PROCESS IMPROVEMENTS IN PRECAST CONCRETE CONSTRUCTION USING TOP-DOWN PARAMETRIC 3-D COMPUTER-MODELING

Sacks R.\(^1\), Eastman C.M.\(^2\), and Lee G.\(^3\)

SYNOPSIS

Computer-aided design and drafting has been adopted widely for all forms of building construction. However, software has been applied to increase the efficiency of traditional design and drafting methods, rather than to improve the process itself, and errors in design and drafting remain common. A shift from traditional 2-D drafting to 3-D top-down parametric modeling of precast buildings may enable producers to approach a near error-free design and production process, with significant consequent improvements in quality, cost and project duration. An examination of detailed case studies of precast concrete projects revealed that the common causes of construction problems are design, detailing and drafting errors, inadequate coordination between different disciplines, and inadequate management of changes. Analysis of the cases indicates that 3-D top-down modeling and automated production of shop drawings holds the potential to eliminate most of the sources of error.

**Keywords:** Precast Concrete, Computer-Aided Drafting, 3D modeling, Building Product Model, Engineering Design, Construction Management, Information Technology, Top-down design.

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\(^1\) Ph.D., Research Scientist, College of Architecture, Georgia Institute of Technology, Atlanta, GA30332-0155, Tel 1-404-894-0437, Fax 1-404-894-1629, rafael.sacks@arch.gatech.edu

\(^2\) Ph.D., Professor and PhD Program Head, College of Architecture and Professor, College of Computing, Georgia Institute of Technology, Atlanta, GA30332-0155, Tel 1-404-894-3476, Fax 1-404-894-1629, chuck.eastman@arch.gatech.edu

\(^3\) College of Architecture, Georgia Institute of Technology, Atlanta, GA30332-0155, Fax 1-404-894-1629, ghang.lee@arch.gatech.edu
INTRODUCTION

Although computer-aided drafting has become prevalent in all branches of the construction industry, a significant proportion of construction dollars are still spent on rework to fix errors that can be traced to the design stage\(^1\). Building parts that do not align correctly, spatial conflicts between components of different systems, and work that must be demolished because drawings were not updated to reflect design changes, are among the common errors. An intensive study of seven large construction projects (employing structural steel, masonry and cast-in-place concrete construction methods) showed that design errors accounted for an average of 26% of all construction defects\(^2\). A field survey of cast-in-place reinforced concrete construction identified numerous and diverse rebar constructability problems\(^3\), arising largely from inadequate detailing, lack of construction experience among designers, lack of coordination between the design of the various disciplines (structural, electromechanical, etc.), and insufficient involvement of contractors in detailing. In a survey of the US precast industry\(^4\), 41% of producers reported encountering problems in production due to ambiguities in design “often” or “very often”. This remains true despite the fact that the industry has fully adopted computers for design and drafting – in a recent survey\(^5\), all of the precast producers reported using CAD drawings (96.3% use CAD in-house, and the remainder out-source their design and drafting to consultants).

The Precast Concrete Software Consortium (PCSC) is currently specifying and procuring 3-D automated and integrated design and management software for its members. One primary goal is to enable precast producers to reduce lead-time on projects from months to just one week\(^6\), and to make production-related activities (procurement, control, shipping, etc.) more efficient. In addition to these benefits, the authors hypothesize that 3-D computer modeling of buildings, if performed with well-structured top-down parametric dependencies between assemblies, pieces
and components, has the potential to reduce or eliminate many sources of error. Case studies of failures and successes provide an effective and convenient resource for initial examination of this hypothesis – its proof will require extensive implementation and adoption of such systems in practice. In this research, eight case studies of precast concrete projects, each of which required significant remedial work, were collected, documented and examined. They allow qualitative tracing of the root causes of the errors that led to rework. In some cases, sufficient detailed cost information was provided to allow quantitative assessment of the impact of the rework on project budgets and schedules.

