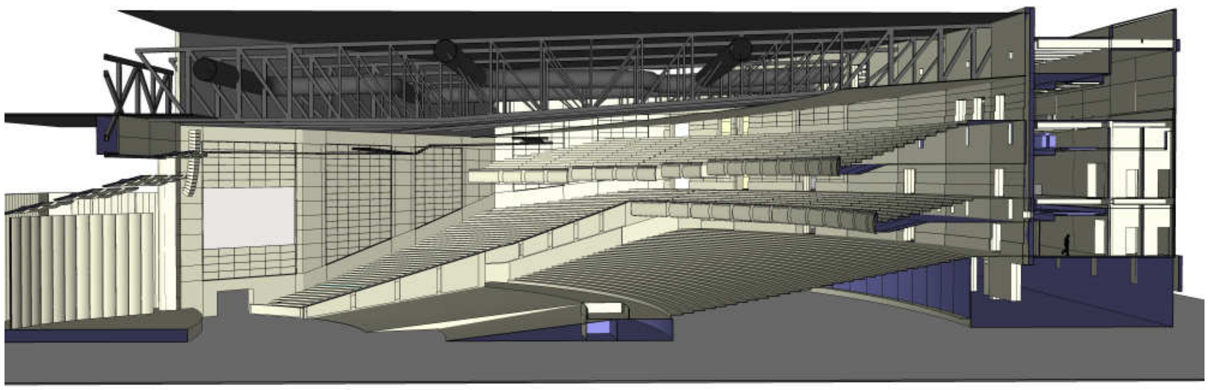

Fig. 4

After several meeting with the project design team to assure them the initial design of the wall would not be compromised the PC fabricator was awarded the design and installation of the wall. The PC fabricator hired a consultant with expertise in the design of structures in seismic regions, and a separate PC detailing firm. By splitting this work the detailing of 247 panels, 23 super columns, and the loose materials could be completed without hindering the overall structural design of the wall.

The PC system consists of full-height 29.3 m (96 ft) columns, 11 m (36 ft) wide by varying height voided wall panels all connected via wet joints, meeting the requirements for special shear walls (Fig. 5). Over 5,500 NMB Splice-Sleeve® connections were used to connect the pieces to each other and the footings. 272 tonnes (300tons) of structural steel braces were used to support the free standing wall during its installation. Over 153 m^3 (200 cu yd) were poured on site to fill the joints between the columns and wall panels, cord joints, and base joints. Reusable forms were fabricated to allow for a fit around the columns.

Fig. 5

Shipping the pieces to the job site was arranged with the owner to allow offsite storage of product. This storage allowed shipping of pieces to be increased during inclement weather, eliminating downtime associated with weather delays caused by shipping in mountainous regions. To maximize the piece sizes allowed Sonovoid® forms were cast in the piece to reduce the weight.

The use of PC subtracted 8 months from the wall construction schedule and solved a great number of construction and site logistics problems. It proved that this construction method is not only possible, but preferable.

TROLLEY SQUARE PARKING, SALT LAKE CITY, UTAH

This project was brought to the PC fabricator after performing a similar conversion on a previous project. This three level structure was occupied by a large retail chain that required a minimum of 6.7 m (22 ft) clear height on the main level, and an open floor plan of 91.5 m (300 ft) by 49.7 m (163 ft). With parking on two levels above the original design called for CIP framing with precast prestressed double-tee members spanning 18.3 m (60 ft). The shear walls were located on the perimeter and were exterior architectural brick clad walls to match the surrounding historic buildings.

Due to previous success in conversions the precast fabricator was awarded the design and fabrication of the precast structure. Working with the architect and SER the load paths were determined and the shear wall sized detailed. Once the initial size and shape of the walls were determined the rest of the framing was detailed, and the intricate connection details of the shear walls was finished.

Fig. 6

Fig. 7

On-site casting of the wet joints had to be done such that they were not exposed to the exterior of the building (Fig. 6 & 7). Using past experience the PC fabricator was able to use detailing that allowed the exterior brick architectural finish to remain intact while the wet joint connection was preformed behind it.

The fabricator was brought into this project due to past successful project completions. This contractor realized a difficult structure and contacted the PC fabricator for a solution. The contractor was to realize a 6month schedule savings on the structure alone. Exterior architectural elements added additional time savings to field laid up brick. Cost savings over cast in place was estimated at 15%.

LP TANKS

Another application of conversion to PC is cylindrical tanks for liquefied natural gas. Those are large structures with very specific requirements that are not typical for commercial buildings, such as prequalification of materials and procedures for cryogenic temperatures. Fig. 6 shows a typical CIP solution that utilizes extensive formwork and on-site operations. Fig.7 illustrates the proposed PC solution for both tank walls.