In the first part of this paper, we describe the integrated assembly and piece modeling approach to computerized design. Next, we classify the design and drafting errors reported in the case studies. Each classification is illustrated with examples tracing the causes and impacts of the error. Lastly, we trace the ways in which each type of error would be avoided in such a design environment.

INTEGRATED PARAMETRIC ASSEMBLY AND PIECE 3-D MODELING

The following two principles for precast concrete modeling software are central to reducing the incidence of errors and consequent rework:

1. **Modeling vs. Drafting**: Instead of generating multiple and discrete drawings to represent a building and its parts, the operator builds a model of the building. Both assembly and piece drawings are generated from the model – drawings are reports of the information, rather than containing the information itself.

2. **Maintenance of integrity from the assembly to the parts, rather than from the parts to the assembly**: Instead of composing a building model as a collection of instances of
typical pieces with fixed geometry, the geometry of each piece is driven subject to the spatial topological relationships between it, its neighbors, and the building grid. In this way changes at higher levels of an assembly can be propagated to lower level parts automatically. Figure 1 illustrates the principle – the beam is automatically sized to fit between the columns, and the corbel supports are automatically sized to fit the beam. Any change made to any of the independent dimensions ($l_{AB}$, $w_1$, $w_2$ or $c$) will result in propagation of the change to the beam and to the supports. Also, if the beam is removed, the supports are automatically removed (recognition of connections between pieces as a separate logical entity is crucial to enabling this behavior).

![Figure 1. Parametric model of a beam between two columns.](image-url)

The former principle was incorporated in pioneering 3-D modeling software for precast concrete design (EDGE)\textsuperscript{8}, which has enabled its developers to significantly reduce the frequency of errors in their projects. The latter has yet to be applied in precast concrete software. Unlike traditional CAD files, the behavior of pieces in a top-down parametric building model closely
mirrors the conceptual thinking of an engineer in putting together a precast building design. The engineer is concerned first with the structure as a whole assembly, next with the pieces that make up that assembly, then the connections between them, and lastly with the details of each individual piece. When changes are made at any level, the elements at a lower level should adapt to the changes made. The potential for automation of such behavior is greater at lower levels.

The approach is effectively illustrated in the sequence of screen shots shown in Figure 2 (prepared using Tekla prototype Xengineer software). Standard or user-defined parametric cross-sections are extruded to form the basic volume of each piece (Figure 2a shows a spandrel beam). All of the pieces are placed in the assembly (Figure 2b – columns are red, spandrels yellow, and the three double tees are cyan). The user does not define the length of the spandrel; the system automatically sets the length parametrically as the distance between the columns. Next, connections are modeled (Figure 2c) – they are selected from a parametric library of connections and automatically adapted to fit the appropriate pieces. The resulting piece model can be seen in Figure 3a, and, with embedded hardware, in Figure 3b. If any change is made to the position or cross-section of any of the pieces in the assembly, the software automatically propagates the effect of the change to all the other pieces and connections, ensuring that the integrity of the model as a whole is maintained. Piece prestress and reinforcement design will be performed directly in the model using plug-in professional software. At any time, production drawings and bills of material can be automatically generated by the system. The drawings are derived directly from, and are therefore fully consistent with, the 3-D model. Any subsequent change must be made to the 3-D model, to ensure that all future piece drawings and assembly drawings will be mutually consistent.

Figure 2. Top-down 3-D modeling of a precast concrete spandrel. This corner spandrel was taken from an office building (not included in the case studies). Preparation of the full piece-ticket drawing file using conventional 2-D CAD, including all dimensions and a bill of materials, was measured in weeks. Modeling the piece and its immediate neighbors, including all connections and reinforcement in the 3-D prototype software, and generating the piece tickets and BOM (without annotations and exploded details) required approximately two hours.
It could be argued that top-down building modeling can be done using conventional CAD systems, even in 2-D, with sophisticated and disciplined use of drawing layers and model/paper view separation. However, in most systems, individual pieces are inserted in assemblies as instances of piece production series (piece-marks) (e.g. as instances of ‘blocks’ in AutoCAD®, ‘cells’ in Microstation®). Their parameters are set at the time of insertion, and so assembly geometry is driven ‘bottom-up’ from the CAD blocks. This means that any localized change to one piece in a series requires the user to separate that piece from the series, create a new piece-mark, adjust the changed locations of other dependent elements in the assembly, and produce a new piece-mark drawing. In contrast, none of this effort and ‘housekeeping’ maintenance of the drawing set is necessary in systems in which top-down parametric dependencies are maintained between assemblies, pieces and components.

The PCSC has specified and tendered for a comprehensive 3-D and knowledge-rich software design tool, which will be integrated with other design, analysis, scheduling, accounting and production management software. Among the priorities identified in this specification are:

- The 3-D modeling software must support a top-down design process with three distinct phases: assembly layout, assembly detail, and piece detailing.

- All assemblies, pieces and connections must be parametrically related to a building grid and to each other, and changes must be propagated automatically so that integrity is maintained.

- The 3-D computer model must be the only repository and source for all product design information. Drawings, bills of material and other documents are to be reports of the project information, not repositories of that information.

- Most of the routine layout, analysis and detailing tasks are to be automated.

These priorities distinguish the proposed system solicited by the PCSC from traditional CAD drafting, as commonly practiced, in terms of the two principles established above: modeling and not drafting, and maintenance of integrity within the model from the assembly down to the parts.

COMMON DESIGN AND DRAFTING ERRORS
Seven precast projects were examined – four parking decks with structural pieces, one office building with architectural and structural pieces, one indoor arena with precast rakers and walls, and one jail complex with precast boxed cell modules (see listing in Table 1). The largest had 3,211 precast pieces, covered 688,000 sq.ft. and had a contract price of $13,400,000; the smallest had 259 pieces, covered 75,000 sq.ft and its contract price was $1,161,000. In these projects, 22 distinct and significant errors were found, each of which impacted on the project duration and cost. In the most severe case, the estimated cost of a single error amounted to 9.9% of the contract price.

Table 1. Precast concrete project case studies.

<table>
<thead>
<tr>
<th>Project Key</th>
<th>Description</th>
<th>Precast Piece Type</th>
<th>Floor Area (sq.ft.)</th>
<th>Other Data</th>
<th>Number of Pieces</th>
<th>Contract Value (7)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>County jail</td>
<td>3D modular cells</td>
<td>688,000</td>
<td>Façade area 140,000 sq.ft</td>
<td>3,211</td>
<td>$ 13,400,000</td>
</tr>
<tr>
<td>B</td>
<td>Multi-use building</td>
<td>Structural &amp; Architectural</td>
<td>220,000</td>
<td></td>
<td>700</td>
<td>$ 5,000,000</td>
</tr>
<tr>
<td>C</td>
<td>Parking structure</td>
<td>Structural</td>
<td>75,000</td>
<td></td>
<td>259</td>
<td>$ 1,161,000</td>
</tr>
</tbody>
</table>
The case studies were collected from companies participating in the PCSC. The case studies were selected to reflect the variety of design, drafting and coordination problems common in their everyday business. As such, they are useful in assessing the nature and the impact of such errors. However, they provide only a rough, empirical indication of how widespread such errors are, or how broad their cumulative financial impact is on the precast companies, their clients, or on other companies in the construction supply chain.

The errors encountered were classified into the following five kinds:

1. Design errors and engineering errors.
2. Errors that introduce inconsistencies between assembly drawings and piece production drawings (i.e. ‘shop tickets’), which include two kinds:
   a. Drafting errors.
   b. Piece detailing errors.
3. Errors resulting from lack of coordination between different building systems.
4. Errors due to inadequate management of design and detailing changes.

Other types of errors, presumed to occur in many precast construction projects, were not included in this investigation. For example, errors in bills of material (wrong quantities, wrong items specified, items missing, etc.), are apparently commonly corrected by field personnel, and not reported as errors in design or drafting. The five error types are described below, each with an example from a case study.
Design Errors

The design errors in the case study include errors of judgment or detail in the engineering design decisions that determine a building’s assembly details. Errors in structural calculations, or in setting prestress or reinforcement, are not included for the current purpose. Design errors were rare in the cases reported, although their impact can be far-reaching.