In this example, the tank consists of two concentric cylinders with a diameter of approximately 75m (250 ft) and a wall height of 36m (120 ft). Several panelization alternatives were considered, such as horizontal vs. vertical joints; full-height vs. half-height panels; identical panels vs. alternating pilaster/infill panels; smooth panels vs. flanged sections (C-channels). Each of these options and combinations thereof was developed conceptually, a cost estimate, handling equipment and bracing requirements were established, and then compared and scored.

Fig. 8

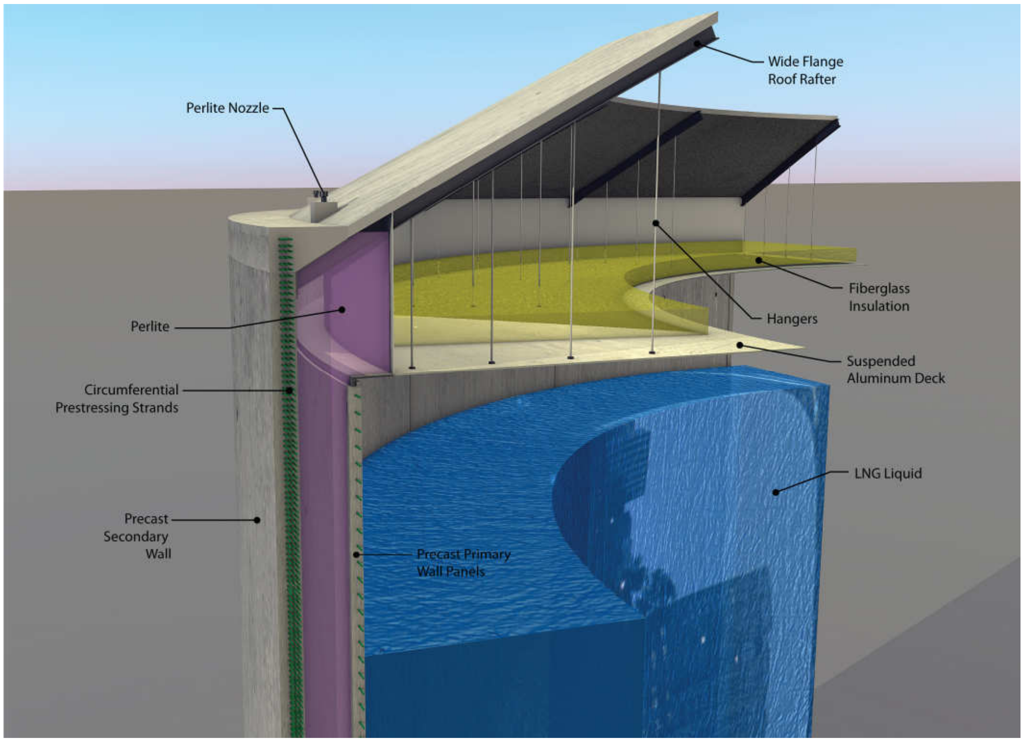

Fig. 9

There was no simple answer on which option was the best. There risk factors for each alternative that needed to be identified, analyzed and quantified to enable comparison. Usually the option with the lowest cost has the highest risk factor. For this particular project, it was found that the lowest cost was for half-height smooth panels (3.3m by 18m or 11 ft by 60 ft dimensions) due to shipping cost and limitation. However, a flanged section solution was chosen to reduce handling stresses and minimize the risks associated with shipping and handling at a minimal cost premium.

To emulate full-height construction and to simplify temporary bracing, the halves of each panel were connected on-site prior to erection. A vertical closure pour between each two panels was necessary for reinforcement continuity. Reusable forms for 9-meter (30-foot) lifts were designed for the closure pours. A modular temporary bracing system and an elaborate erection sequence for both panels and bracing were developed to minimize risks during construction due to work complexity and high construction loads.

CONCLUSION

A conversion to PC of structures designed as CIP is an intricate process that involves several teams. The ability of the PC producer to gather an experienced team only enhances the process. Contractors look for a reduction of risk, faster schedule, and reduced costs. By being pro-active, PC producers can offer systems that are the solution of choice for large-scale shear wall structures including in areas of high seismicity. Eventually the construction community will recognize producers of PC as providers of innovative and efficient solutions to difficult problems. As codes change and projects become increasingly difficult, prefabrication of structures in controlled environments will become the preferred alternative to conventional structural systems.

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