Project ‘B’ provides an example. In this 5 story multi-use building, the floors are composed of double-tees, which are supported at the edge of the building on spandrels. In such situations, this precaster commonly designs the double tee stems to be supported in pockets in the interior face of the spandrels. The engineer explained that problems arose because, “the tee was drawn and detailed on the shop drawings as if both stems were to bear in 6 inch deep pockets in the spandrel. Due to the production schedule, the framing and double tees were drawn and checked several months before the spandrels needed to be. However, when the elevations were drawn and the spandrels were checked against the elevations, one stem of the tee was shown held back and bearing on a haunch”, as can be seen in Figure 4. “Normally, when this error is found before erection, the stem can be cut back and properly reinforced. However, in this case, the stem being discussed was dapped(cutting back the stem to raise the bearing pad) 10 inches. This prohibited the stem from being cut back, because it would be very difficult to properly reinforce the stem after removing the dapped section. We looked at placing this tee in another location in the building and re-pouring a corrected tee in that production slot (of the alternative tee), but to no avail. The tee had to be thrown away, and re-poured correctly. A total cost of a 12DT28 with all the materials, labor, and disposal is about $750/c.y. So, this tee cost us about $8000.”
Inconsistent Assembly and Piece Drawings - Drafting

Assembly drawings are the medium that enables engineers to develop, record and communicate their concept of the building as a whole. They are usually developed at the start of a project. The main purpose of piece drawings, on the other hand, is to define the individual pieces of a building for production. If disparities are introduced between the assembly drawing set and any piece drawing, it is likely that the resulting piece produced will not function properly the overall structure. This was the single most common type of error in this study. This type of error is common to all construction industry trade sectors in which parts are prefabricated off-site according to custom project specifications – including structural steel, HVAC, curtain-walls, ironwork, rebar fabrication, and others.

To understand the nature and the potential impact of inconsistencies between assembly and piece production drawings, consider project ‘G’, a typical precast parking structure. The interior ramp spandrels in this building were detailed with the batter length (the distance by which the top and bottom edges of a spandrel must be increased to account for its slope) subtracted instead of added. As a result, 75 spandrels were cast too short, at a total cost of $193,000 (9.9% of the contract value).
An additional example is provided by the design of a geometrically complex stairwell that was built using separate precast pieces for landings and stair sections (Figure 5). Frustration with conventional methods led this precaster to pursue an ad-hoc top-down design of the pieces using 3-D solid-modeling software, although with no automation. The engineer noted; “Each set of stairs connected a series of curved landings in a triangular pattern. Location of doors, railings and electrical units in relation to the stair locations were critical. Calculating locations and dimensions manually, devoured much valuable time and created frustration when calculated figures would not agree with the information given.” 3-D modeling “cleared up many misunderstandings and brought everyone into agreement. It also assured us that the landings and the stairs all fit together properly.”

Figure 5. Precast Stairwell

**Inconsistent Assembly and Piece Drawings - Piece Detailing**

In current 2-D design practice, the detailed components cast into each piece are not shown in assembly drawings. Such detail is shown in piece (shop) drawings, in which the pieces are
designed and drawn for production. Improper coordination between this detail and the overall assembly can introduce inconsistencies between assembly and piece drawings.

A typical example of this type of error occurred in Project ‘F’. On the eastern façade of the elevator core, spandrel beams connect the corner column to the wall panels at all eight levels of the structure (Figure 6a). The connections to the corner column are designed to consist of threaded bars passed through holes through the width of the columns and screwed into sockets embedded in the spandrel, which sits in a recess in the column on its outer face (Figure 7). At their opposite ends, the spandrels are designed to connect to the wall panels with plate-to-plate welded connections.

Figure 6. a) Spandrels in elevation, b) Spandrel piece detail.
When the first spandrel was hoisted into place, it became clear that the two connection hardware types had each been embedded at the wrong ends of the piece. This can be seen clearly in Figure 8 – the bolts through the columns could not be anchored, and the welds to the wall plates could not be made because there are no connection plates embedded in the spandrel. The detailing error can be seen in the piece drawing, Figure 6b. Work on the core was halted for consultations, as it appeared that the spandrels would have to be abandoned and that erection would have to wait for new, corrected pieces. The elevator shafts were on the critical path of the general contractors’ project schedule. It was decided that the slab connections to the spandrels would suffice to hold the spandrels in place until new field connections could be designed, fabricated and implemented. The event impacted on all three key measures of project success: time, cost and quality.

Figure 7. Spandrel connections to wall and column: as designed.
Figure 8. Spandrel connections to wall and column: as made.
Similar detailing errors were reported in project ‘C’:

- “One column was missing all the corbels necessary to support an entire stack of double tee stems (this is an unusual condition, and though it was clear in plan view in the layout drawings, the fabrication drawing detailer referenced the building elevations where the support requirement wasn’t shown). Had to bolt on major remedials which shutdown erection for several days.”

- “Several ramp columns were detailed too short. This wasn’t discovered until after most of the deck had been erected, and necessitated $50,000 (4.3% of contract value) worth of shoring, jacking, and shimming.”

**Building System Co-ordination Errors**

This classification includes all spatial and other conflicts between precast pieces and parts of other building systems. These errors result from insufficient coordination between different system designs. They are common and insidious, and, as with the other error types reported, they are often not discovered until the time of erection.

Project ‘A’, a large prison, (Figure 9) suffered over $500,000 (3.7% of contract value) cost overruns as a direct result of lack of coordination between the precast structural system (3-D cells) and various cast-in-place, mechanical, plumbing and architectural systems. The project manager reported; “One of the biggest problems of all was the coordination of openings for ducts, vents, draws, sprinklers, etc…. Usually when an opening was added or changed it affected many other adjacent modules….”. A unique problem in this case was coordination of steel anchors embedded in the exterior walls of each prison cell module for the sliding cell doors. The doors of all the cells along a row are connected together with a mechanism that allows automatic opening of all the doors in an emergency. As the mechanism design developed, the anchor positions and sizes had to be propagated to each cell module throughout the building. This is
complex to monitor because the door mechanisms are designed at the assembly level, but the modular cells are drawn on separate piece-mark drawings.

![Prison construction using 3-D cell precast elements.](image)

**Figure 9.** Prison construction using 3-D cell precast elements.

**Errors Resulting From Design Changes**

Changes in architectural designs or other building systems require that precast designs be updated to match. The difficulty is exacerbated by the relatively long duration of design detailing in most precast projects – late changes must be coordinated through assembly drawings and a complete set of piece drawings. Nevertheless, owners and architects expect the precaster to be agile in responding to changes submitted before physical production of each piece. Inadequate management of those changes often results in significant rework on the site, and in certain cases, the need to replace incorrect pieces.

In the case of the indoor arena, project ‘D’, precast rakers (sloped beams that are stepped to support stadium seats) and walls were supplied to rest on a cast-in-place substructure. Many electrical and railing embeds were required. A major architect’s design change, relatively late in the project, aggravated the task of coordination. Precast erection, scheduled for 16 weeks, was extended by over one month for correction of railing posts, lighting fixtures and other embeds and holes, all at the precaster’s expense. The photograph in Figure 10 shows a situation in which
the location of a 6x6 in. hole was changed in a cast-in-place wall, but not updated in the production drawing of the adjacent precast piece. The impact is not only in the cost of rework and schedule delay, but in the quality of the finished product and damage to the precaster’s reputation.

Figure 10. Mis-aligned 6x6 in. holes between a precast piece and a cast-in-place wall.

The prison construction project described above (project ‘A’) provides an additional example: “Holes for the shear pins (in the bottom of the module walls) were field drilled in the cast-in-place slab on grade. Due to changes in the modules used to make up the space the location of these kept changing daily – some module locations had three sets of holes by the time the module arrived.”

THE POTENTIAL FOR ELIMINATION OF ERRORS

The following features of a integrated assembly part 3-D modeling and knowledge-rich system can contribute to eliminating or reducing errors:

I. The logical relationships between connections and pieces are embedded within the system.

This together with the parametric behavior of the assembly and of the pieces means that the
spatial integrity of the 3-D model is maintained without the need for any intervention on the part of the user.

II. The 3-D model is the single source for all the product information; 2-D drawings are generated as reports from the 3D model information. The inconsistencies that arise between multiple repositories (as exist in the 2-D drawing paradigm) cannot occur. Errors of coordination between assembly drawings and shop tickets are essentially eliminated.

III. Automated detailing, such as placing connection hardware and making all the necessary geometrical adaptations to the connected pieces, removes the opportunity for human error. Even in unique design situations, where automated detailing cannot be applied and the detailing must be done manually, the detailing is done in the context of all other pieces, so that chances of making an error are significantly reduced.

IV. Any building system that impacts on the precast pieces can be imported or directly modeled in 3-D (possibly requiring significant additional work). If these are updated over time to reflect all changes, then any piece drawings produced will correctly show any holes that are required, and any automated detailing procedures can account for the building systems’ components. An associated benefit is that the lead-time required to produce piece production drawings is reduced from months to days, so that changes can be accommodated much later in the process than is currently possible.

V. The 3-D building model provides a platform for automated design checking routines. For example, pieces without adequate connections, spatial conflicts, and other errors can be automatically identified and reported to the user.
The errors encountered in the case studies were each re-examined in light of the 3-D modeling system as specified by the PCSC. For example the mirrored spandrel connections in case ‘F’ could not have occurred if the shop drawings had been produced automatically from a 3-D model. This is because the stage of transfer from assembly to shop drawings, currently performed by a human operator, is eliminated entirely in the proposed software paradigm (items I, II and III). The level of confidence is considered ‘complete’. Errors related to coordination between building systems such as in case ‘A’ are dealt with as described in item IV. However, they can only be considered eliminated with ‘medium’ confidence: human error can still be introduced if the various building systems are not updated in the 3-D model. Table 2 summarizes this analysis for all the cases – it lists the features of such a system that would apply in each case, and provides an assessment of the likelihood that each would be eliminated. Of the 22 errors listed, all are considered eliminated with at least medium confidence, 16 (73%) with at least high confidence, and 11 (50%) with complete confidence.
Table 2. Probability of elimination of case study errors.

<table>
<thead>
<tr>
<th>Errors</th>
<th>Project</th>
<th>Error Classification</th>
<th>System Feature</th>
<th>Confidence Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Holes for shear pins drilled 3 times over</td>
<td>A</td>
<td>Change Management</td>
<td>I, IV</td>
<td>complete</td>
</tr>
<tr>
<td>Could not maintain integrity through changes</td>
<td>C</td>
<td>Change Management</td>
<td>II</td>
<td>complete</td>
</tr>
<tr>
<td>Holes did not align on different pieces</td>
<td>D</td>
<td>Change Management</td>
<td>I, IV</td>
<td>complete</td>
</tr>
<tr>
<td>Architectural changes not dealt with correctly</td>
<td>D</td>
<td>Change Management</td>
<td>I, II</td>
<td>high</td>
</tr>
<tr>
<td>Sliding door mechanism alignment</td>
<td>A</td>
<td>Systems coordination</td>
<td>II, IV</td>
<td>high</td>
</tr>
<tr>
<td>Holes for Ducts, draws, vents, sprinklers</td>
<td>A</td>
<td>Systems coordination</td>
<td>IV</td>
<td>medium</td>
</tr>
<tr>
<td>Railing and electrical embeds not detailed correctly</td>
<td>D</td>
<td>Systems coordination</td>
<td>IV</td>
<td>medium</td>
</tr>
<tr>
<td>Lighting and railing embeds not coordinated</td>
<td>D</td>
<td>Systems coordination</td>
<td>IV</td>
<td>medium</td>
</tr>
<tr>
<td>Inverted T detailed too long for CIP support</td>
<td>E</td>
<td>Systems coordination</td>
<td>I, IV</td>
<td>high</td>
</tr>
<tr>
<td>3D design for placement of electrical, doors, railings</td>
<td>F</td>
<td>Systems coordination</td>
<td>I, IV</td>
<td>high/medium</td>
</tr>
<tr>
<td>Designed pocket instead of haunch for Double Tee at end of spandrel</td>
<td>B</td>
<td>Design error</td>
<td>I, III</td>
<td>high</td>
</tr>
<tr>
<td>Angles on slabs and panels incorrect</td>
<td>A</td>
<td>Drafting error</td>
<td>I, II</td>
<td>complete</td>
</tr>
<tr>
<td>Ramp columns too short (shored and jacked)</td>
<td>C</td>
<td>Drafting error</td>
<td>I, II</td>
<td>complete</td>
</tr>
<tr>
<td>Horizontal block outs for sloped spandrels</td>
<td>E</td>
<td>Drafting error</td>
<td>I, III</td>
<td>complete</td>
</tr>
<tr>
<td>Incorrect length for batter on sloped spandrels</td>
<td>G</td>
<td>Drafting error</td>
<td>I, II, III</td>
<td>complete</td>
</tr>
<tr>
<td>Varying wall thicknesses due to varying modules and triangular building</td>
<td>A</td>
<td>Drafting errors</td>
<td>I, II</td>
<td>complete</td>
</tr>
<tr>
<td>Column detailed without DT corbels</td>
<td>C</td>
<td>Piece Detailing</td>
<td>V</td>
<td>medium</td>
</tr>
<tr>
<td>No end finish detailed for strands in spandrels</td>
<td>E</td>
<td>Piece Detailing</td>
<td>V</td>
<td>medium</td>
</tr>
<tr>
<td>Spandrels with wrong connections (mirrored)</td>
<td>F</td>
<td>Piece Detailing</td>
<td>I, II, III</td>
<td>complete</td>
</tr>
<tr>
<td>Incorrect thickness for ledger beam bearing pads</td>
<td>F</td>
<td>Piece Detailing</td>
<td>I, III</td>
<td>high</td>
</tr>
<tr>
<td>Spandrel and Double Tee detailed with different connections</td>
<td>B</td>
<td>Piece Detailing</td>
<td>I, II, III</td>
<td>complete</td>
</tr>
<tr>
<td>Block outs missing from inverted tee beam supported on CIP concrete</td>
<td>E</td>
<td>Piece Detailing;</td>
<td>I, III, IV, V</td>
<td>complete</td>
</tr>
</tbody>
</table>

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CONCLUSIONS

Modeling buildings in computers, instead of drafting representations of them and of their parts in drawings (whether CAD or manual), holds the potential to reduce the occurrence of errors and the need for rework in construction projects. Employing 3-D CAD is necessary, but not sufficient: the building model must be developed in an integrated fashion, must be comprehensive, as complete as possible, and must drive the production of all drawings and reports, if the benefits are to be realized.

The seven case studies of precast concrete construction projects show that design and drafting related errors occur despite the use of 2-D computer-aided drafting technology. It seems reasonable to assume that many more errors occurred, which were intercepted and corrected; the case studies do not allow estimation of their frequency or severity. All of the errors reported in these cases resulted in the precast companies losing time and money.

The PCSC has specified, and is currently procuring, 3-D modeling and knowledge-rich software for precast assembly design and detailed engineering. The authors’ expect that introduction and use of such software may eliminate multiple types of errors that are common today. Additional benefits will accrue from the drastic reduction in time required to produce both assembly and piece production drawings. The PCSC has also begun development of a precast data model, which will enable integration of all of the information technologies throughout the precast construction business process (for background information on the subject of Building Product Modeling, see Eastman⁹). This will extend the benefits gained in adopting 3-D computer modeling, by allowing immediate communication of engineering changes to scheduling, procurement and other non-engineering activities, further reducing errors and improving the overall management of changes as they inevitably occur.
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